Supplemental Crop Information

Sunflower as a Crop

Sunflower, *Helianthus annuus* Linnaeus, is an annual row crop that is grown primarily for its edible oil. Other uses and byproducts include animal feed, human snacks, and various chemical and industrial products.

The crop, and indeed the entire genus *Helianthus*, was unknown in the Old World until after Columbus. But it was grown by North American Indians for millennia throughout much of the United States and portions of Canada and Mexico. Sunflower subsequently spread to Europe for garden and oil use, and finally to Russia in the eighteenth century, where its use as an oil crop developed seriously. Reintroduction as a commercial crop in North America probably occurred in the latter nineteenth century. Commercial interest in North America and other parts of the world has increased throughout the current century.

Taxonomy of Sunflower

Sunflower belongs to the genus *Helianthus*, a genus of 67 species, all native to the Americas. The genus consists of both annual and perennials; some, such as *H. annuus*, are very common; some, such as *H. niveus* (Bentham) Brandegee, are quite rare; some are very weedy; and some are grown as ornamentals. In addition to the sunflower, the Jerusalem artichoke, *H. tuberosus* Linnaeus, is grown for food. Taxonomists have repeatedly noted that the distinctiveness of the genus within the Asteraceae (Compositae),is matched by the indistinctness of the species within the genus. This is perhaps caused by the variability within each species, natural interspecific hybridization, and various polyploid states of the native species.

Reproduction of Sunflower

Flowers are borne on a fairly standard Asteraceae capitulum of 700–8,000 individual florets. Disk flowers are perfect; ray flowers are sterile with a rudimentary pistil. Disk flowers within a single capitultum open centripetally for a period of 5–10 days or more; each capitulum may have, depending on timing, a central portion of unopened buds, surrounded by a ring of florets with exposed stamens, another ring of florets with exposed stigmas, and finally a ring of pollinated florets. On the morning of anthesis of an individual floret, the stamens elongate and shed pollen inward. Later that day, the style elongates and by the following morning presents a receptive stigma above the stamens with pollen brushed upward by stigma hairs. At this stage pollination of the stigma occurs. Removal of fertile flower parts at various stages, insect pollination, self-incompatibility, and male sterility alter the above pollination outline and can be used in breeding programs. Pollen can be moved physically from one flower to another, but movement of the large spiny grains by wind cannot occur farther than a few feet.

Traditional cultivars have been maintained as open pollinating populations, but more recent breeding approaches have involved hybrids dependent on male sterility/restorer systems introduced from wild *Helianthus* species.

Pollination of Sunflower

Honey bees are the primary pollinators of sunflower. Bumble bees, wild bees, and other insects may also be pollinators. Wind pollination is negligible. Without adequate numbers of pollinating insects, yield of sunflower may be low. Movement of sunflower pollen to other cultivated, wild, or weedy sunflower by bees can occur over considerable distance. Certified seed distance is 2,640 feet, and is increased to 5,280 feet between seed fields and wild or volunteer sunflower plants.

Crossability of Sunflower

Cultivated sunflower crosses readily with wild and weedy forms of *H. annuus*, which are common in many areas. Insect-aided pollination is the predominant method by which a high degree of cross-pollination takes place in sunflowers. Cultivated sunflowers are potentially capable of crossing with many other species of *Helianthus*, and naturally occurring hybrid swarms are known in North America. Interspecific hybridization involving *H. annuus* as one of the parents has been conducted for many years as part of breeding programs and taxonomic research. Hybridization ranges from easy and generally fertile crosses, such as with many of the other annual species, to high levels of incompatibility.

Weediness of Sunflower

The Asteraceae are one of the premier weed families. Sunflower follows the family pattern well. Aside from its value as a crop, sunflower is a common and difficult weed of cultivated land and disturbed areas. It is a common volunteer in field crops, developed from stray seed of the previous season. Any genetic alteration that would increase weedy tendencies or make control difficult would be a cause for concern to agriculture.

Seed Dispersal in Sunflower

The subject of seed dispersal inevitably leads to birds. For several reasons, sunflower seed is very attractive to many birds. The seeds have high levels of protein and fat that are useful to growth, molt, fat storage, and energy needs of birds. The seeds mature during the postbreeding season of most birds, when their energy demands are greatest. In some parts of the world, birds have many years of co-evolution with sunflower. Although most of the seed is consumed by the birds and becomes nonviable, an inevitable fraction is moved but not consumed. A certain percentage of seed always falls to the ground before and during harvest of commercial sunflower fields. This frequently results in volunteer plants in the next season.

Modes of Gene Movement

Genes may move out of the test areas by pollen or by seed. Because insect-vectored sunflower pollen may readily transfer genes to wild, weedy, or cultivated *H. annuus*, or other *Helianthus* spp. outside test areas, some means, such as flower removal, caging, etc., must be used to prevent such movement. Spatial isolation may not be realistic for some test sites. Seeds may serve as a means of movement either by bird dissemination, or simply by falling to the ground. Some means, almost certainly physical, must be implemented to prevent seed from falling and to prevent birds from taking seed.

Cotton as a Crop

Four species of the genus *Gossypium* are known as cotton, which is grown primarily for the seed hairs that are made into textiles. Cotton is predominantly used as a textile fiber because the mature dry hairs twist in such a way that fine, strong threads can be spun from them. Other products, such as cottonseed oil, cake, and cotton linters are byproducts of fiber production. Cotton is a perennial plant cultivated as an annual.

Taxonomy of Cotton

The genus *Gossypium*, a member of the Malvaceae, consists of 39 species, four of which are generally cultivated. The most commonly cultivated species is *G. hirsutum* L.; the others are *G. arboreum* L., *G. barbadense* L., and *G. herbaceum* L.

Genetics of Cotton

At least seven genomes, designated A, B, C, D, E, F, and G, are found in the genus. Diploid species (2n = 26) are found on all continents, and a few are of some agricultural importance. The A genome is restricted in diploids to two species (*G. arboreum* and *G. herbaceum*) of the Old World. The D genome is restricted in diploids to some species of the New World, such as *G. thurberi*.

By far the most important agricultural cottons are *G. hirsutum* and *G.barbadense*. These are both allotetraploids of New World origin and presumably of ancient cross between Old World A genomes and New World D genomes. How and when the original crosses occurred have been subject to much speculation. Euploids of these plants have 52 somatic chromosomes and are frequently designated as AADD. Four additional New World allotetraploids occur in the genus, including *G. tomentosum*, a native of Hawaii. *Gossypium tomentosum* has been crossed with *G. hirsutum* in breeding programs.

The New World allotetraploids are peculiar in the genus, because the species, at least in their wild forms, grow near the ocean as invaders in the constantly disturbed sandy habitats and associated environs. It is from these "weedy" or invader species that the cultivated cottons developed.

Pollination of Cotton

Gossypium hirsutum is generally self-pollinating, but in the presence of suitable insect pollinators can exhibit cross-pollination. Bumble bees (*Bombus* spp.), Melissodes bees, and honey bees (*Apis mellifera*) are the primary pollinators. Concentration of suitable pollinators varies from location to location and by season and is considerably suppressed by insecticide use. If suitable bee pollinators are present, distribution of pollen decreases considerably with increasing distance. In an experiment in which a cotton field was surrounded by a large number of honey bee colonies and movement of pollen was traced by means of fluorescent particles, 1.6 % of the flowers on plants 150 to 200 feet away showed the presence of the particles.

Gossypium tomentosum seems to be pollinated by lepidopterans, presumably moths. The stigma in *G. tomentosum* is elongated, and the plant seems incapable of self-pollination until acted upon by an insect pollinator. The flowers are unusual too, because they stay open at night. Most *Gossypium* flowers are ephemeral: They open in the morning and wither at the end of the same day.

Weediness

Although the New World allotetraploids show some tendencies to "weediness," the genus shows no particular weedy aggressive tendencies.

Modes of Gene Escape

Genetic material of *G. hirsutum* may escape from a test area by vegetative material, by seed, or by pollen. Propagation by vegetative material is not a common method of reproduction of cotton. Physical safeguards that inhibit the movement of vegetative material from the area should be adequate to prevent gene movement by this means. Movement of seed from the test area can likewise be inhibited by adequate physical safeguards.

Movement of genetic material by pollen is possible only to those plants with the proper chromosomal type. Movement to *G. hirsutum* and *G. barbadense* is possible if suitable insect pollinators are present and if there is a short distance from transgenic plants to recipient plants. Physical barriers, intermediate pollinator-attractive plants, and other temporal or biological impediments would reduce the potential for pollen movement.

Movement of genetic material to *G. tomentosum* is less well known. The plants are chromosomally compatible with *G. hirsutum*, but there is some doubt about the possibility for pollination. The flowers of *G. tomentosum* seem to be pollinated by moths, not bees. And they are receptive at night, not in the day. Both these factors would seem to minimize the possibility of cross-pollination. However *G. tomentosum* may be losing its genetic identity from introgression hybridization of cultivated cottons by unknown means.

Soybean as a Crop

Importance of Soybean

Soybean, *Glycine max* (L.) Merr., combines in one crop both the dominant world supply of edible vegetable oil and the dominant supply of high-protein feed supplements for livestock. Other fractions and derivatives of the seed have substantial economic importance in a wide range of industrial, food, pharmaceutical, and agricultural products.

Taxonomy of Soybean Relatives

The soybean is a papilionoid legume (family Fabaceae, subfamily Faboideae), and a member of the tribe Phaseoleae, subtribe Glycininae. The subtribe to which soybean belongs consists of 16 genera, none of which, except soybean (*Glycine*) and kudzu (*Pueraria*), are commonly known outside of botanical science. The genus *Glycine* is unique within the subtribe on several morphological and chromosomal characters, and does not seem to bear an especially intimate relationship with any other genus in the subtribe. A single exception may be the genus *Sinodolichos*, a rarely collected and poorly known genus from Asia. *Sinodolichos* is unknown in the living state outside of Asia.

The genus *Glycine* is divided into two questionably distinct subgenera: *Glycine* and *Soia*. The first consists of six or seven perennial species primarily from Australia. The second consists of three annual species from Asia: *Glycine max, Glycine soia* Sieb. & Zucc., and *Glycine gracilis* Skvortz. The first species is the cultivated soybean, the second species is the wild form of the soybean, and the third species is the weedy form of the soybean.

Morphology and Sexual Reproduction

The soybean plant is a branched, non-frost-tolerant annual about one meter above ground level and two meters below ground level. The stem tissues are mostly primary, although the basal and more mature portions of the stems develop secondary vascular tissues during later development. This woody development is in accord with the derivation of soybean from tree ancestors in the rosewood tribe, Dalbergieae. The nodulated root system is intermediate between a taproot type and a diffuse type. The foliage leaves are alternate, pinnately trifoliolate, with pulvini, stipels, and stipules.

The soybean flower is a standard papilionaceous flower with calyx of five united sepals; zygomorphic corolla of carina, alae, and vexillum; androecium of ten diadelphous 9+1 stamens; and gynoecium of a single carpel. Two to four seeds develop in the pods. The seeds have two large cotyledons and scant endosperm.

The anthers mature in the bud and shed their pollen directly onto the stigma of the same flower, thus ensuring a high degree of self-pollination. Cross-pollination is less than 1%, often substantially so. Soybean plants are thus virtually pure breeding homozygous lines, although manual cross-pollination is practiced routinely in breeding programs.

Distribution of Soybean

The United States, Brazil, China, and Argentina account for more than 90% of world soybean production. Soybeans are grown throughout much of the United States. The wild and weedy forms of soybean (*G. gracilis* and *G. soia*) and all other nonsoybean species of *Glycine* grow naturally only in Asia, Australia, and closely associated areas. In the United States, the wild and weedy forms of soybean are only known at university and other specialized research stations.

Modes of Gene Escape

Pollen is unlikely to escape from research plots. Soybeans are almost completely self-pollinated. Studies have shown that honey bees are responsible for the occasional cross-pollination and that thrips are ineffective pollination vectors. Certified Seed Regulations (U.S.) recognize this cross-pollination unlikelihood in the safeguards set up for Foundation, Registered, and Certified seed. For Foundation seed, the most stringent category in the Certified Seed Regulations, soybeans are permitted to be grown zero distance from the nearest contaminating source (i.e., other soybean cultivars), as long as the distance is adequate to prevent mechanical mixing.

Soybean seed has a short time potential for high germination and vigor, and, in commercial operation, fresh soybean seed is produced annually for each new season. However, some remaining seed from one crop is capable of germinating the following season and is therefore able to cause a temporal, if not geographic, dispersal of the soybean plant. Certified Seed Regulations stipulate that at lease one year must elapse between the destruction of a stand of soybean and a subsequent establishment of a new soybean stand. Vegetative reproduction of soybean plants does not occur under field conditions.

Maize as a Crop

Zea mays Linnaeus, known as maize throughout most of the world, and as corn in the United States, is a large, annual, monoecious grass that is grown for human consumption, animal feed, silage, vegetable oil, sugar syrups, and other miscellaneous uses. Maize has been cultivated since earliest historic times from Peru to central North America. The region of origin is now presumed to be Mexico. Dispersal to the Old World is generally deemed to have occurred in the sixteenth and seventeenth centuries; however, recent evidence indicates that dispersal to India may have occurred before the twelfth and thirteenth centuries by unknown means. In Africa, maize is a primary human food source and is grown throughout the continent wherever soils and water permit its cultivation. Cultivation is generally in small plots around rural villages, often interspersed with other food crops. Villagers mostly use landraces and keep seed from year to year to provide planting material for subsequent seasons. Maize is grown commercially as a row crop of monocultures of uniform plants from hybrid seed. Agronomic practices have developed a high degree of scientific sophistication in the use of tillage, pesticides, planting, fertilizer, harvesting, distribution, and all other agronomic aspects.

Taxonomy of Maize

Zea is a genus of the family Gramineae (Poaceae), commonly known as the grass family. The genus consists of some four species: *Zea mays*, cultivated maize and teosinte; *Zea diploperennis* Iltis et al., diploperennial teosinte; *Zea luxurians* Bird; and *Zea perennis* Reeves et Mangelsd., perennial teosinte. Various of the species have been assigned to the segregate genus *Euchlaena*, which is not currently recognized, or have been divided into numerous small species within the genus *Zea*.

The closest generic relative to *Zea* is *Tripsacum*, a genus of seven species. *Tripsacum* differs from maize in many respects, including chromosome number (n = 9), in contrast to *Zea* (n = 10). All species of *Tripsacum* can cross with *Zea*, but only with difficulty and only with extreme sterility.

Cultivated maize is presumed to have been transformed from *teosinte, Zea mays* subspecies mexicana (Schrader) Iltis, more than 8,000 years ago. During this transformation, cultivated maize gained several valuable agronomic traits, but lost the ability to survive in the wild. *Teosinte*, however, remains a successful wild grass in Mexico and Guatemala. Despite some confusion over proper taxonomic groupings of the noncultivated members of *Zea*, wild members maintain a successful array of annual or perennial plants with visible chromosomal peculiarities and ploidy levels, and many adaptive macroscopic phenotypes. Cultivated maize and the wild members of diploid and tetraploid *Zea* can be crossed to produce fertile F1 hybrids. Nonetheless, in the wild, introgressive hybridization does not occur because of differences in flowering time, geographic separation, block inheritance, developmental morphology, and timing of the reproductive structures, dissemination, and dormancy.

Morphology and Reproduction

Maize is a tall, robust, monoecious annual with overlapping sheaths and broad, conspicuously distichous blades; staminate spikelets in numerous long spike-like racemes forming large spreading terminal panicles (tassels); pistillate inflorescence in the axils of the leaves, the spikelets in 8–16 (30) rows, on a thickened, almost woody axis (cob), the whole enclosed in numerous large foliaceous bracts or spathes, the long styles (silk) protruding from the summit as a mass of silky threads; grains at maturity greatly exceeding the glumes. Pollination, fertilization, and caryopsis development of maize follows a fairly standard pattern for chasmogamous wind-pollinated grasses, with the following points of exception and note:

- Pollen is produced entirely in the staminate inflorescences. Eggs are produced entirely in the pistillate inflorescences.
- Self-pollination and fertilization and cross-pollination and fertilization are usually possible, and frequencies of each are usually determined by physical proximity and other physical influences on pollen transfer. A number of complicating factors, such as genetic sterility factors and differential growth rates of pollen tubes, may also influence the frequencies of self-fertilization versus cross-fertilization.
- The "silk" on a developing ear is the style, a part of the female flower through which a pollen grain must travel; the styles on maize are the longest known in the plant kingdom.
- Shed pollen typically remains viable for 10 to 30 minutes, but may remain viable for much longer under refrigerated conditions.
- The staminate and pistillate inflorescences do not develop at the same time. The pistillate inflorescence is precocious. However, there is the appearance of slight rotandry because the elongating styles are delayed for about seven days in emergence from the bracts of the pistillate inflorescence, while the development of the later-developing staminate inflorescence is fully visible.
- The genetics of maize are better known than those of any other crop plant.

Pollination of Maize

Studies of pollination of maize have mostly centered on the needs of hybrid seed production. This production involves the development and maintenance of inbred lines and the subsequent crosses to produce commercial seed. In the former, self-pollination is mandatory. In the latter, cross-pollination is mandatory. Mechanisms have been developed to ensure each kind of pollination.

Breeder seed is usually derived from self-pollinated seed at the F8 to F10 generation of inbreeding. A high degree of self-pollination is ensured by planting well-isolated blocks that virtually guarantee natural random sib mating. Minimum isolation distances for foundation seed are one-eighth mile (660 feet) from the nearest contaminating source. Other safeguards, such as physical barriers or unharvested border rows, can further reduce the possibility of contamination. Fields are preferred that have not been recently planted in maize. This is to minimize the appearance of volunteer maize from a previous season.

Hybrid seed production fields also require isolation, similar to that for foundation seed. Isolation distance may be modified by such factors as high winds, additional border rows, size of field, natural barriers, and differential flowering dates. Flowering dates are often adjusted by differential planting dates, planting depth, or fertilizing. The two different parents are planted in a regular pattern of rows, such as four pistillate to one staminate (4:1), or 4:2, or 6:2, or a variety of other combinations. Detasseling or use of cytoplasmic male sterility prevents pistillate plants from shedding viable pollen and thus ensures cross-pollination.

Weediness

Maize appears as a volunteer in some fields and roadsides, but it never has been able to establish itself outside of cultivation. Some of the other species of *Zea* are successful wild plants but have no pronounced weedy tendencies.

Modes of Gene Escape

Genes of maize may escape from the test plot in two ways. The first is by pollen transfer. The second is by movement of the grain.

If viable pollen of the transgenic plants can be transferred by wind to any receptive maize stigma within the 30-minute period of pollen viability, an escape of genetic material could take place. This potential transfer becomes more unlikely as distance increases from the transgenic plants, and from a practical standpoint becomes increasingly unlikely at distances much beyond the foundation seed isolation distance of 660 feet. Temporal isolation would further reduce the likelihood of effective pollination and fertilization. In addition, any physical impediment to this movement, such as effective detasseling or bagging, would completely eliminate the possibility of gene escape by way of pollen.

To prevent grain from remaining in the field or otherwise escaping, all ears would have to be collected or otherwise destroyed. To ensure that no grain escaped harvest, the field would have to be monitored for volunteer maize plants in the following season.