ISOLATION DISTANCES

Principles and practices of isolation distances for seed crops: an organic seed production manual for seed growers in the Mid-Atlantic and Southern U.S.

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ISOLATION DISTANCES FOR SEED CROPS: Principles and Practices

The principles and practices of using isolation distances in seed crop production are some of the most important, yet least understood parts of seed crop production. This document seeks to explain the principles of pollination ecology, and how to apply those principles for the purpose of isolating crop plants to ensure seed purity.

FUNDAMENTAL DEFINITIONS AND CONCEPTS

Isolation distance:

Isolation distance is the minimum separation required between two or more varieties of the same species for the purpose of keeping seed pure. Species in the same genus or family often have similar minimum isolation distance requirements, but occasionally certain varieties within a species may require larger isolation distances. In addition, many environmental factors can affect how far and how effectively pollen can be transferred by wind or by insects.

Pure seed:

The definition of pure seed depends on the intended use of the seed. Home gardeners, seed savers, and commercial seed growers all have different intended uses for their seeds, and therefore different definitions of pure seed. Commercial seed growers basically have two classes of pure seed: seed for sale and seed to be used for growing future seed crops unrelated to the direct sale of seed. Large-scale commercial seed producers have additional definitions of purity as indicated by such terms as “grower’s stock”, “stock seed”, “no. 1 seed”, “breeder’s seed”, “foundation seed”, “certified seed”, “registered seed”, “elite seed”, and ”super-elite seed”. For our purposes, it is not necessary to get into the meaning of these different classes of seed. The take-home message for the small-scale seed grower is that the definition of “pure seed” is related to the intended use of the seed. Following are some examples of intended use of seed as related to small-scale seed production:

- **Seed grown for home use:** If you are saving seed for your own use, and are not selling it or exchanging it with someone else, (the consequences of some impurity in the seed can be relatively unimportant and limited to you. If on the other hand, you have a named variety that gets accidentally outcrossed, and then send that seed in the mail to a seed exchange or to a magazine seed swap, what would otherwise be small impurities, can be multiplied many times.

  In some cases, impurity in homegrown seed may be beneficial, as accidental outcrossing followed by selection may eventually lead to the development of a new variety. In fact, some family heirloom varieties later introduced to the commercial seed trade had their origin in the accidental crossing of two or more varieties of home-saved seed. So, in this context, outcrossing is not necessarily a bad thing. Prior to 1800 there were no commercial seed companies in the U.S., and seed saved for home or farm use was the only type of seed available, except perhaps for seed raised by local farmers who sold or traded seed to the general store. Seed raised in this tradition probably led to many regionally or locally adapted strains and varieties.

- **Seed grown for seed exchanges or seed swaps:** If you are growing seed for your own use and then decide to send the seed to a seed exchange or seed swap, the consequences of impurity start to become fairly important. Based on my own experience of seed obtained from member listings in the Seed Savers Exchange during the 1990’s, I have seen as much as 10 to 20% off-types. This is a little hard to interpret because some of these are family heirloom varieties that have a natural range of variation, and in this context it is harder to define what is meant by “off-type”. It is important to be aware that small seed companies sometimes obtain their starter seed from members of nationally known seed exchanges or local seed swaps. (I obtained some seed in this manner, and invariably, I often had to extensively rogue or clean up the seed, and was left with lingering questions about the true characteristics of a particular variety.

- **Seed grown for seed companies:** Seed grown by small-scale seed producers for seed companies has to be pure. In this context, the consequences of outcrossed seed are far-reaching and may possibly lead to the loss of a particular variety. This is important for organic seed production now more than ever because many genetically modified crops are being grown, and organic seed must be 100% free from the genes of these crops. In short, commercial-grade seed has to be properly isolated, and properly handled from planting to harvest, and later during processing and shipping.

ABIOTIC POLLINATION

- **Wind Pollination:** Wind pollination is common in various tree families, members of the Gramineae (grass family) and Chenopodiaceae (goosefoot family). The grass family includes cereal grains and corn, and the goosefoot family includes beets, Swiss chard, spinach, and orach. Cereal grains are mainly self-pollinated, but can be cross-pollinated by the wind. The pollen of wind-pollinated plants is often very light, and with ridges on the surface to help make the pollen airborne. Members of the goosefoot family have pollen that can be carried long distances by the wind, often at least a mile or more. Plantings of beets or chard grown for seed often have to be separated by three to five miles where the seed is grown commercially. Small-scale seed producers in the Mid-Atlantic and South usually don't have to be concerned about maintaining such large isolation distances since seed production for these crops is not likely to be located in these regions. Nevertheless, because beet and chard pollen is so easily wind-borne it is best to grow only one variety for seed because it is impractical to try to isolate two varieties on one farm. One variety can be grown for seed while other varieties can be grown for food as long as the varieties grown for food are not allowed to flower. The likelihood of beets or chard going to seed in neighboring gardens is quite small, and if present at all, would likely be present in negligible quantity. Corn pollen is heavier and in large-scale commercial plantings is usually isolated by one mile (sometimes two) in corn-growing regions. Since corn is grown in many areas of the country, it is necessary to scout neighboring gardens and farms for possible sources of contamination. However unlike the Midwest, much of the East has denser vegetation and rolling countryside that provides patches of woods and geographic barriers to the movement of pollen. In addition, many areas of the Mid-Atlantic and South do not have much acreage devoted to growing corn. So for our region of the country, one-half mile separation is usually adequate.

- **Water and Rain Pollination:** This category applies mainly to certain aquatic plants and certain terrestrial plants that have flowers that partially or completely fill up with rainwater. In some cases the pollen is dispersed by rain splash, but most pollen, unless specially adapted, is killed or rendered inactive by water. Though not a common phenomenon, water or rain-pollinated plants have a specialized flower structure and specialized pollen. Water and rain pollination does not apply to commercial vegetable or flower crops, with the exception of black pepper (in the family Piperaceae).

BIOTIC POLLINATION (INSECT POLLINATION)

- **Domesticated bees (honeybees):** Honeybees are not native to North America. They were brought here from Europe with the first colonists who also brought most of our food crops with them. Most of our major food crops co-evolved in Europe and Asia with the honeybee, so over time many of our food crops have become dependent on the honeybee. Before the arrival of the Europeans, the primary native pollinators were wild bees and solitary bees. The arrival of the honeybee subjected many of the native bees to disastrous competition. The native bees are more dependent on certain nesting materials, type of soil, and climate and temperature for time of emergence from the soil. Though the honeybee is native to the tropical and subtropical parts of the Old World, it has gradually adapted and radiated to cooler climates.

  Honeybees are very efficient pollinators and will forage year-round if the temperature permits. Honeybees can communicate to other members of the colony the direction of the pollen source, the distance to the pollen source, and the amount of pollen (to some degree). It is because of this difference that honeybees are more efficient pollinators than bumbles and wild bees.

  Honeybees prefer to forage near their hive if pollen and nectar resources are sufficient. Most bees forage within one-eighth mile (or less) from the hive. If weather and resources are favorable, as much as one-fourth of the hive may forage up to a quarter mile. Very few bees will forage as far as a mile. This is why the recommended minimum isolation distance for bee-pollinated crops is one-half mile.

Honeybees exhibit a behavior called “flower constancy” - that is they do not visit flower species randomly. Instead of flying from one species of flower to another they tend to focus on one type of flower at a time. This means that once a bee finds, for example, a squash blossom that it likes, it generally will prefer squash and will forage on squash for a while. The good news is that the squash gets pollinated well, but if you are trying to isolate two varieties of squash, the bee has its mind made up to stick with the squash until it switches preferences.

- **Native wild bees:** Due to mite problems in recent years, honeybees have become scarce. Therefore, wild native bees have become significant pollinators of crops, though with less efficiency because of their foraging behavior and more limited numbers.

  - **Bumblebees:** Bumblebees are the next most efficient pollinator after the European honeybee. Depending on the species, their nests are either underground at the end of a tunnel made by a small mammal, in the unused nest of a bird, at the bottom of a hedge, or in a depression under a thick matting of grass. Bumblebees are colonial insects with a more primitive social organization. Unlike honeybees they are unable to communicate to each other about the location and amounts of pollen in an area. Though they are often efficient pollinators, their numbers are often too few for large-scale pollination. Part of the problem is that their nests have often been destroyed by intensive cultivation. Also use of herbicides has destroyed some of their food sources, and insecticides have destroyed the bees themselves. The practice of small-scale organic agriculture may be helpful in bringing back these pollinators.

    One of the problems with bumblebees as pollinators is that they are often too large to get inside some flowers that don’t have an open flower structure, so they resort to different behaviors to get at the pollen. One such behavior typical of bumblebees with short tongues is that instead of trying to get into a flower by the usual route, they will sometimes bite a hole in the side of the flower to get at the pollen, thereby completely bypassing the usual pollination mechanism. A good example of this can be seen when hand-pollinating squash. When doing hand pollination of squash the male and female blossoms are taped to exclude the pollinator. Bumblebees will sometimes chew a hole in the side of the squash blossom in order to get at the pollen, so when you are hand pollinating squash this is something to look for.

    Another behavior of bumblebees is that they can sometimes be found hanging upside down on tomato, pepper, and eggplant blossoms, especially tomato where they vibrate the flower, causing the pollen to fall onto the body hairs. This is a case where bumblebees can cause a significant amount of cross-pollination on normally self-pollinated plants. They are not abundant on tomato flowers, but they are present often enough to cause a problem.

  - **Other native wild bees:** In some parts of the country and in many parts of the world, solitary, semi-social, and gregarious bees are valuable pollinators of certain crops, but because their numbers are limited and because their populations fluctuate erratically it is difficult to rely on them for pollinating crops.

    There are about 5,000 species of bees in North America, all grouped in the category of “wild bees”. Their population levels have been adversely affected by large-scale agriculture through reduction of habitat and use of agro-chemicals. On the other hand, their populations have been increased by: (1) logging of forests which have allowed growth of flowers, (2) paving of roads which has concentrated moisture along roadsides, (3) introduction of non-native plants (“weeds”), upon which they forage, (4) introduction of certain agricultural crops, and (5) introduction of crops into desert areas with irrigation.

    Many of the wild bees tend to specialize in some manner. Some species may forage only at dawn, others feed at dawn and dusk, others forage in the morning or during the day, and a few species are nocturnal. Some are found only in certain types of habitats and some specialize only on certain families of plants, or even on only one species.

Most people aren't very aware of wild bees, largely because they are small, quiet, relatively unobtrusive, and not brightly colored, except for the relatively large metallic green bees. Many people are familiar with "sweat bees" which will cross-pollinate tomatoes and other vegetable crops.

Many species of wild bees forage just several hundred feet. Some species of wild bees will forage much further than the honeybee. The record foraging distance is 15 miles, reported for the species *Euplusia surianamensis.*

We cannot depend entirely on strict numerical guidelines for determining isolation distances, especially where there is a tight relationship between the plant and the pollinator. Wild bees that specialize on certain species or families of plants can, and will, forage for considerable distances. For example, two genera of bees, *Peponapsis* and *Xenoglossa* have co-evolved with the squash plants they pollinate. The following story illustrates how strong the connection is between these bees and their preferred plants.

There is a small island seven miles off the coast of Massachusetts. An entomologist who was researching wild bees, especially the wild bees that pollinate members of the squash family, visited the island and looked for squash bees on the island. There were no members of the squash family growing on the island that year, and no squash bees. The next year, he went back, and there was a new vegetable garden with squash planted in the garden. He found that squash bees had located this patch of squash over seven miles of open sea! Squash bees are highly tuned to locating squash plants, so in some ways it is not surprising that they can detect the chemical signature of squash plants over long distances.

Insects other than bees (with some exceptions) are generally not important pollinators of most vegetable crops. They tend to be significant only for specific herb or ornamental crops. Their relationship with flowers is often more highly specialized. Following are some of the types of insects that are important pollinators.

- **Butterflies:** Butterflies have a well-developed visual sense and the ability to see certain colors. Flowers pollinated by butterflies are often brightly colored, often red or orange, and are open during the day. These flowers sometimes have "nectar guides", colored areas that help guide the butterfly to the source of the nectar which is their food source. Butterflies seem to have a preference for these guiding marks on the flower since they are probably not sensitive to three-dimensional contours. The nectar is usually well hidden in narrow spurs or tubes. The fragrance of butterfly flowers is often weak or absent and the olfactory sense of butterflies is not well developed. Butterflies are generally not well equipped for carrying pollen because their wings are covered with scales rather than hair, though the head and thorax of some butterflies are capable of transporting pollen. The blossoms of some butterfly flowers tend to exclude bees and the placement of the floral reproductive parts favors cross-pollination by butterflies.

- **Moths:** Moths have a well-developed olfactory sense and moth pollinated flowers are often heavily perfumed. Peak odor production begins at dusk when moths become active. Though moths do not seem to have a visual sense for color, their night vision is well developed. Moth flowers are often large, tubular, and white, greenish-white, or pale pastel in color. The flowers are often closed during the day and open around dusk. Unlike butterfly flowers that are not well dissected, moth flowers often have deeply dissected lobes or fringed petals that help differentiate the flower against a dark background. Nectar guides are generally absent since color is harder to detect at night, so guidance to the deep nectar tubes is accomplished by the visual contours of the flower. Unlike butterfly flowers where pollen is shed during the day, moth flowers predominately shed their pollen at night. Moths (especially sphinx moths) are often strong fliers and tend to hover in front of blossoms without alighting, which is contrast to butterflies which alight but do not hover. Their wings are not adapted for carrying pollen, but the hairs on the anterior part of the moth are capable of carrying pollen and causing cross-pollination. Examples of moth-pollinated flowers include evening primrose and tobacco.

Flies: Flies are important pollinators of some of our vegetable crops, mainly the Umbelliferae and the Brassicaceae. Plants in these families have open exposed nectaries which flies prefer. Because flies are hairy they can pick up and transport significant amounts of pollen, though they do no exhibit flower constancy. In some climates flies are active most of the year, unlike bees which are more demanding in terms of climate and habitat.

Wasps: The bodies of wasps are covered with a sparse covering of short spines, not the dense hair that is found on bees. For that reason most species of wasps are not considered important pollinators of vegetable crops, except for the family Umbelliferae (carrot family) in some regions of the country. Elsewhere their importance is secondary compared to the role of bees and flies. Some species of wasps are very important for the pollination of alfalfa. Wasps in the family Scoliidae collect nectar from cotton and are important pollinators of cotton, but unlike bees they do not exhibit flower constancy. Wasps tend to prefer blossoms that are open where the nectar is freely accessible.

- **Other Types of Pollinators:**

  - **Invertebrates:** There are a lot of pollinators with some interesting stories behind them. For the most part, they don't really pertain to vegetable crops. These include thrips, midges, beetles, snails, and slugs. In many cases these involve specialized relationships between the pollinator and the flower.

  - **Vertebrates:** A number of vertebrates, especially birds and bats, have highly specialized relationships with flowers and are important in pollination. Many small mammals such as rats, squirrels, and flying squirrels are also important, but often do not have specialized relationships with blossoms and are somewhat destructive in their feeding habits. Birds, especially hummingbirds, are important for pollination of certain flower and herb crops, but are not significant for vegetable seed production.

SELF-POLLINATED PLANTS

PROBLEMS WITH ISOLATION DISTANCE RECOMMENDATIONS

In much of the popular seed saving literature, and in some well-respected reference books, a number of seed crops are cited as being self-pollinated, and therefore requiring little or no isolation to produce pure seed. Some examples include beans, peas, lettuce, chicory, endive, and tomato. Because these crops are considered to be self-pollinated, it is frequently stated that these crops need only be isolated enough to prevent mechanical mixing of the crops at planting time and harvest.

Minimum isolation distance recommendations from some government agencies tell a different story. For example, Canada requires a minimum of 150 feet separation between self-pollinated commercial seed crops. During World War II, when food and seed was in short supply, the United States government enacted the Lend-Lease Act to support U.S. allies with food and supplies. One of the provisions of the Lend-Lease Act was that for seed production; self-pollinated crops should be separated by a minimum of 150 feet plus a barrier crop. The uniform recommendation of 150 feet suggests that there was an understanding that self-pollinated crops could outcross easily. The 150 foot separation guideline did not take into account that some of these crops cross more readily than others.

What is the explanation for the inconsistency in the recommendations from various sources? Most of the inconsistencies result from lack of research, lack of understanding the variables that affect such research, or improper generalization of research results. When the principles of pollination ecology are understood, many of the inconsistencies can be explained. Minimum isolation distance recommendations are heavily dependent on context, the environment in which the crops are grown. Crop environment includes a number of factors such as climate, weather, agricultural practices, biodiversity, and pollinator pressure.

CASE STUDIES: LESSONS FROM CERTAIN SELF-POLLINATED CROPS

Below, case studies of several crops are presented to illustrate some of the issues involved in understanding some of the factors affecting isolation distances in crops. Though the following discussion focuses on certain crops, the principles illustrated apply to most crops.

OKRA

Okra has perfect flowers (male and female reproductive parts in the same flower) and is self-pollinating. If okra flowers are bagged to exclude pollinators, 100% of the flowers will set seed. Although insects are unnecessary for pollination and fertilization, the flowers are very attractive to bees and the plants readily cross-pollinate. The observation that a plant is capable of self-pollination has sometimes been made into an argument that isolation of self-pollinators is not necessary. On the contrary, the ability to self-pollinate often has little to do with the amount of cross-pollination that can occur naturally.

The few studies available on the amount of natural cross-pollination in okra show that there is a considerable amount of outcrossing when two varieties are planted in alternate rows. See for example the data in the table below:

Source for data on cross-pollination under field conditions (two varieties planted in alternate rows)	Percent cross-pollination
University of Missouri, Dept. of Horticulture	4 to 18%
U.S. Dept. of Agriculture	4 to 42%

The data above does not take into account the amount of crossing within the row, and therefore the reported values under-represent the actual amount of cross-pollination. Furthermore, the data are affected by the size of the growing area. In large intensively cultivated fields, the amount of cross pollination is smaller than it would be in small fields because the ratio of pollinators to plants is smaller in large plots than in small plots. In addition, if the fields have been sprayed with agro-chemicals, the pollinator pressure will be even less, and the amount of cross-pollination will be correspondingly lower. Thus, the lesson for organic growers producing seed in small plots is that the amount of cross-pollination will be substantially higher than the values shown in the table above.

A survey (Gibbs, 1984) of the minimum isolation distance recommendations for okra is summarized in the table below. Note that the minimum recommended isolation distances vary by a factor of four.

Source of recommendation	Recommended isolation distance
University of Missouri, Dept. of Horticulture	1 mile
State of Oklahoma (registered or foundation seed)	1/4 mile (1,320 feet)
State of Oklahoma (certified seed)	1/8 mile (825 feet)
U.S. Dept. of Agriculture (1905)	1/4 mile
Plant breeder from Florida (Tom Williams)	1/2 to 1 mile

Okra is an example of a self-pollinating crop that requires a considerable degree of separation between varieties to maintain purity.

TOMATOES

In 1982, when I founded Southern Exposure Seed Exchange, one of the biggest challenges was gathering information about the required minimum isolation distances for growing small lots of different seed crops. The information available applied to very large seed-growing operations. It was especially difficult to find the minimum isolation distance requirements for tomatoes. I called a national tomato expert as well as USDA tomato breeders. Both sources said that tomatoes are essentially self-pollinated and that you only need to keep varieties about ten feet apart to avoid mechanical mixing of the seed during harvest.

Because I knew that the ancestor of the modern tomato is pollinated by wild bees, I questioned the validity of recommendations on minimal isolation distance. So, the first year that I produced a crop of tomato seed, I was cautious, and decided to isolate several heirloom tomato varieties by 25 feet. When I grew out the seed from those tomatoes the following year, it was evident that there was a significant amount of outcrossing in two of the varieties. Why was this expert advice incorrect for my situation in the Mid-Atlantic? There were two reasons. The first had to do with the fact that both experts were basing their recommendations on modern varieties of tomatoes. In contrast, I was growing mostly heirloom varieties of tomatoes, which as explained below, have a slightly different flower structure that encourages cross-fertilization. The second reason was that I was growing my plants organically in an ecologically diverse, pollinator-rich environment. The tomato breeders that I had talked with were growing their tomatoes in an ecologically limited, pollinator-poor environment treated with agrochemicals.

Factors influencing the amount of natural cross pollination (NCP) in tomatoes:

The amount of NCP in tomatoes is a function of a number of variables: (1) wind movement; (2) variety characteristics such as style length; (3) environmental variables affecting style length; (4) pollinator pressure; (5) isolation distance; and (6) biodiversity - presence of other pollen-producing plants in the area of the seed crop.

1. **Wind movement:**
   Although tomato pollen can become air-borne (I have observed a thin, diffuse cloud of tomato pollen being blown a distance of at least twelve feet), the role of wind in cross-pollination of tomatoes is virtually zero because the stigmatic surface of the tomato flower presents such a small target. Also there is a possibility that by the time tomato pollen becomes wind-borne it may be infertile. Therefore, cross-pollination by wind is a theoretical possibility, but the odds of success are extremely remote. If you look at the flower structure of wind-pollinated plants, the stigmatic surface is often quite large and feathery, whereas the stigmatic surface of the tomato flower is approximately one millimeter or less. The major role of wind in tomato pollination is that it increases self-pollination because wind vibrates the flower causing pollen to fall from the anthers onto the stigmatic surface. Tomatoes grown in a greenhouse often have to be vibrated by hand in order to effect pollination, or a better fruit set.

2. **Variety characteristics:**
   Tomato varieties having long styles (pollen-receptive organs) are more likely to be cross-pollinated by bees than varieties with short styles. If the length of the style exceeds the length of the anther cone (pollen-producing organ), NCP by bees is more probable, and probability increases as style length increases (Figure 1). Gardeners attempting to preserve old varieties need to be aware of this point because many older varieties generally have longer styles than modern varieties. Most modern varieties have styles equal in length, or shorter than, the anther cone (Figure 2). Our modern varieties were derived originally from wild tomato ancestors (primarily from Ecuador and Peru) which relied on bee pollination to a large degree. As these wild types were transported out of their center of origin to new geographic areas, the absence of their usual bee pollinators resulted in selection for variants that had shorter styles and an increased capacity for self-fertilization. Although style length is genetically determined, environmental conditions may cause style length to increase, thereby affecting the probability of cross-pollination.

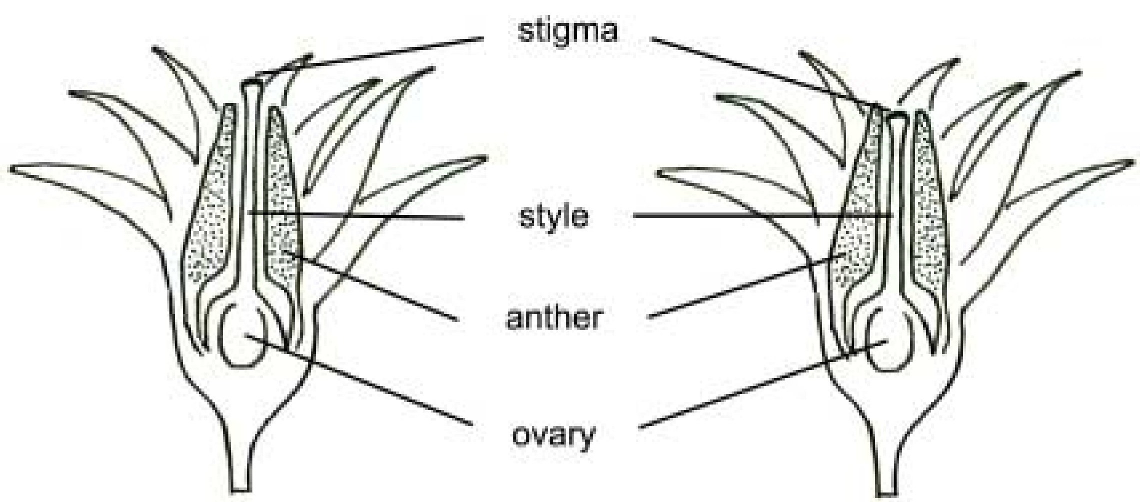

Figure 1. Tomato flower – old variety (adapted from McCormack, 1984)

Figure 2. Tomato flower – modern variety (adapted from McCormack, 1984)

3. **Environmental variables affecting style length:**
   Environmental effects have a physiological and developmental effect on style length, which in turn affects the rate of cross-pollination. Some of the environmental factors are day length, light density,

and carbon-nitrogen ratio. Even though style length is genetically determined it may be modified by the environment. The same variety grown in the North may have a slightly different style length than one grown in the South. Also the amount of nitrogen in the soil may have an effect on the length. Because these environmental factors cannot be easily controlled, style length is not a constant.

4. **Pollinator pressure:**
Pollinator pressure is a term loosely defined as the number of pollinators, types of pollinators, and their efficiency in performing pollination. Pollinator pressure is high when the number of possible pollinators is high, and when one or more of the pollinators is efficient in causing pollination. Pollination pressure is generally higher when crops are grown organically in biodiverse plantings.

Generally, tomato flowers are unattractive to bees if other pollen sources are available; however, in some bioclimactic regions of the U.S., bee visitation of tomato flowers may be quite common even in the presence of other pollen sources. Such a situation exists in regions of California and parts of the Mid-Atlantic region. For example, in central Virginia I have observed and photographed bumblebees (Figure 3) and halictid bees (Figure 4) such as sweat bees collecting pollen from tomato flowers. Bumblebees tend to vibrate the flowers, while halictid bees appear to chew the anthers to get at the pollen.

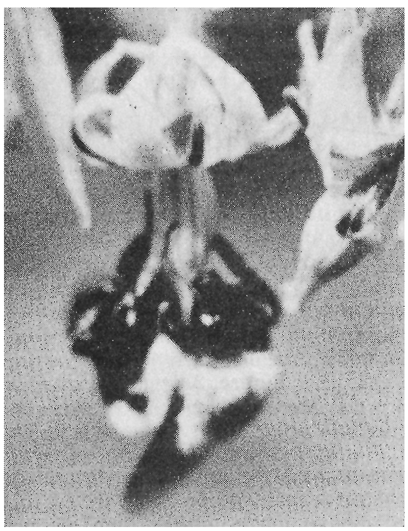

Figure 3. Bumblebee collecting pollen by vibrating tomato flower. (McCormack, 1984)

Figure 4. Wild bee (halictid bee) collecting pollen from tomato blossom. (McCormack, 1984)

5. **Isolation distance - rates of natural cross pollination (NCP) in interplanted varieties:**
In one study of two tomato varieties planted in adjacent rows, the amount of NCP reported ranged from 2 to 5%. Factors such as long style length, frequent visitation of tomato flowers by bees, and suitable environmental conditions produce much higher NCP values. Various studies have reported values of 12, 15, 26, and 47% NCP in rows of interplanted tomatoes. The wide range of results reflects the influence of different methods and variables used in these studies. In addition, microclimate factors and plot size has an influence on these results. Nevertheless, it is clear that NCP values can be very high under the right conditions.

The relationship between isolation distance and NCP is geometric, not linear. Thus as isolation distance increases, the amount of NCP falls off rapidly. A study by Currence and Jenkins (1942) illustrates this point very well (Figure 5). The main point is that even a separation of a few feet between varieties in a small garden will greatly reduce NCP of tomatoes even though minimum recommended isolation distances cannot be achieved. Also NCP can be reduced or eliminated by taking advantage of different blooming times of early and late varieties.

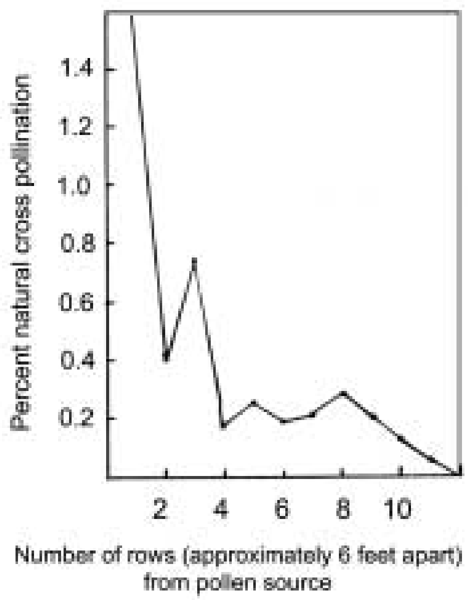

Figure 5. Amount of natural cross-pollination (NCP) of tomato at increasing distance from pollen source. (Data from Currence and Jenkins, 1942).

6. **Biodiversity and the presence of other pollen-producing plants in the area of the seed crop:** The presence of other pollen producing crops has a significant effect on pollinator pressure. Certain pollen sources are more attractive to certain pollinators than others because a particular type of pollen may be easier to harvest, more accessible, or in greater abundance; the flower may be more attractive; or there may be less competition from other pollinators. This is where the role of barrier crops comes into play when attempting to maintain the variety purity by reducing the amount of NCP. When planting a barrier crop between two varieties, attractiveness of the pollen source may be a factor to consider. Though barrier crops may be effective even as a physical barrier, the effectiveness of the barrier will be greater if there is a large source of pollen or nectar during the flowering period of the seed crop. One of the most effective barrier crops is ornamental sunflowers, which tend to have an extended blooming time compared to the oil-seed type of sunflowers. Squash plants are also effective though they are less of a physical barrier and the blooms are attractive to pollinators mostly during the morning hours.

PEPPERS

Peppers are self-pollinating and seed in the absence of pollinators, but under natural conditions they are cross-pollinated to a considerable extent. The amount of NCP has frequently been underestimated, and there are few studies which have documented the amount of NCP. In 1941 Odland and Porter wrote that, "Plant breeders and seedsmen disagree considerably in their opinions relative to the amount of natural cross-pollination in the cultivated pepper….in seed production, knowledge relative to natural crossing is a great aid in determining the isolation necessary in the seed plots". The lack of information is due partly to the number of variables affecting NCP such as location, time of year, changes in insect populations, and climatic factors. Several seed saving guides recommend isolation distances ranging from “several feet” to “50 feet”, to “separation of the length of the garden”, to “separation as far as practical”, to “500 feet”.

What percent of NCP can be expected of two varieties of pepper grown side by side? In a series of experiments conducted over a two-year period in five commercial fields in New Mexico, test plants of one variety were transplanted into commercial plots of another variety. Tester plants were placed 12" (30 cm) from adjacent plants of the commercial variety. The average NCP was found to be 42% with individual plants having a NCP value as high as 91%. This percentage may be unusually high because the commercial cultivar outnumbered the tester plants, and it's not an usual procedure to plant two different varieties in this fashion. In a similar series of experiments by Odland and Porter (1941) it was demonstrated that NCP values ranged from 9 to 38% depending on the variety of pepper tested. In my own experience I have had peppers appear to cross at 6, 15, and 25 feet with barrier plantings in between. The pollinating agents in most of these examples are honeybees, bumblebees, and halictid bees such as sweat bees. The authors of the New

Mexico study did not recommend specific isolation distances possibly because there are so many variables involved whose effect are only partially understood.

The Lend-Lease Act stated that for peppers, one-fourth mile isolation distance is recommended for isolating two varieties, but the distance should be not less than 150 feet, plus a barrier crop between two varieties. The recommendation does not differentiate between sweet peppers, long-fruited sweet peppers, and hot peppers. Long-fruited sweet peppers have longer styles (stigmas exserted beyond the anther cone) than bell or squash peppers, and hot peppers have a longer style than sweet peppers and are therefore more susceptible to cross-pollination. If sweet peppers are grown within pollination range of hot peppers, the isolation distance between hot and sweet peppers should be twice the isolation distance between two varieties of sweet peppers.

Regarding barrier crops, crossing in peppers occurs primarily between 7 a.m. and 11 a.m., so a barrier crop of squash (combined with adequate isolation) would be effective since squash pollen is present and harvested at approximately the same time by pollinating insects.

COTTON

There are four commonly cultivated species of cotton, but the one that is most cultivated is *Gossypium hirsutum* (upland cotton). Many breeders who consider cotton to be self-fertile and self-pollinating are working with upland cotton which is more likely to self-pollinate. Since cotton is a heavily sprayed crop, it may be more difficult to interpret pollination data. Nevertheless, all species of cotton cross-pollinate to varying degrees. The flower opens at dawn and withers by the end of the day. Hummingbirds and many types of insects visit the flowers but because the flowers have five sets of nectaries, one floral and four extra-floral, not all of the visitors are involved in pollination. In a study done in India by Sidhu and Singh (1961), forty-one species of twenty-three families of insects in seven insect orders visited the cotton flowers, but most visited the extra-floral nectaries and did not come in contact with the sexual part of the flowers. This is important to mention, because observation of a visitor on a floral does not necessarily equate with pollination. If you are making observations for the purpose of assessing potential cross pollination, you have to observe both the flower structure and the behavior of the visitor on the flower parts in order to determine if pollination is taking place. In North America, bumblebees and honeybees are the most efficient pollinators of cotton. It is worth noting that when cotton is cross pollinated, the pollen tube from the foreign plant (non-self pollen) grows faster than the pollen tube produced by the flower's own pollen. Even though more self-pollen may land on the stigma than foreign pollen, the foreign pollen will disproportionately fertilize the ovules more than the self-pollen. This is a general phenomenon for plants, and a manifestation of hybrid vigor.

As mentioned previously, the amount of cross-pollination between two varieties, and the distance over which it occurs, is proportional to the square of the distance between the two varieties. Every doubling of isolation distance decreases the amount of cross-pollination by a factor of four. This concept is very nicely illustrated in the graph below which shows the percentage of cross-pollination of cotton at different distances from pollinator source.

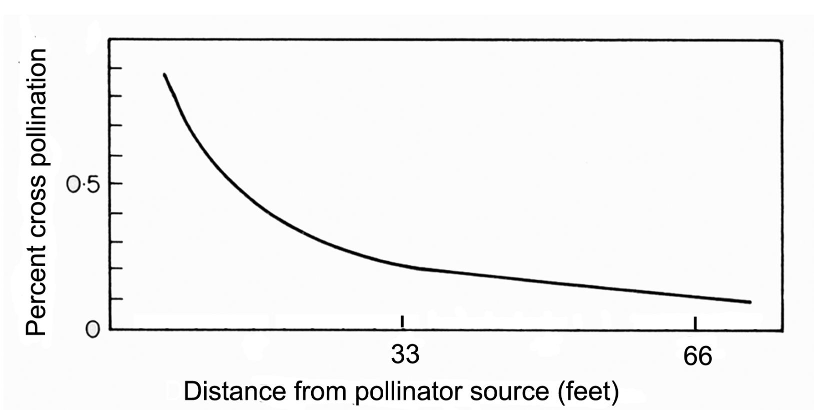

Figure 6. Percentage of cross-pollination of cotton at different distances from pollinator source. (adapted from Trought, 1930)

Note that the curve of the graph, if extended along the bottom axis, never reaches zero. It approaches zero, but never reaches zero. So, in pure mathematical terms, there is no safe isolation distance! It is an interesting concept to consider and lends an interesting and important perspective to the whole discussion of isolation distance. However in biological terms, there is a safe isolation distance, because the graph that is mathematically generated is based on real limits in the biological world. It is the complex of factors such as biodiversity, climate, variety characteristics, and other variables that determine the shape, slope, and end point of the curve.

LARGE-SCALE VERSUS SMALL-SCALE SEED PRODUCTION

Isolation distance recommendations can also be affected by the scale and scope of production.

The isolation distance requirements for large-scale growers can be summarized as follows. For self-pollinated plants, minimum isolation distances range from fifty to several hundred feet, depending on the type of plant. Selfers that are easily cross-pollinated by insects require isolation distances ranging from one-eighth mile to one mile. Outcrossers that are routinely cross-pollinated by insects are typically isolated by one mile. Crops that have light, wind-borne pollen (most notably beets) are often isolated by distances up to three miles. Crossing in beets has been noted at a distance of up to 12 miles. In general, the isolation distance recommendations for large-scale seed production are more dependent on size of the plantings and local geography when compared to isolation recommendations for small-scale seed production.

Small-scale seed growers, especially those in the Mid-Atlantic and South, usually do not have to be as concerned about issues of scale. In the eastern U.S., the geography and natural vegetation often provides pollen barriers that are an aid to isolation, especially in the piedmont and mountain regions. On the other hand, there may be more small farms and garden plots that are potential sources of contaminating pollen. Local geography, crop size, and distribution of native vegetation are other variables that have a bearing on determining a safe isolation distance.

UNDERSTANDING THE CONTEXT OF ISOLATION DISTANCES

By now it should be clear that isolation distance recommendations are general guidelines that need to be modified for some growing environments. They may also need to be modified according to the purity of seed desired. Purity, as noted before, is based on the intended use of the seed, and there are different definitions of purity, which in turn have a bearing on isolation distance. The greater the degree of purity desired, the greater the isolation distance required. Isolation distances are not absolute values. They must always be interpreted within the environment or context in which the crops are grown. Though the seed grower has no control over some aspects of the growing environment, other aspects of the environment may be manipulated or controlled in such a manner that isolation distances may be decreased.

HOW TO MODIFY ISOLATION DISTANCE RECOMMENDATIONS

TECHNIQUES FOR DECREASING THE MINIMUM ISOLATION DISTANCE

When it is not possible to achieve the recommended isolation distance there are methods that can be used to decrease the distance. These are not techniques for ignoring isolation distance, but rather for decreasing isolation distance when it is not possible to achieve the desired minimum. Following are some techniques that may be used, but always err on the side of caution.

- **Plant in blocks rather than rows:**
  Planting crops in blocks rather than rows decreases the exposure of crops to foreign pollen. A block planting has a much smaller periphery than a row planting. For example, one hundred plants, spaced 12” apart in a row, has a periphery of approximately 200 feet (counting both sides of the row), whereas 100 plants, spaced 12” apart in a block ten feet square has a periphery of approximately 40 feet (counting all sides of the block). In this case the periphery of the block is only 40% of the periphery of the row.

Collect seed from center of block plantings:
This technique is an extension of the previous technique, and takes edge effects into account. There usually will be a larger percentage of pollinators at the edges of a block than in the center of the block. Therefore, the plants in the center of the block are more likely to produce pure seed than those at the edges. This technique works well on a large scale where the block is a small field, but is less effective in a small garden plot. Nevertheless, it may have some effectiveness in a small planting. Given the option of planting two potentially cross-pollinating crops in rows it is better to plant in blocks than rows.

- **Collect seed from fruits produced during peak flowering:**
At low planting densities, the ratio of flowers to pollinators remains relatively constant. As the number of flowers increases toward maximum blooming, a point may be reached in which the ratio of flowers to pollinators increases. This has the effect of decreasing the amount of cross-pollination between two separated varieties. For example, if you have two varieties of tomatoes grown for seed, and have concerns after planting that the crops are too close together, you can collect fruit for seed during peak fruit production, but not at the beginning or end of production. This decreases the likelihood of collecting outcrossed seed.

- **Use barrier crops:**
Barrier crops serve several functions:

1. They provide a physical barrier for pollinators, disrupting the line of flight and the line of sight. Honeybees and bumblebees have a behavior called “flower constancy” which helps keep them single-minded about staying with the flowers they are visiting rather than flying over or through a barrier to visit another crop. Barrier crops are semi-permeable, and the degree of permeability depends a lot on the types of plants used, their blooming period, and types of nectar and pollen resources.

2. They distract pollinators by providing alternative pollen and nectar sources, and they add a distinctive fragrance or chemical signature to the air which may attract pollinators away from the main seed crop.

Ideally a barrier crop should be taller than the seed crop; it should be dense, and should produce an abundance of flowers during the period in which the seed crops can be cross-pollinated.

Plants that are frequently used as barrier crops include corn, sorghum, ornamental sunflowers, borage, members of the squash family, and showy annuals and perennials. There are advantages and disadvantages with each of the barrier crops. Corn and sorghum can form a dense, tall barrier, and although bees are attracted to pollen on the tassels, the period of pollen production has a narrow time window. Ornamental sunflowers often make an excellent barrier crop. They are tall and dense, but may need to be planted in a three–week succession to ensure that flowers are produced over a long enough period. Borage and members of the squash family are highly attractive to bees, but have the disadvantage of low height and a narrow pollen-production window (early morning until noon or mid-day). Showy annuals and biennials with wide-open nectaries, and single-petalled flowers can be quite effective. Avoid the showy, ornamental, doubled-petalled flowers which often make the pollen and nectar more inaccessible. Perennial flower borders around seed garden can be very effective because they provide a range of pollen and nectar sources throughout the growing season. Herb borders can also be effective, for example Echinacea, anise hyssop, borage, and members of the carrot family such as dill and parsley (when in flower).

- **Offer alternate pollen sources:**
Though barrier crops often serve as alternate pollen sources in themselves, having the seed production area surrounded by perennial borders can be very effective in distracting pollinators. Islands of annuals may also be placed within the seed production area. This strategy can be especially effective for self-pollinating plants that are susceptible to out-crossing by pollinators. For example, beans, peas, peppers, and tomatoes have flowers that are not nearly as attractive to bees as showy members of the Compositae (composite family).

- **Isolate in time (staggered blooming times):**
All of the above techniques rely in some fashion, on isolation in space (isolation distance), but isolation in time is another option. This technique can be used with annual seed crops such as sunflowers, corn, lettuce, okra, and members of the Umbelliferae (parsley family). For example, an early variety of corn can be planted early in the season, followed three weeks later by a planting a late variety. The early variety will have finished tasselling and the silks will have dried before the late variety comes into tassel. This technique also works well for sunflowers, and more than two varieties can be grown in a season, especially if the first variety is started in cell packs before the last frost. In Virginia, I have grown as many as four different varieties of oil-seed sunflowers for seed in this manner, though I don't recommend growing more than two varieties this way because the weather may not always be so cooperative. Weather variation in the spring and fall can make timing tricky causing an overlap in the blooming sequence. Due to weather variation, the early-planted variety will grow more slowly in the spring because of cooler temperatures, and the late-planted variety will grow more quickly because of warming temperatures. If an overlap in blooming occurs due to weather variation or miscalculation, it will be necessary to remove the flower buds from the last flower buds of the early variety, or the first flower buds of the late variety.

SITUATIONS REQUIRING INCREASED ISOLATION DISTANCE

Certain situations arise where it is necessary to increase the recommended minimum isolation distance. These are described below:

- **Larger population of plants:**
The larger the population size of plants, or the larger the plot size, the greater the need to isolate. This recommendation depends again on the context of the growing situation. If there are no crop barriers and little or no alternate pollen sources, the pollinators are going to be focused on the two seed crops being isolated. Large plant population size becomes less of an issue if the size of the barrier crop is increased or there are other mitigating factors such as an abundance of pollen and nectar resources in the area. So the issue here is to consider the ratio of seed crop size to other pollen and nectar-bearing crops in the vicinity.

Larger number of varieties:
If growing more than two varieties for seed, the placement of the varieties in relation to each other can become an issue. When a third variety is added, each variety should not be equidistant from the others by the recommended isolation distance unless the isolation distance is increased. Each time an additional variety is added, the ecological complexity of the area is increased, decreasing the predictability of the system. This makes it harder to define minimum isolation distances and therefore it is best to err on the side of caution by increasing the distances or growing fewer varieties.

- **High pollinator pressure due to apiculture:**
If you or your neighbor is a beekeeper, there will be a lot of pollinator pressure on your crop plants, and isolation distances may need to be increased dramatically. For example, under these circumstances, the 150 to 300 foot isolation distance (without crop barriers) for lima beans would be inadequate for keeping two lima bean varieties pure. In this case, it may be best to grow only one variety of lima bean.

- **High pollinator pressure due to a biodiverse environment:**
Factors that increase biodiversity also tend to increase pollinator pressure on crops. Such factors include organic growing versus conventional growing. Conventional growers often use agrochemicals such as Sevin which is highly toxic to bees. Small-scale growers often have a larger variety of crops than large-scale growers who specialize in one or more crops. The larger the variety of crops, the more likelihood of higher pollinator pressure. Growers in rural environments surrounded by natural areas will have more diverse pollinators than growers in rural farm areas where the predominate activity is large-scale farming.

- **Variety characteristics:**
Certain varieties of tomatoes and peppers are much more susceptible to outcrossing than others. Heirloom tomatoes with double blossoms, potato-leaf varieties of tomatoes, certain varieties of cherry tomatoes, and currant tomatoes all are more susceptible to outcrossing to various degrees. The susceptibility to outcrossing is approximately proportional to the degree which the stigma is exserted

(the distance the style protrudes from the top of the anther cone). Likewise certain species of peppers are more susceptible to outcrossing. Hot peppers cross more readily than sweet varieties and pimiento varieties cross more easily than bell varieties – again due to the amount of stigma exsertion. Even bean varieties differ in their ability to outcross. Though this is not a factor for all crops, it is important to be aware that flower structure may differ among varieties.

➢ **Genetically-modified crop nearby:**
Genetically modified crops may have higher outcrossing rates than non-gmo crops. One noteworthy and troubling example, is an herbicide-resistant mustard which has over twenty times the outcrossing rate than non-altered plants (Bergelson, 1998). Researchers working on this mustard noticed that the genetically modified flowers look slightly different than the flowers of non-modified plants. Though the genetic basis of this floral modification is not yet understood, there are far-reaching implications for organic growers who must produce seed which is 100% free of genes from genetically modified crops.

SUMMARY OF ISOLATION DISTANCE FACTORS AND ADJUSTMENTS

Factors having an effect on isolation distance	Increase or decrease distance
Plants planted in blocks rather than rows	Decrease permissible
Seed collection from center of blocks	Decrease permissible
Seed collected only from peak production	Decrease permissible
Use of barrier crops	Decrease permissible
Use of alternate pollen and nectar sources	Decrease permissible
Time isolation (staggered blooming times)	Decrease permissible
Large seed crop population size of each variety	Increase suggested
Larger number of varieties grown for seed	Increase suggested
High pollinator pressure due to apiculture	Increase required
High pollinator pressure due to biodiversity	Increase required
Organic agricultural practices instead of conventional	Increase required
Variety characteristics which favor outcrossing	Increase required
Genetically modified crop grown nearby	Increase required

WEIGHTING THE ADJUSTMENT FACTORS

So the question may arise: "How much can I decrease the isolation distance if I grow my seed crop in blocks rather than rows?" There is no easy answer to that. As a general rule, I suggest for example, no more than a 10% decrease for each factor, but in the reality of a multi-variate seed-growing environment where studies are few, there is no magic number, no magic formula, no definitive multiplier or adjustment factor that can be applied to decrease or increase the isolation distance for a particular situation. Perhaps the two most important rules to remember are: (1) always err on the side of caution, and (2) space plantings with the knowledge that every doubling of isolation distance decreases the probability of outcrossing by a factor of four. In any case, the purpose of the discussion and table above is to allow the seed grower to consider the circumstances of the grower's unique situation and to make intelligent choices based on the understanding of what dynamics are operating within the grower's situation.

MECHANICAL ISOLATION

When it is not practical to isolate varieties either in time or space, there is a third option which is called mechanical isolation. Mechanical isolation involves the use of a physical barrier that prevents access of pollinators to the blossom. There are a number of different methods which include bagging flowers, building pollination cages to exclude pollinators, or in some cases caging introduced pollinators to increase pollination. Mechanical isolation is also used to exclude pollinators so that pollination can be done by hand in a controlled fashion.

Pollination cages are constructed by covering wooden or plastic frames with window screen or spun polyester material such as Reemay™. An inexpensive caging option is to cage crops under hoops of flexible plastic water supply pipe. The ends of the hoops are fitted over the ends of rebar or metal pipe inserted in the ground at 18 to 24” intervals along both sides of the crop. The height of the hoops is determined by the length of plastic pipe or the length of the rebar, or both. The hoops are then covered with spun polyester and fastened to the ground with soil clips, or held in place by boards on the soil surface. It is important to check that there are no small openings, because bees will find them very easily.

Simultaneously flowering crops can be isolated using alternate-day caging. This causes some reduction in seed set, but the flowering period may be extended due to a lower rate of seed set during the caging period. Alternate day caging involves leaving crop “A” caged while crop “B” is uncaged on the same day. At the end of the day, crop “B” is covered, and the next morning, crop “A” is uncovered. It is important that both crops be covered at the end of the day so that pollinators clean off their pollen before the beginning of the next day. The caging process is continued until flowering stops. If enough fruits have been produced, both crops are left covered. The technique of alternate day caging can be expanded to include as many as three crops. The caging procedure is noted in the table below:

	Day one	**Day two**	**Day three**
Variety “A”	covered	covered	uncovered
Variety “B”	covered	uncovered	covered
Variety “C”	uncovered	covered	covered

Note: All crops must be covered at the end of each day.

Hand pollination techniques can also be used to isolate seed crops. These techniques are beyond the scope of this manual and are covered instead in manuals dealing with specific seed crops.

RECOMMENDED MINIMUM ISOLATION DISTANCES FOR SPECIFIC CROPS

A chart of minimum recommended isolation distances for vegetable seed crops grown in central Virginia is included in Appendix A. The chart includes three minimum distance recommendations: (1) seed saved for home use, (2) commercial seed grown with pollination barriers, and (3) commercial seed without pollination barriers. These distances are subject to weighting as addressed above. These Virginia-based recommendations are applicable to much of the Mid-Atlantic and South.

APPENDIX A

Minimum Recommended Isolation Distances for Virginia-Grown Seed Crops

Seed Crop	Min. for home use	Min. w/ barriers *	Min. w/o barriers *	Comments
Bean, asparagus (*V. unguiculata*)	40-75’	150’	300’	Crosses with cowpeas (*V. unguiculata*)
Bean (*Phaseolus coccineus*)	75-150’	225-300’	450-600’	
Bean (*Phaseolus vulgaris*)	20’	40-75’	150’	
Bean, lima (*Phaseolus lunatus*)	40’	75-150’	150-300’	
Beets (*Beta vulgaris*)	> 600’	> 0.25 mi	> 0.50 mi	Or grow only one var./yr.; light pollen
Broccoli (*Brassica oleracea*)	600’	0.25 mi	0.50 mi	
Brussels Sprouts (*B. oleracea*)	600’	0.25 mi	0.50 mi	
Cabbage (*Brassica oleracea*)	600’	0.25 mi	0.50 mi	
Collards (*Brassica oleracea*)	600’	0.25 mi	0.50 mi	
Cauliflower (*Brassica oleracea*)	600’	0.25 mi	0.50 mi	
Carrots (*Daucus carota*)	600’	0.25 mi	0.50 mi	Crosses with Queen Anne’s lace
Celery (*Apium graveolens*)	600’	0.25 mi	0.50 mi	Crosses with celeriac
Chard, Swiss (*Beta vulgaris*)	> 600’	> 0.25 mi	> 0.50 mi	Or grow only one var./yr.; pollen light
Corn (*Zea mays*)	600’	0.25 mi	0.50 mi	
Cucumber (*Cucumis sativus*)	600’	0.25 mi	0.50 mi	Armenium cucumber is *C. melo*
Eggplant (*Solanum melongena*)	75’	150’	300’	
Endive (*Cichorium endiva*)	35’	75’	150’	Crosses with chicory
Gourd (Ovifera, Lagenaria, & Luffa spp.)	600’	0.25 mi	0.50 mi	Know which species
Kale (*Brassica oleracea*)	600’	0.25 mi	0.50 mi	
Kohlrabi (*Brassica oleracea*)	600’	0.25 mi	0.50 mi	
Leek (*Allium ampeloprasum*)	600’	0.25 mi	0.50 mi	
Lettuce (*Lactuca sativa*)	40’	75’	150’	Double distance if wild lettuce in area
Muskmelon (*Cucumus melo*)	600’	0.25 mi	0.50 mi	
Onion (*Allium cepa*)	600’	0.25 mi	0.50 mi	
Okra (*Abelmoschus esculentus*)	600’	0.25 mi	0.50 mi	
Parsley (*Petroselinum crispum*)	600’	0.25 mi	0.50 mi	
Parsnip (*Pastinaca sativa*)	600’	0.25 mi	0.50 mi	
Peas (*Pisum sativum*)	20’	40-75’	150’	
Radish (*Raphanus sativus*)	600’	0.25 mi	0.50 mi	
Rutabaga (*Brassica napus*)	600’	0.25 mi	0.50 mi	
Peppers (*Capsicum annuum*)	40-75’	75-150’	300-600’	Larger isolation required for hot pepper
Salsify (*Tragopogon porrifolius*)	20-40’	75’	150’	
Spinach (*Spinacia oleracea*)	> 600’	> 0.25 mi	> 0.50 mi	Or grow only one var./yr.; pollen light
Squash (*Cucurbita* species =4)	600’	0.25 mi	0.50 mi	Know the species of each squash/pumpkin: (*C. maxima, C. mixta, C. moschata, and C. pepo).*
Pumpkin (*Cucurbita* species =4)	600’	0.25 mi	0.50 mi	
Sunflower (*Helianthus annuus*)	600-900’	0.25-0.50 mi	0.50-1.0 mi	Ornamental & population size an issue
Tomato, modern var. (*L. lycopersicum*)	10’	35’	75’	Style length + bees is an issue
Tomato, potato leaf or heir. (*L. lyco.*)	35’	75’	75-150’	Style length, flower structure + bees
Tomato, wild type (*L. pimpinellifolium*)	45’	90-135’	180’	Style length + bees is a big concern
Turnip (*Brassica rapa*)	600’	0.25 mi	0.50 mi	Crosses with Chinese cabbage (*B. rapa*)
Watermelon (*Citrullus lanatus*)	600’	0.25 mi	0.50 mi	

*** Note: Minimum isolation distance recommendations are dependent on the context of the growing environment.** They are also based on the assumption that crops grown on adjacent land are garden-size plots, rather than large commercial plantings. When seed crops are grown within range of large plantings, the recommended distances above should be doubled for wind-pollinated and insect-pollinated crops. As a general rule, every doubling of isolation distance decreases the amount of cross-pollination by a factor of four. Most self-pollinated crops require no more than 150 feet isolation from large plantings, but there are exceptions. Pollination barriers should consist of flowers (annuals and perennials) and/or physical barriers (trees, shrubs and dense tall plantings). “Home use” means exactly that! Do not disseminate seed to seed exchanges without proper isolation precautions. Other isolation methods, such as isolation in time, or mechanical barriers such as caging, bagging, etc. may be used. The table on page 16 can be used to help determine how isolation distances may be adjusted for your situation. Each factor below which allows a decrease of isolation distance can be used to decrease the distance by perhaps no more than 10%: this figure is a guideline, not a rule. Keep in mind that an understanding of microenvironment and pollinator pressure is very important in making adjustments to isolation distance. When in doubt, don’t compromise. These recommendations supersede previous recommendations in seed grower guides, and although they are based on crops grown in central Virginia, the distances can be generalized to much of the Mid-Atlantic and South.

APPENDIX B

Preferred Relations between Pollinators and Blossom Types and Colors

Blossom Class or Flower Shape						Pollinator	Flower Color						
Dish or bowl	Bell or funnel	Brush	Gullet	Flag	Tube		Red-brown	Drab or dull	White	Yellow	Blue	Red	Green
X						Beetles	X	X	X				
X	X					Wasps	X	X					
X	X					Flies	X	X					
X	X	X				Bats		X	X				
	X	X	X	X	X	Bees			X	X	X		
		X	X		X	Moths		X	X				
		X	X	X	X	Butterflies				X	X	X	
		X	X	X	X	Birds						X	X

Note: The above chart summarizes the blossom preference of the main groups of animal pollinators. These are typical preferences, and the information is not meant to convey that pollinators are restricted to certain blossom classes and colors. Green blossoms in the above case refer only to conspicuous green rather than the small inconspicuous green flowers that are pollinated by the wind. (modified from Faegri and van der Pijl, 1971, with additions by the author)

SELECTED BIBLIOGRAPHY AND LITERATURE CITED

Bergelson, J. et al. 1998. Promiscuity in transgenic plants. Nature 395: 25.

Currence, T.M. and J.M. Jenkins. 1942. Natural crossing in tomatoes as related to distance and direction. Proc. Am. Soc. Hort. Sci. 41: 273-276.

Faegri, K. and L. van der Pijl. 1979. The Principles of Pollination Ecology, 3rd edition. Pergamon Press Ltd., London.

Free, J.B. 1970. Insect Pollination of Crops. Academic Press, London.

Gibbs, T. 1984. Insect cross-pollination in okra. Seed Savers Exchange: Harvest Edition 9(1): 28-32.

McCormack, J.H. 1983. Isolation distance for tomatoes. Seed Savers Exchange: Harvest Edition 8(1): 247-250.

McCormack, J.H. 1984. Guidelines for maintaining purity of pepper varieties. Seed Savers Exchange: Harvest Edition 9(1): 24-27.

McGregor, S.E. 1976. Insect Pollination of Cultivated Crop Plants. U.S. Department of Agricultural Research Service. Agriculture Handbook No. 496.

Meeuse, J.D. 1961. The Story of Pollination. Ronald Press, NY.

Odland, M. L. and A.M. Porter. 1941. A study of natural crossing in peppers (*Capsicum frutescens*). Amer. Soc. Hort. Sci. Pro. 38: 585-588.

Percival, M. 1969. Floral Biology. Pergamon Press Ltd., London.

Proctor, M. and P. Yeo. 1973. The Pollination of Flowers. Collins, London.

Richards, A.J. (ed.) 1978. The Pollination of Flowers by Insects. Academic Press, London.

Sidhu, A.S. and S. Singh. 1962. Role of honeybees in cotton production. Indian Cott. Grow. Rev. 16: 18-23.

Trought, T. 1930. Notes on certain facts on vicinism and artificial pollination in Egypt. Emp. Cott. Grow, Rev 7:13-18.

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