The Benefits of Insecticide Use: Soybeans

Soybean Aphids on Leaves

Stink Bug Damage to Soybeans

Untreated Treated
Insecticide Treatment for Soybean Aphids

Soybean Field Defoliated by Soybean Looper

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Leonard Gianessi
Key Points

- High-yielding insect-resistant soybean cultivars have not been developed despite decades of breeding research.
- Natural enemies provide considerable control of insect pests of soybeans in most years and regions.
- When insect outbreaks occur in soybean fields, chemical insecticides provide the only consistent effective control.

Technical Summary

US growers produce 190 billion pounds of soybeans with a value of $20 billion from 75 million acres annually. About 82% of the soybean acreage occurs in inland states drained by the Mississippi River and its tributaries, with the remaining 18% split near equally between the Gulf and Atlantic Coast states.

Traditionally, U.S. soybean acres were not widely-treated with insecticides with only about 2% acres treated. However, with the advent of the soybean aphid in 2000 in the Midwest, approximately 16% of U.S. soybean acres are currently treated with insecticides (Figure 1).

Most soybean insect pests in the Midwest are attacked by natural enemies, or biological control agents. The most effective of these agents are beneficial insects and insect diseases which usually help to keep pest populations well below the economic injury level [27]. The most common predators in Midwest soybean fields are lady beetles, lacewings, and several bugs.

Occurrence of soybean pest insects follows a north-south gradient, and in general, insect pressure is greatest on soybean grown in the South, particularly in southern states bordering the Gulf of Mexico and the Atlantic Ocean. Insect pressure is greatest in the southern states because of the increased survival and multiple generations per year facilitated by the warm climate, and also because of proximity to the tropics where some insect pest populations, particularly defoliators, overwinter. About one-third of the soybean acres in Louisiana, North Carolina, and Georgia have been sprayed regularly with insecticides in most years since 1991.

Insect pests on soybean can be categorized by the type of damage they cause, including leaf feeders or defoliators, pod feeders, and stem feeders. Pod feeders can severely reduce yields by consuming immature seed or causing deformation of developing seed, in the case of piercing and sucking pests. Stem feeders can reduce stands by weakening the stems to cause lodging.

A soybean field contains millions of insects. Although >700 species of phytophagous insects are reportedly present on soybean in the United States, in most years, only nine species account for most arthropod damage to soybean. The most damaging defoliators are velvetbean caterpillar, soybean looper, green cloverworm, Mexican bean beetle, and
bean leaf beetle. The most damaging pod feeders are southern green stink bug, green stink bug, corn earworm, and bean leaf beetle.

The most damaging defoliating insects in the South are velvetbean caterpillar and soybean looper. Corn earworm is more severe in the southern states of the Atlantic Coastal Plains. The most abundant phytophagous stink bug in the South is the southern green stink bug which occurs in Texas, southern Arkansas, and the southeastern states [44]. The inland states of Kentucky, Tennessee, Missouri, and Arkansas harbor soybean insect pests common to both North and South. For instance, Mexican bean beetle, which has a very small pest impact in the Gulf coast states but a greater impact in the Midwest, is a major pest in Kentucky and Tennessee. In addition, corn earworm has an important economic impact on soybean grown in the South including Arkansas and Missouri, but not in more northern states. The most serious lepidopteran defoliator in Tennessee, Kentucky, and Missouri is the green cloverworm [44].

Three soybean insects, bean leaf beetle, soybean aphid, and spider mites are considered the key drivers of insecticide use in the Midwest [28]. Spider mites tend to be a problem pest somewhere in the Midwest on an annual basis and a key pest across most of the region every eight to ten years [28]. Spider mites can be a significant problem during hot dry drought years.

Unlike many crop species, soybean has a remarkable capacity to withstand much insect injury without significant yield loss. It accomplishes this by both tolerating and compensating for injury. Yield losses are prevented because soybean plants typically produce excess leaves. Soybean plants often compensate for defoliation by producing additional leaves. When leaf loss becomes too great, plants compensate by retaining older leaves and maintaining high levels of photosynthesis.

The amount of damage a soybean plant can tolerate before yield is significantly impacted varies with the type of damage and the plant developmental stage. Before flowering begins and after seed pods have filled out, soybean plants can tolerate as much as 35% defoliation, or eight or more feeding larvae per foot of row. During flowering and pod development, however, they can only tolerate 20% defoliation, or four or more feeding larvae per foot of row. Foliage loss greater than these threshold amounts has been shown to cause economic yield loss because of the reduction in light interception by the soybean canopy.

An abundant and diverse complex of predators is important as biological control agents in soybean fields attacking both lepidopteran and stink bug species. Because beneficial insects may not suppress populations of pest species below their respective economic threshold levels, insecticide treatments are often necessary to control pest infestations and protect crop yields [23][32].

Three plant introductions (PIs), PI 171451, PI227687, and PI 229358, were identified in the early 1970s as being resistant to the Mexican bean beetle [32]. Breeding programs across the United States have used these PIs as donor parents due to the high level of
multiple insect resistance each possesses. Conventional breeding strategies have not produced insect resistant cultivars accepted by soybean growers because insect resistance has not been introgressed into high-yielding cultivars. Both yield and insect resistance are inherited quantitatively, and transferring all desired genes into an adapted cultivar has proven to be difficult [32]. These four germplasm lines are low yielding, poor agronomic types, and are susceptible to diseases and nematodes to which the better adapted cultivars are resistant. The undesirable agronomic characteristics include the propensity of each to produce pods that dehisce and disperse seed and tendency for the plants to lodge, making mechanical harvest almost impossible [36].

Thirty years after the initial identification of insect-resistant germplasm, success has been limited in developing high-yielding insect-resistant cultivars [32]. Success in insect-resistant cultivar development has been somewhat limited due to yield reductions, small seed size, and other less desirable agronomic qualities possessed by these accessions [56] 31 soybean germplasm releases have been made in recent years including the Georgia Agricultural Experiment Station’s GAT81-296 with resistance to soybean looper, corn earworm, and certain armyworms. However, only a few insect-resistant soybean cultivars have been released in the US, and they include “Shore”, “Crockett”, “Lamar”, and “Lyon”. The acreage planted to these cultivars is very limited [56].

Two concerted efforts to import and establish exotic parasites from abroad have been successful. *Pediobius foveolatus* was imported from India and annual releases provide some control of Mexican bean beetles on the Atlantic Coastal Plain [22]. *Euplectrus puttleri*, imported from South America, has become established in southern Florida, where it kills substantial numbers of the velvetbean caterpillar each year [22].

The use of conventional chemical insecticides constitutes the only presently available tool that affords consistent, economical and effective suppression of insect outbreaks on soybean [22].

USDA has estimated that soybean yield losses in the Southeast and Delta states would be about 39% without the use of insecticides [30][31]. The main yield-reducing pests were identified as soybean looper, stink bug, corn earworm, and velvetbean caterpillar. Soybean insecticide costs in southern states are approximately $20/acre [68].

*Soybean Aphid*

Soybean aphids are small and yellow with distinct black cornicles (tailpipes). The soybean aphid is native to Asia where it is the main pest in soybean fields. In 2000, soybean aphid was first detected in Wisconsin. Subsequent surveys detected the pest in Michigan, Indiana, Illinois, Missouri, Iowa, Ohio, West Virginia, Kentucky and Minnesota. Hundreds of aphids were observed on every leaf on plants in some fields in northern Illinois. In 2001, distribution of the aphid expanded to 15 states with new finds in Virginia, Pennsylvania, New York, and North and South Dakota. In 2002, the range of the aphid in the U.S. continued to expand with a total of 20 states reporting the presence
of the aphid. Nebraska, Kansas, Delaware, Georgia and Mississippi reported the aphid for the first time in 2002 [1].

The rapid spread of soybean aphid occurred despite the fact that aphids are considered weak flyers. However, it is well known that aphids are readily moved by wind, which has the potential to carry these insects long distances in a short period of time [1]. The consensus among soybean researchers is that the soybean aphid was present but remained undetected for some years before 2000[2].

Soybean aphids overwinter as eggs on buckthorn, a commonly occurring shrub often found along the margins of soybean fields, with spring generations on buckthorn producing winged migrants that fly to soybean. Common buckthorn is an invasive European woody shrub. In the fall, migrants produced on soybean fly back to buckthorn where the overwintering eggs are deposited. Soybean is a secondary host; mating and egglaying occurs on buckthorn. The eggs are extremely cold-hardy and can survive temperatures as low as -29 degrees F. The capacity for soybean aphid eggs to survive winter temperatures may depend on their ability to supercool. Supercooling is a form of protection against low temperatures in which insects lower the freezing point of body fluids to avoid formation of ice crystals [51]. During the growing season, the soybean aphid is almost exclusively found on soybeans.

Once on soybean, aphids are relatively sedentary on the plant as they remove plant sap with piercing-sucking mouthparts. Even at low densities, feeding by soybean aphid can greatly impair photosynthetic processes in soybean [52]. Soybean aphid feeding is known to disrupt the plant’s photosynthetic processes at relatively low aphid densities [54]. High soybean aphid densities cause damage by reducing plant height, pod number, and total yield. Indirect damage from feeding (i.e. virus transmission and sooty mold formation from honeydew excretion) is also a concern. Soybean aphid feeding on soybean can result in a reduction in photosynthetic capacity as well as cause leaf curling and stunted plant growth. Since 2000, heavy infestations of the soybean aphid have caused economic yield losses up to 45% in some untreated fields [3]. In Michigan, 13,000 aphids per plant and 40% loss in seed yield were recorded in 2001 [14].

Soybean aphids reproduce asexually while on soybean, increasing their numbers rapidly. In the summer, the population in soybeans is comprised of females that essentially clone themselves and give birth at rates of 3 to 8 aphids per day for about a month. The generation time is 7 to 10 days. As many as 18 generations per season are possible on soybeans. The soybean aphid population doubles every two to three days on soybeans [4]. The aphid population can go from 10 to 1000 per plant in less than two weeks. A major phenomenon in the aphid population dynamics is the formation of winged individuals as the population grows. Early in the season, only 5-10% of the aphids develop wings and fly away as adults. In mid- to late July, the number can rise to 90%. Crowding of wingless adults is the major factor affecting the production of winged aphids. Winged aphids disperse to other fields and regions [48].
In 2001, aphid populations reached outbreak levels (e.g., thousands of aphids per plant) in many fields, particularly in Minnesota, Wisconsin, Michigan, Illinois, and Indiana, as well as parts of Ontario, Canada [2]. In 2002, few fields anywhere in North America reached high densities, and many fields being sampled weekly had no aphids detected. In 2003, aphid densities again increased significantly. The statewide average in Wisconsin in 2003 was 770 aphids per soybean plant [7]. The mechanisms underlying these outbreaks are not well understood but are thought to include temperature and moisture regimes (cooler and wetter favoring aphid population growth) [2]. In years of high populations, predators invest the time and energy to decimate the egg-laying soybean aphids in buckthorn, which then usually translates into lower survival and fewer aphids the following spring [17].

The recommended economic threshold for spraying for the soybean aphid is 250 individuals per plant through pod set. Even with this threshold, 50% of the soybean acres in Minnesota were treated in 2003 [3]. In 2003, an estimated 7 million soybean acres (10%) were treated for soybean aphid [18]. In 2005 entomologists estimated that 15 million acres of soybeans in the U.S. were treated for soybean aphid [4]. Insecticide use adds an estimated $7 to $13 per acre to the cost of soybean production [54]. During soybean aphid outbreaks, it is imperative that insecticides are applied in a timely manner, if a producer wants to avoid significant yield loss [4]. The threshold provides growers with a seven-day lead time before damaging aphid densities (675 aphids/plant) are reached.

Research trials in the midwestern US show that insecticide sprays reduce the number of aphids per plant from 1823 to 73 (95% reduction) [6]. Insecticide treatments to control soybean aphid have increased soybean yields by 30-50% [9]. Soybean plant height was 20% greater with treatments while 4 more pods (+30%) were produced on the treated plants [10]. In Southeast Minnesota in 2001, 30-50% of producers sprayed for soybean aphid, and many situations resulted in 10-15% yield savings [28].

The aphid has even shut down major civic events. For example, during a baseball game between the Blue Jays and Orioles in Toronto in 2001, the home plate umpire ordered the game to be stopped so that the Sky Dome could be closed and the ventilation reversed to expel a cloud of migrating soybean aphids that prevented batters from seeing the ball. In August 2003, soybean aphids swarmed Wrigley Field, nearly canceling a Cubs game.

Insecticides are widely used in Asia to control feeding damage from soybean aphid. Growers in China may apply insecticides as many as four times per year to prevent yield loss [8]. In its native Asia, the soybean aphid can reduce soybean production by over 25% because of feeding injury and by over 50% because of its virus vectoring ability [53].

USDA scientists have screened 800 commercial cultivars and 3000 soybean germplasm accessions for aphid resistance which was found in two old southern cultivars that are no longer grown (Dowling, Jackson) and in a USDA plant introduction that has not been used commercially (PI200538) [11]. The resistance in the old cultivars suggests that
resistance present in ancestral germplasm did not persist through the development of current commercial cultivars in the U.S. In greenhouse and field tests, the soybean aphid did not survive long when confined to the leaves of these soybeans. Typically, 94-100% of the aphids died within 10 days. Resistance is related to a single gene-named Rag1. Exactly how resistance works is not known [11]. Complete starvation was not the main reason behind the resistance; less ingestion of sap or ingestion of toxic compounds could be involved in increasing aphid mortality on resistant leaves [12]. Work is ongoing to breed the resistance into commercial cultivars.

After the detection of soybean aphid in the U.S., scientists affiliated with USDA programs initiated studies of its natural enemies in the U.S. and Asia [15]. In U.S. soybeans, generalist predators (damsel bugs, ladybugs, minute pirate bugs) dominate the natural enemy community while parasitoids and pathogens are virtually absent [15]. The existing predators and parasitoids in North America have frequently not controlled aphid populations and outbreaks have occurred [14]. Parasitoids were not found to substantially reduce aphid numbers mostly because parasitoids occurred after aphid densities were already above the economic injury level [50].

A common general predator in midwestern soybean fields is the minute pirate bug *Orius insidiosus* which has been observed eating soybean aphids in the field [5]. *O. insidiosus* can complete its life cycle on a diet of soybean aphids. The potential ability of *O. insidiosus* to suppress soybean aphid outbreaks depends on its ability to locate and kill sufficient number of aphids when they are at relatively low numbers early in the growing season[5]. As a generalist, *O. insidiosus* can feed on a variety of prey, including spider mites, thrips, leafhoppers, and other small insects. Naturally occurring predators can have a large impact on soybean aphid populations when predator populations are established before initial aphid colonization.

In Asia, the soybean aphid is attacked by a number of natural enemies, including >30 species of predators, eight species of parasitoids and several species of fungal pathogens [16]. From 2001 to 2006, U.S. entomologists worked in China, South Korea, and Japan to collect natural enemies of soybean aphid. Each parasitoid was tested for effectiveness against soybean aphid. The parasitic wasp, *Binodoxys communis*, was chosen for further testing and approved for field release.

*Bean Leaf Beetle*

The bean leaf beetle (BLB) is one of the most widespread soybean pests in the United States. A native species, it has been a significant problem in the South, but traditionally was an infrequent problem in the North Central Region. During earlier times, the major concern with BLB was early season invasion of soybean fields, causing localized problems through seedling defoliation. In the 1980s, however, grower reports of pod feeding were received, and these have increased dramatically until the present.

Pod injury occurs as leaves mature and beetles begin feeding on younger soybean in the region. They feed mainly on the pod surface, consuming tissue down to the endocarp,
which directly encloses the seed. BLB pod lesions increase seed vulnerability to weather and secondary pathogens, particularly *Alternaria tenuissima*. Seeds beneath the lesion become shrunken and discolored. The result is loss of seed weight and quality. In many instances, beetles have also been observed feeding on the pod peduncle and surrounding tissue, an activity which can cause breakage and complete pod loss. Grain value is discounted when 2% damaged seed is exceeded [46].

The bean leaf beetle life cycle begins in spring as adults leave their overwintering habitats. These habitats include woodlots, clumps of grass, and leaf litter. Overwintered adults become active in early to late April, moving into alfalfa fields and other suitable habitats. Once in the alfalfa, beetles feed and lay some eggs. Upon soybean emergence and first cutting of alfalfa, there is emigration from the alfalfa and other hosts into the soybean. When females enter soybean fields, they have mated, and most have a full complement of eggs. Females lay clusters of 10-30 eggs over a period of three to four weeks in the top 2 inches of soil beneath the soybean plants [43]. Each female lays between 130 and 200 eggs. The bean leaf beetle undergoes 1-2 generations in the North but as many as three in the South [44].

To date, there is no known resistance to bean leaf beetle damage in soybean varieties. In the southern United States, trap cropping has been researched. In BLB trap-cropping programs, a portion of a field (5 to 10%) is planted to an early maturing variety 10 days to 3 weeks earlier than the late-maturing main planting. Subsequently, overwintering BLB enter the early planting and lay eggs. About 7 to 10 days after emergence of first-generation adults, insecticides are applied to the trap area, thereby preventing an economically damaging population from developing in the main planting. Although trap cropping has been effective in preventing economic damage and in reducing amounts of insecticides applied, in the North Central Region it is probably impractical because of larger soybean fields and labor demands at a time when corn also requires planting.

It has been hypothesized that if soybean planting were delayed, at least until late May, active BLB either would colonize wild hosts and not move into the soybeans or suffer reduced fecundity by the time the late-planted soybeans emerge. Planting soybeans near the end of the recommended planting date will reduce early bean leaf beetle colonization and, usually, subsequent pod injury [47]. Producers express concern over susceptibility of late plantings to early frost [47].

In the last 2-3 years, about 30% of fields were treated for bean leaf beetle in parts of southern Minnesota and northern Iowa. In 2002, there were areas in northeast Iowa where nearly all fields were treated, but in the same year, little to none were treated in Illinois or the Dakotas.

**Stink Bug**

The southern green stink bug is found throughout the tropical and subtropical regions of Europe, Asia, Africa, Australia, and the Americas and is believed to have originated in
Ethiopia. Its distribution in the US is limited to the southern region. The green stink bug is widely distributed throughout North America.

Both nymphs and adult stink bugs obtain their food by puncturing the tissues of soybean plants with their piercing and sucking beaks and extracting plant fluids. Salivary fluid is pumped down the salivary duct and liquefied food is pumped up the food canal. In addition to direct injury, each puncture is a potential site for entry of pathogens. They attack stems, foliage, blooms and seeds of the soybean plant, but prefer the young tender growth and developing seeds. Brown to blackish spots appear on the plant where the mouthparts puncture the plant tissue. Yield and quality losses can be severe. The loss of plant fluids, the injection of digestive enzymes, the deformation and abortion of fruiting structures, and predisposition of the feeding puncture to colonization by pathogenic and decay organisms are the principal means by which stink bug feeding is detrimental to the plant. Feeding injury during early seed formation can result in shriveled, deformed, undersized and even aborted seeds.

A large incidence of stink bug-damaged kernels can result in lower market values or even prevent sale of seed. Seed quality is reduced by stink bug feeding, and beans are more likely to deteriorate in storage [42]. An insecticide application for control of stink bugs may be warranted when the level of infestation reaches one adult bug or large nymph per foot of row during pod fill [42]. Insecticide treatments reduce the incidence of stink bug damage from 32% to 1.5% [59].

Stink bugs overwinter in the adult stage mainly under leaf litter, bark, wood piles and other materials offering protection. As temperatures rise in early spring, hibernating adults move out of winter cover and begin feeding on clover, small grains, vegetables, corn and weed hosts, where the first generation is completed. As the soybean crop begins to bloom and set small pods, it becomes highly attractive to egglaying female stink bugs. A female southern green stink bug can lay as many as 260 eggs over her life span.

Several parasites of stink bug eggs are known, but none is effective enough to provide control of stink bugs in soybean fields. Successful biological control of the southern green stink bug with parasites has been achieved in several parts of the world. The egg parasite *Telenomus basalis* was introduced into Australia from Egypt and reduced stink bugs to subeconomic levels in certain regions [60]. Similar results with this species have been reported from New Zealand and Hawaii. However, although *T. basalis* has been introduced into Louisiana, it has failed to provide adequate biological control of stink bugs [58]. Often, the effectiveness of parasitoids is limited at the edge’s of a host’s range because of greater sensitivity to environmental factors. This may be the case with *T. basalis* in the US because the Gulf Coast and southeastern Atlantic states represent the northern limit of the distribution of the southern green stink bug and *T. basalis*.

Because stink bugs are so highly attracted to soybean in the bloom through early pod-fill stages of development, large numbers can be attracted to relatively small trap crops of early maturing soybeans where they can be effectively controlled with insecticides before they infest the main soybean planting.
Considerable research has been conducted to identify stink bug resistance in soybeans [55]. Sixty-five soybean breeding lines containing the stink bug resistant “IAC-100” in their pedigrees were evaluated for their resistance to stink bug feeding in replicated field trials from 2001-2005 in Georgia [57]. (IAC-100 is a soybean cultivar developed in Brazil that has a high level of resistance to stink bug feeding). 12 entries were selected for an advanced field screening trial in 2005. Damaged soybean seeds ranged from 18 to 54% under heavy stink bug pressure. Four of these lines were identified as possible breeding material for future soybean stink bug resistance cultivar development [57].

Spider Mite

In northern states, twospotted spider mites overwinter as adult females in sheltered areas such as field margins. In the spring, the females typically crawl from the plants on which they overwintered to other plants such as soybean. The females lay small eggs on the plants and the larvae hatch within a few days. Adult females produce as many as 300 offspring in the first month of egglaying [20]. The life cycle of twospotted spider mites is completed in 4 to 14 days, depending on the temperature. Fastest development occurs at temperatures above 91 degrees F. When temperatures are high and moisture is lacking, twospotted spider mite populations in soybean undergo exponential growth. Numerous generations are completed within a single growing season. In one experiment, the density of spider mites peaked at 1122 mites per five soybean leaves [20].

The most effective natural enemy of twospotted spider mites is a fungal pathogen, *Neozygites floridana* which is host-specific to spider mites. Mites become exposed to the disease when spores adhere to the legs or body. Mite death occurs within 1-3 days of infection. Production of spores is dependent on environmental conditions requiring conditions cooler than 85 degrees F and with at least 90% relative humidity. Periods of at least 12-24 hours of such conditions are necessary for extensive spread of the disease. Spider mite populations may decline rapidly in response to fungal disease activity. Research has documented 95% mite population decline in 6 days with 100% of remaining mites infected.

Spider mites feed with long stylet-like mouthparts that are inserted into leaf cells. Contents of individual living cells are extracted by mites in contrast to most piercing-sucking insects that feed on plant sap and vascular tissue. Generally, spider mite feeding results in a reduction of photosynthesis and chlorophyll content of leaves. As mites insert their mouthparts deeper into leaf tissues, the protective leaf epidermis becomes highly disrupted. Water loss through these wounds results in moderate to severe leaf water stress. Yield reductions of 40-60% in fields infested with two spotted spider mites during late vegetative and early reproductive growth have been documented [20]. Fields with spider mite infestations commonly produce wrinkled beans which are susceptible to early shattering.
Major spider mite outbreaks in the Midwest occurred in the drought years of 1983, 1988, and 2005. In Iowa, 2.4 million acres of soybeans were treated with insecticides during the 1988 outbreak. Detailed pesticide use data for Illinois indicate that 35-36% of soybean acres were treated to control spider mite in the 1983 and 1988 outbreaks in contrast to 1-3% in other years (Figure 2). More than 1 million acres of soybeans in Illinois were estimated to be treated for spider mites in 2005 [20]. It is estimated that soybean producers in Illinois saved $220 million by following IPM extension thresholds and scouting procedures in determining whether to treat for spider mites in 1988 (bu/A saved X $8.00/bu soybeans = $64.00/A - $9.00/A treatment = $55./A saved X 4 million treated A = $220 million) [45]. Research has shown that miticide treatments increase soybean yield by 18% [20] [29].

**Velvetbean Caterpillar/ Soybean Looper**

The most damaging defoliating insects in southern soybean production are velvetbean caterpillar and soybean looper. The insects feed most often in mixed populations. Frequently, soybean looper larvae occur simultaneously with other caterpillar foliage feeders such as green cloverworm and velvetbean caterpillar.

Soybean is the primary host for velvetbean caterpillar, although more than thirty other broadleaved plants are also its hosts. Velvetbean caterpillar does not survive the winter in the U.S. Each spring, moths migrate north into the U.S. from tropical regions where they have overwintered. As the season progresses, the adult moths migrate northward with infestations on soybeans seldom reaching economic injury levels north of a line from Arkansas through North Carolina [22]. Velvetbean caterpillar larvae are voracious feeders and high populations can rapidly defoliate soybeans, leaving nothing but the mainstems [39]. Velvetbean caterpillars may completely strip foliage in just a few days and immediately afterward begin feeding on pods. The moths lay single eggs on the underside of leaves, the eggs hatch within five days and the larvae feed on leaves for about three weeks before dropping to the ground to pupate. In southern states, there are three to four generations of velvetbean caterpillar each year. Infestations are most damaging in the late summer.

Epizootics of a fungal pathogen, *Nomuraea rileyi*, typically occur on larval populations of the third generation of velvetbean caterpillar, although unacceptable economic damage usually results before this happens [44]. *Nomuraea rileyi* reached the point of area-wide testing, but industry’s interest declined because of host-specificity of *N. rileyi* strains and their sensitivity to low humidity [44].

Soybean looper is similar to velvetbean caterpillar in that it does not survive winters in the U.S., but migrates from the south each year and produces three to four generations per season. Soybean looper moths arrive in Georgia in June and July and in South Carolina during August and September. The preferred host of the soybean looper is soybean. The soybean looper is a pest only in areas where cotton and soybeans are grown in rotation; the looper requires nectar produced by cotton in order to develop a normal complement of eggs [35]. Adult females feed on cotton nectar which provides carbohydrates needed
for egg production and then move into adjacent soybean fields where eggs are laid on the underside of soybean leaves. Soybean looper females may lay about 20 eggs without feeding on cotton. After feeding on cotton nectar, she will lay 1200 eggs. This insect eats large holes in leaves and high populations may completely defoliate plants.

Soybean looper can produce up to four generations in a growing season. Larvae usually begin feeding on foliage about the time that soybean reaches full bloom in early August through mid-September. The period of greatest leaf consumption by soybean looper coincides with the early pod development stage during which defoliation can be more detrimental to yield [25].

Soybean seed yields can be severely reduced under conditions of heavy infestation with worm pests, especially during early reproductive stages and/or when environmental stresses impede compensatory regrowth. Defoliation reduces leaf area and thus decreases photosynthesis. Current recommendations for control of insect defoliators were designed to protect against excessive yield loss by preventing defoliation from exceeding 35 percent in pre-bloom soybeans or 20 percent in reproductive soybeans [33]. Current integrated management programs for soybean worm pests depend on timely applications of insecticides to reduce yield losses under conditions of heavy infestation. Insecticide tests have been shown to reduce populations of soybean looper and velvetbean caterpillar by 90-95% [63][64].

Although the soybean looper is a migratory pest, native parasitoids and fungi use this species as a host in southern soybean fields. Often, however, economic damage has been caused before these natural control agents can reduce looper populations effectively [35]. The soybean looper is invariably brought under control during late August and early September by a fungus pathogen, Entomophthora gammae [35].

Resistance in soybean to defoliating insects was identified in the early 1970s. Only three cultivars with host plant resistance have been introduced and none has been widely accepted by growers due to agronomic inferiority and to the inability of breeders to capture the level of resistance exhibited by the resistant ancestor.

Collections of the parasite Euplectrus putleri were made in Columbia, South America, from velvetbean caterpillar larvae. This parasite has since been introduced and established in south Florida [60]. Suppression of velvetbean caterpillar populations in south Florida would help reduce the numbers of the pest moving north.

The use of the gemmatalis nucleopolyhedrovirus to control the velvetbean caterpillar in soybean fields in Brazil began in 1979 and represents one of the most successful examples of microbial control in the world [61]. Field trials conducted in Florida demonstrated that the Brazilian virus is efficacious against velvetbean caterpillar populations, although the levels of suppression were lower than those in Brazil. Applications of the virus in the US have not shown promise for establishment in the field for long-term suppression [37][22]. In South Carolina, velvetbean caterpillars collected from locations the year after virus application showed no symptoms or mortality due to
This failure to reinfect the larvae the next year would indicate that it may be difficult to establish the virus as a natural control agent. This virus does function as a control agent in Brazil. However, velvetbean caterpillar populations in Brazil develop early in the growing season from individuals which overwinter in the area, whereas populations in South Carolina develop from migrating moths which do not arrive until late in the growing season [62].

A nuclear polyhedrosis virus was isolated from larvae of the soybean looper in Guatemala and tested in Louisiana and Arkansas. Several large soybean fields were sprayed in an effort to establish it as a permanent regulator of larval numbers. In the following years, a low percentage of larvae in the fields died from the viral infection but epidemics did not develop [60].

The early soybean production system has been adopted to alleviate late season insect problems and drought stress often encountered in the mid-South during early-August to mid-September, and thereby improve profitability [40]. Early planting dates allow these soybeans to escape damage from late-season foliage-feeding lepidopterous larvae, because the plants are mature before migratory pests build to damaging population peaks in late season [40]. Although yields have increased with the adoption of the early production strategy, the cost of insect control will probably be comparable to that of the conventional production system primarily because of consistent stink bug pressure in the early production system. This pressure can be expected because *N. viridula* often colonize the early-maturing cultivars first because pods are available early. After colonizing the early-maturing cultivars, however, stink bugs successively move to the later maturing cultivars as each becomes attractive because of the presence of developing pods [40]. Since moving to early soybeans, bean leaf beetles have become more of a problem [65].

*Corn Earworm*

Corn earworm has a host range of more than one hundred plants including several crops, such as corn, cotton, and tomatoes, planted in the southeastern U.S. With the continuous presence of suitable host plants, corn earworm populations can easily build to economically significant levels. Further contributing to its status as a severe pest in the Southeast is the fact that corn earworm overwinters as a pupa in the soil in the southern U.S. and produces approximately four generations per year.

In soybean, corn earworm not only causes indirect losses by feeding on leaves, but also causes direct yield losses by feeding on flowers and pods. Outbreaks of corn earworm in soybean can partially or completely destroy yields. In the Atlantic Coastal Plains states of Virginia, North Carolina, and South Carolina, corn earworm is the most serious insect pest of soybean and it ranks second to the Mexican bean beetle in Maryland [44]. In 1980, a very dry hot year in Virginia, the use of insecticides for corn earworm and spider mites increased soybean yield by 27% [21].
The corn earworm causes the most serious damage to soybeans in a geographic band that includes Costal Plain areas from southern Virginia to Alabama [22]. In the east-central U.S., second generation corn earworm develops in corn and adults move to new hosts as corn matures. Because of its availability and the lack of other suitable hosts, soybean is used almost exclusively by corn earworm for development of the third generation [24]. Pod feeding from heavy infestations of corn earworm can result in nearly complete crop loss in the southeastern U.S. when insecticides are not used [26].

**Green Cloverworm**

A native species, the green cloverworm is a widespread defoliator of legumes and has occurred in outbreak numbers in soybean since 1919. Although outbreaks in soybean have been recorded in southern states, the insect has been most serious in northern states. Population outbreaks of the species can be explained in the northern United States by unusually high numbers of migrating adults. Major outbreaks, as occurred in 1966, 1968, and 1973, are characterized by rapidly expanding larval numbers in June and July. Such populations reach an “economic peak” (15-30 larvae per row-ft) by late July when soybean are in full bloom. Subsequently, these peaks are followed by declining larval numbers for the remainder of the season. Soybean leaf consumption has been estimated at 53.9 cm² per larva [44]. In major outbreak years, over 2.5 million acres have been treated with insecticides for green cloverworm.

The green cloverworm is attacked by several species of predators and parasitoids; however, the primary regulating factor of populations is disease caused by the fungus *Nomuraea rileyi*. The outbreaks are almost always subdued by epizootics of *N. rileyi*, which cause a collapse in numbers, and, consequently, late-season problems rarely occur. Because green cloverworms are occasional pests, the primary management tactics include regular monitoring, and use of economic thresholds, followed by insecticide applications when necessary [44].

**Mexican Bean Beetle**

The Mexican bean beetle is native to Mexico where it feeds on legumes. Its geographic range expanded northward into the western US apparently with the cultivation of *Phaseolus* beans by native Indians. Before 1918, the MBB was restricted to the western US, but in that year it was accidentally introduced into the east where it spread rapidly. Eastern and western distributions are separated by the central plains, where climatic conditions apparently do not allow establishment [66].

When first introduced, it was only occasionally observed feeding on soybean plants. High population densities did not develop in soybean fields until the 1960s coinciding with expanding soybean cultivation. Severe MBB infestations presently are limited to certain states on the Atlantic coast, especially Delaware, Maryland, and Virginia, and the states of Indiana, Kentucky, and Ohio in the Midwest. The co-occurrence of reproductive soybean growth stages and high second generation densities of MBB may reduce soybean yield by 40-50% in untreated fields [66].
Mexican bean beetle feeds on and economically damages several legume species. Preferred hosts include lima beans, snap beans, and cowpeas. The Mexican bean beetle can be a serious defoliator of soybean. Both adults and larvae cause plant injury by scraping, crushing, and ingesting leaf fluids and tissue. The tissue that remains gives the leaf a lacy appearance. Yield reductions are the result of the adults and larvae feeding on the foliage of the soybean plants. Outbreaks vary considerably from season to season but most economic injury occurs during moist growing seasons in the mid-Atlantic region of the United States, although isolated damage to soybean can occur in the southern region [39].

Mated and unmated adults overwinter in protected areas, such as within plant debris, under rocks, and in cracks in the ground, surrounding soybean fields. Upon emergence, adults seek various legumes including soybean, lima bean, alfalfa, clover, vetch, beggarweed, and kudzu. After feeding for 7-14 days, the adults begin depositing eggs. Each female lays from several hundred to over 1000 eggs during her approximately 40 day lifetime. In southern latitudes, there are three or four generations each year, with two generations in more northerly areas.

Naturally occurring predators such as predacious stink bugs, nabids, and minute pirate bugs can reduce Mexican bean beetle populations. However, these predators usually do not significantly lower populations during an outbreak.

The recognized absence of effective MBB natural enemies in the eastern states prompted attempts at classical biological control. In the 1920s a larval endoparasite was imported from central Mexico, but failed to establish in the US. In the 1940s another tachnid endoparasite of MBB larvae was imported from Argentina and Brazil, but also failed to establish. Establishment failures apparently were due to inabilities to overwinter in the US [66].

In 1966 the larval endoparasite *Pediobus foveolatus* was imported from India and released in several eastern states beginning in 1967. An adult female wasp lays about twenty of her eggs per Mexican bean beetle larva. The wasp eggs hatch inside the MBB larva and feed on it, eventually killing it. The wasp caused high rates of MBB parasitism but also failed to overwinter. Studies were begun in Maryland in 1972 to develop an inoculative release program. Late spring and early summer releases of *Pediobus foveolatus* caused from 90-100% parasitism in soybean fields by the end of the growing season (September). To foster the establishment and increase in parasites following release, early plantings of snap beans adjacent to soybean fields were recommended. High numbers of the parasite dispersed from the snap bean fields to surrounding soybean fields[66]. An economic analysis assumed that such releases were as effective as insecticide applications. However, several problems and questions arose from the original studies. Parasitism was highest in September when the soybean plants were near or beyond the stage where defoliation would have significantly affected yield [66]. Additionally, the costs of planting and maintaining nursery plots were not evaluated.
Pediobius is expensive to rear and to purchase. The Maryland Department of Agriculture sells the wasp for $25/1000[67]. With a need to release 12000 wasps per acre, the cost to growers would be $300/A.

References


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Figure 1. U.S. Soybean Acreage Treated with Insecticides

Source: [18] [19].

Figure 2. Insecticide Use in Illinois Soybeans