IV. Management Tactics – Implementation of IPM Programs

A. Introduction

IPM uses historical records of pest incidence, pest mapping, and scouting as the bases for decisions about the application of control measures using the concept of EILs. If control actions are needed, IPM utilizes all available methods or tactics, singly or in combination to form a comprehensive control strategy aimed at preventing crop injury and potential losses in yield or crop quality. Through the use of IPM strategies, crop managers can achieve economically sound crop protection with minimum impact on the environment. IPM allows for long-range sustainability of soybean production systems that are well adapted to the local situations. The sustainability will be reflected in the increased profitability and reduced losses to pests in the whole production system. The choice of a particular control tactic, such as extensive soil-tillage vs. no-tillage practices, should be dependent on an assessment of potential damage by the pest or pests involved the cost and benefits of the tactic, and the long-term environmental impact. Control tactics for plant pathogens, arthropods, and weeds can be broadly subdivided into preventive, preemptive, and remedial tactics (Table 11).

Preventative measures include the use of resistant or tolerant cultivators and biological and cultural methods to maintain population of arthropod pests or pathogens low enough to be economically insignificant. Crop seeds free of weed seeds is essential.

Preemptive measures are adopted in a certain areas where there is a repeated history of arthropod pest outbreaks or disease epidemics; fungicides, insecticides pr herbicides are applied according to a certain calendar date or growth stage. Applications are made with the expectation of damage, regardless of actual detection of pest or injury level. Because weeds generally are predictable in their occurrence and severity, most preplant and preemergence applications of herbicides are considered preemptive control measures.

Remedial measures are adopted when pest populations reach established threshold.

Table 11. Principal management tactics for soybean pathogens, arthropods, and weeds.

Control Tactic	Pathogens	Arthropods	Weeds
PREVENTIVE			
Pest exclusion	+++[1]	+	+
Host plant resistance	+++	++	NA
Biological control	+	+++	+
Cultural methods			
Crop rotation	+++	++	+++
Row spacing	++	++	+++
Planting dates	+	+	++
Trap cropping	NA	++	NA
PREEMPTIVE			
Fungicides	+++	NA	NA
Insecticides	NA	NR	NA
Herbicides			
Preplant herbicides	NA	NA	+++
Preemergence herbicides	NA	NA	+++
REMEDIAL			
Biological control	+	+++	NA
Cultural control			
Cultivation	NA	NA	+++
Chemical control			
Insecticides (EIL's)	NA	+++	NA
Postemergence herbicides	NA	NA	+++

[1] + = limited use, ++ = useful, +++ very useful, NA= not applicable, and NR = not recommended.

Application of these measures, usually chemical pesticides, is decided based on information obtained on the status of the crop and the population levels actually detected in the field. Detection of these populations is accomplished by periodic scouting. IPM prefers to use preventive and remedial measures and avoid preemptive measures that often are either uneconomical or ecologically and socially unsound, except for herbicide use.

Both preventive and preemptive tactics are deployed based on previous records of pest incidence and the anticipation that, if not treated, the pest will occur and cause economic losses. Preventive tactics usually are environmentally compatible and fit well in an IPM program. Preemptive tactics, such as the application of a pesticide on a calendar basis in anticipation of the occurrence of a pest, run the risk of impacting on the environment and wasting money should the pest not occur; these are, however, the prevalent methods for the control of certain pathogens and most weeds. Remedial tactics are deployed only if the pest reaches their EIL. A list of the most commonly used tactics in soybean IPM, with reference to relative importance or applicability to the various pest categories is provided (Table 11) (Sinclair & Backman, 1989).

B. Preventive tactics

1. Pest exclusion

Pest exclusion is not easily applicable as a preventive method of pathogen control, but it can be effective in avoiding arthropod pests and weed infestations. There are two major approaches to exclusion methods, legislative and pest—free seeds. Exclusion methods are useful where the pest does not exist, cannot survive between soybean crop cycles, or, if not present in an area, is not likely to be airborne.

Legislative embargoes, inspections, and quarantines are used to prevent the introduction of soybean pests into new areas. These legislative actions limit the spread of pests that may or may not occur worldwide but pose a significant risk to soybean production. These include the USDA, Animal and Plant Health Inspection Service (APHIS) governs the importation of uncleaned soybean seeds to prevent the introduction of the soybean rust pathogens from Asia and Latin America (including the Caribbean), and the State of Hawaii to the continental United States (Sinclair & Hartman, 1996).

The use of seed lots that generally are free of disease agents, arthropods, and weed seeds is an effective means of preventing the introduction of pests associated with soybean seeds. Such seed lots can be produced in areas free of a particular pest or isolated from it or from fields inspected to ensure the absence of a pest. Seeds can be treated with one or more pesticides or come from fields that have been sprayed with fungicides and/or insecticides and the seeds thoroughly cleaned of weed seeds. Special care must be taken when a pathogen, such as a virus, bacterium, or fungus, is internally seedborne and may or may not show symptoms of the infection (Sinclair, 1991a).

2. Soybean resistance

Plant resistance to pathogens and arthropod pests is one of the most desirable components of an IPM program. There is an ongoing effort in many parts of the world to identify sources of resistance to the most important viral, fungal, nematode, and bacterial pathogens of soybean, and, in some parts of the world, only resistant cultivars can be grown because of the virulence of some pathogens.

a. Resistance to pathogens

The use of pathogen—resistant cultivars is the most economical and most efficient means of disease management if the cultivars yield competitively (Tisselli *et al*, 1980). Where they yield less than susceptible cultivars, resistant or tolerant cultivars should be used in rotations on a prescription basis. Prescription cultivars have been effective in IPM programs for brown stem rot fungus and the soybean cyst nematode. Resistance often is not available in adapted cultivars or is race-specific. Race-specific resistance often is a problem in cultivars used for controlling the soybean cyst nematode, downy mildew, frogeye leaf spot, and Phytophthora root rot pathogens, since numerous races of the causal agents are known. In these cases, it is important to know the predominant race present.

b. Resistance to arthropods

Soybean genotypes resistant to arthropod defoliators, pod-sucking insects, and some stem-boring genera have been identified (Table 12). Perhaps the best available resistance mechanism is displayed against small leafhoppers. In most commercial cultivars in use in North and South America, the epidermis of leaves, stems, and pods is covered with trichomes or hairs of a length and density that deter leafhopper colonization and feeding. Glabrous lines are decimated by leafhoppers. Levels of resistance against other pests are not consistently high, and much additional screening is needed to identify superior genotypes for use in breeding programs. Progress has been made in breeding cultivars that

Table 12. Soybean genotypes identified as possible sources of resistance against arthropods.

Genotype[2]	Maturity group	Level of resistance	Target species	Source
PI54615	III	M	Epilachna varivestis	Kogan, 1976
90481, 96089, 157413	V	M	E. varivestis	Elden et al., 1974
163453, 203246, 229321	VII	H	E. varivestis, Cerotoma trifurcata	Campbell, 1974, 1975
171451, 227687, 229358	VII	H	E. varivestis, Helicoverpa zea, C. trifurcata, Plathypena scabra, Epicauta spp.	Van Duyn et al., 1971 Clark et al., 1972
			Trichoplusia ni	Luedders & Dickerson, 1997
171444, 171451, 227697 228357, 417061		M	C. trifurcata, Diabrotica balteata	Layton et al., 1987
83868, 92748, 180520	IV, II	H	Ophiomyia phaseoli	AVRDR, 1975
"Kent" , "Vicosa-Permambuco" VE-65-13	?	M	Lourencão	Talekar &Chen, 1983
G2101, G2105, G3473 G3517, C3818, G8448, G8506	?	H	E. zinckenella	Talekar & Chen, 1983
171444, Chi-Kei #1B, 77-10439, 227687	VI, VII	M	N. viridula , Piezodorus guildinii, Euschistus heros	Panizzi et al., 1981
IAC 78-2318	?		Epinotia aporema	Lourencão & Miranda, 1983
IAC 73-228	?	H	N. viridula , P. guildinii	Miranda et al., 1979
274453		H	Omiodes indicata	Lourencão et al., 1984
171451, 229358	VII	M	Bemisia tabaci	Rossetto et al., 1985
K-5776, K-309 Amurskyaya 401, Amurskyaya 405, Moneta	?	H	E. zinckenella	Sichkar et al., 1983
UPSM-349, UPSM-1123, UPSL-6, UPSL-586, UPSL-801, J-323, WT-47VHC-3067	?	M	Melanagromyza sojae	Bhattacharya, 1984

[2] Genotypes are (a) plant introductions (PI's) following the numberings systems in the US Department of Agriculture germ plasm collection at Urbana, IL; (b) named cultivars; (c) breeding or germ plasm line maintained in various in various collections at the Asian Vegetable Research and Development Centre, Tainan; Instituto Agronomico de Campinas, Sao Paulo, Brazil; Academy of Sciences of the Ukrane, Kiev, Russia; and the G. B. Pant University of Agriculture and Technology, Pantnagar India.

incorporate genes for resistance from the genotypes Kasamame (PI 171451), Sodendaizu (PI 229358), and Niyako White (PI 227687). Genes from these genotypes confer good levels of resistance against leaf-chewing arthropods. Several germ plasm lines and at least two cultivars, Crockett and Lamar, with one or more of these genotypes in their background have been released. Resistance to pod—sucking arthropods has proven more elusive, but a cultivar was developed in Brazil (C. J. Rossetto, personal communication) that displays a high degree of tolerance to *Nezara viridula* L. (Plates 24, 25). This cultivar, IAC 100-Centenaria, suffers no foliar retention, even when heavily infested.

The genetics of resistance to arthropod defoliators is complex, although only a small number of genes are involved. Resistance mechanisms in those genotypes include physical and both constitutive and inducible chemical defenses. The nature and importance of the induced chemical defenses remain unclear but seem to include phenolic compounds and isoflavonoid pterocarpans (Kogan, 1989).

c. Resistance to herbicides

Sulfonylurea tolerant soybean (STS) minimize thifensulfuron (Pinnacle) injury. Glyphosate resistant (cv. Roundup Ready) soybean allow glyphosate, a broad-spectrum nonselective herbicide, to be used selectively in soybean production. The glufosinate tolerant soybean (cv. Liberty Link) is scheduled for future release. Herbicide-resistant crops should be managed to minimize the probability of herbicide-resistant weeds.

3. Biological control tactics

Biological control in soybean has been most effective in the management of arthropod pest populations. If naturally—occurring parasitoids and predators are not disturbed by the use of broad spectrum insecticides, many potentially damaging soybean arthropod pests frequently are kept below the EIL. Biological control for soybean pathogens and weeds, although potentially useful, has not been widely used.

a. Biological control of pathogens

Biocontrol of plant diseases has prevailed in nature since the beginning of the co-evolution of plants with pathogens, and biocontrol of crop pathogens has existed since the beginning of crop cultivation. Crop disease biocontrol is accomplished by crop rotation, clean tillage practices, or organic manures. Within the recent past, there has been an effort to control crop diseases through the introduction or enhancement of microorganisms antagonistic to plant pathogens. The effectiveness of a biocontrol agent depends on its density and that of the pathogen, the efficiency of the individual agents against the pathogen units, and the portion of the pathogen population affected by the agent. With development of new methods and equipment and the refinement of old methods in biotechnology, new tools have been provided to exploit, develop, and enhance the biocontrol of crop diseases.

The use of successful biocontrol agents for soybean pathogens is still being investigated. One example of a potential biocontrol agent for control of a soybean disease is seed or soil treatment with *Bacillus megaterium* de Bary, strain B153-2-2 (Liu & Sinclair, 1991, 1992). Another is the use of *Bacillus cereus* Frankland & Frankland, strain UW85, to reduce seedling damping-off caused by *Phytophthora* spp., which also is effective against *Rhizoctonia solani* Kiihn (Handelsman *et al.*, 1988). Strains *of Bacillus subtilis* (Ehrenberg) Cohn can be phytotoxic to soybean and do not grow well under all environmental conditions at which pathogens survive (Schiller *et al.*, 1977; Tenne *et al.*, 1977). The future will provide commercially acceptable biocontrol agents applied as seed treatments or foliar sprays.

b. Biological control of arthropods The use of biological control as a management tactic involves: i) the conservation of naturally occurring parasitoids, predators, and arthropod diseases (entomopathogens) through the management of the habitat that most favors the survival and efficacy of those biological control agents; ii) the augmentation of natural enemies through the periodic releases of mass reared species, such as *Trichogramma* spp., to control lepidopterous eggs; and iii) the importation of new natural enemies to control exotic pest invaders. Natural enemies of arthropod pests usually occur in soybean fields at levels capable of holding most species in check. It is a good IPM practice to make the crop environment as favorable as possible for the conservation of natural enemies. Under certain circumstances, more than 90% of the stink bug, *Nezara viridula* (Plates 24, 25), eggs and nymphs are killed by natural enemies and by weather related factors before reaching the adult stage. Insecticides should be used only when necessary to manage certain pest outbreaks and should be carefully chosen with preference given to selective insecticides that are least likely to disrupt biological control agents. A comprehensive review and assessment of the value of natural enemies in soybean arthropod management was published (Pitre, 1983).

If naturally-occurring predators, parasitoids, and diseases are not sufficient to control an arthropod pest, it is possible to mass produce the natural enemy and release or apply it in the field, either as a sole control tactic or in combination with other tactics. One of the best examples is the production of *Baculovirus anticarsia*, a deadly disease of the vel-vetbean caterpillar, *Anticarsia gemmatalis* (Plates 36, 37), in Brazil. The virus has to be ingested by the caterpillars to begin infection. In Brazil infected caterpillars are collected in the field (Moscardi & Corso, 1982). Infected caterpillars are recognized by their yellowish color and flaccid texture, and may be preserved in a freezer from the end of one cropping year to the next, when they can be used to produce a biotic pesticide. The collected or frozen caterpillars are ground with a small amount of water and strained through cheese cloth. The filtered liquid contains the virus that can be sprayed in the field using conventional sprayers. The filtrate equivalent of 50 large (>2.5 cm long) caterpillars is the recommended dosage to be applied in 100 to 200 liters of water per hectare.

c. Biocontrol of weeds

Biological control utilizing crop residues or cover crops provides some allelopathic and competitive weed control. Mycoherbicides show some promise, but no mycoherbicides are currently commercialized for soybeans.

4. Cultural control tactics

Many crop management practices can be used alone or in various combinations affecting the management of all pest categories: disease agents, nema-todes, arthropods, and weeds. These cultural practices (in random order) are (Sinclair and Backman, 1989):

a. Avoidance of water deficit or excess

b. Minimization of plant stress by providing optimum nutrients and soil pH

c. Proper harvest date

d. Proper harvest to avoid seed injury

e. Proper storage conditions

f. Use of nonhost buffer crop(s)

g. Use of trap crops

h. Crop rotation optimum nutrients and soil pH

i. Soil tillage prior to planting

j. Planting of high quality seeds

k. Proper planting date

1. Proper row spacing

Cultural practices, such as maintaining adequate availability of plant nutrients and proper soil pH, supplying adequate but not excessive water, avoiding excessive plant density, and planting high—quality seed in a favorable seedbed, are effective in reducing damage from many plant diseases because these practices reduce plant stress and aid in weed control. Healthy, vigorous plants suffer less yield loss from diseases than plants under stress.

Planting date also can influence diseases other than those that affect seedlings. Early plantings tend to minimize damage from the soybean cyst nematode and the charcoal rot and stem canker organisms. It minimizes the likelihood that soybean will be in the critical growth stages for infection by *D. phaseolorum* var. *caulivora* (Plate 85) during wet periods. However, early planting can accentuate damage from *D. p.* var. *sojae* (Plate 85), particularly if conditions in the middle to late summer favor this pathogen. Therefore, seedling damage should be adjusted for soil fertility, soil moisture, seed quality, cultural factors, and the growth habit of the cultivar. Excessive seedling rates and plant densities contribute to increased damage from *M. phaseolina*, *Sclerotium rolfsii*, and diseases caused by *Rhizoctonia* (Plate 85) and *Pythium.*Arthropod pests also may be affected by planting dates. Soybean thrips are potential vectors of tobacco ring spot and tobacco streak viruses. The incidence of thrips populations and severity of virus infections in Brazil have been correlated with planting date and precipitation. Late-planted soybean was less affected by the thrips, the peak population of which occurs very early in the season (Almeida *et al*, 1988).

Seedbed conditions that favor rapid seed germination and emergence minimize damage from pre-and postemergence damping-off. Soybean seeds germinate when soil temperatures are above 12 to 14° C and seed moisture exceeds 50%. Planting in relatively warm soil can help soybeans to emerge quickly and compete better with weeds. Narrow row spacing will shade the centers faster and help soybean compete better with weeds. Row spacing also affects soybean diseases. Narrow row widths have been reported to increase the severity of downy mildew, Rhizoctonia aerial blight, and Sclerotinia stem rot, but have little effect on Septoria brown spot. When soybeans are planted early the rapid canopy closure in narrow rows may lower soil temperature, reduce the severity of charcoal rot, and suppress damaging weed populations. Water management is critical particularly in root diseases. Saturated soils create favorable conditions for infection by *Phytophthora* and *Pythium*, deficit of water in the soil contribute significantly to losses caused by nematodes, and the charcoal rot and brown stem rot fungi. Excessively dry seedbeds can contribute to seed decay by *Aspergillus* and *Penicillium*. These fungi can decay seeds with moisture contents far less than 50% moisture required for germination.

Irrigation water management can help control the pathogens causing anthracnose (Plate 89), bacterial blight, pod and stem blight (Plate 85), Sclerotinia stem rot, and Septoria brown spot. Furrow irrigation reduces pod and seed infections in many areas, whereas excessive sprinkler irrigation during pod fill and pod maturation increases them. In areas where Sclerotina stem rot is a threat, avoidance of irrigation during flowering helps reduce floral infection. Irrigation to maintain adequate moisture can reduce damage from the brown stem and charcoal rot organisms. In the control of brown stem rot, adequate moisture is particularly important during growth stages R6 to R8. On the other hand, lengthy drought periods favor outbreaks of spider mites. Severe infestations may occur in a very short time, greatly aggravating the stress on the plants already suffering from the lack of adequate moisture.

Adequate rainfall is required to activate many preemergence or preplant herbicides. If adequate rainfall does not occur, then a rotary hoe can be used after weed seeds have germinated but before most weeds have emerged. Rotary hoeing also aids crop emergence if the soil is crusted.

Optimal fertility, particularly adequate phosphorus and potash nutrition, is important in the management of bacterial blight, bacterial pustule, charcoal rot, Fusarium blight, pod and stem blight, Rhizoctonia root rot organisms, and the soybean cyst nematode.

Optimal soil pH (pH 6.2 to 7.0) is important for root nodulation. Acid soils accentuate the damage from Sclerotium blight. Suboptimal soil pH, which reduces nutrient availability, increases the damage caused by a number of plant pathogens.

Tillage also can influence disease development. Reduced tillage practices, including no—, strip—, and zone—tillage, affect (i) the growth of a ground cover, (ii) soil temperature and moisture, (iii) earthworm populations, (iv) soil compaction, (v) pathogens, (vi) arthropods, and (vii) weed populations. Each of these environmental factors have direct or indirect effects on soybean production and therefore plant disease incidence. For example, root and lower stem diseases, such as those caused by Phytophthora, Pythium and Sclerotinia (stem rot), increase from year to year and within any single year under such practices. Foliage blights, such as Septoria brown spot, is more severe under no—tillage practices. These fungi survive in crop debris or as dormant elements, which plow—down helps to destroy or inactivate. Tilling when plants are wet spreads the bacterial blight and pustule organisms and is likely to spread other bacterial pathogens. However, damage from Rhizoctonia root rot (Plate 88) can be minimized by cultivating soil against the stem to encourage adventitious root development. This practice increases the damage from Sclerotium blight, however, and should be avoided if this disease is present. If row cultivation is required for weed control, it should be done while weeds are small. Throwing soil into the row can help smother small weeds. Proper adjustment of equipment is essential to avoid injuring the crop or root pruning.

Soybean growth habit is another factor in cultural control. Septoria brown spot and pod and stem blight are more severe in either dwarf or semidwarf determinant cultivars than in nondwarf cultivars.

These and other cultural methods may be used in a soybean production system to either adversely affect arthropod species or to aid beneficial species. Trap cropping is a tactic potentially useful in IPM programs. Example of the trap crop principle is that involving the stink bug complex. Stink bugs (Plates 21 to 29), colonize soybean during the repro ductive stages of pod—set and seed filling (R3 to R5). Thus, early maturing or early planted soybean are highly attractive to stink bugs and may be used as a trap to take advantage of this preference of colonizing stink bug adults seeking oviposition sites in fruiting soybean. The concentration of ovipositing adult females and the less mobile nymphal populations in the early—planted or—maturing plants allows chemical controls to be directed to only that portion of the crop. The key factor is to control the stink bug nymphs before they become winged adults. If controls are not correctly timed, the impact of this method may be lost or, even worse, the trap crop may serve as a nursery from which the main crop is infested to a much greater degree (Todd et al., 1994)