Chapter 20

SAMPLING ARTHROPOD PESTS IN VEGETABLES

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I. SPECIAL CONSIDERATIONS IN SAMPLING VEGETABLE CROPS

The word "vegetable" is not very descriptive. *Webster's Third Collegiate Dictionary* defines a vegetable as "a usually herbaceous plant grown for an edible part which is usually eaten with the principal part of a meal." Other dictionaries broaden this definition to include any leaf, pod, tuber, or small fruit from virtually any plant which is not grown as a tree. For the purposes of this chapter, "vegetable" is used in the broadest sense, but is limited to those plants which generally are grown in annual, biennial, or 3-year plantings.

This broad definition includes plant species of exceptional diversity, providing substantial challenges for pest population assessment to both researchers and pest control advisors (PCAs). Differences in plant morphology can be dramatic, with some crops such as strawberries growing in dense stands close to the ground, and others such as sweet corn growing over 1.5 m in height. Many plants exhibit substantial changes in morphology with age. The harvested portions of vegetable crops vary from underground tubers such as potatoes, to leaves of spinach, buds and flowers of broccoli and cauliflower, whole heads of lettuce and cabbage, petioles of celery, or above-ground fruit such as tomatoes and beans. Variability is further increased by temporal and geographic disparity in cropping cycles between production areas, use of different cultivars, and a wide disparity in horticultural practices among growers. Finally, the key insect pests of these crops have representatives from virtually all major insect taxa. Not surprisingly, their behavior and damage potential are remarkably diverse. Thus, covering all of the sampling programs for insect pests in vegetable cropping systems is impossible, and this chapter focuses on some representative systems which provide insight into how sampling programs have evolved.

The importance of sampling in vegetable production is increasing. Many vegetables are grown in short-term plantings of considerable value. Although the relatively low thresholds for insect damage or contamination in vegetables would appear to justify a greater effort and cost of sampling to detect low pest population densities, most producers demonstrated a risk-adverse behavior in the 1950s, 1960s, 1970s, and the early 1980s; they sprayed pesticides on a calendar schedule. In spite of the fact that vegetable crops are categorized as "minor use" for pesticides due to low acreage, historically this low priority for registration was not a significant problem since so many new pesticides were developed each year that an effective compound was nearly always available. However, since the late 1970s a substantial reduction in the introduction of new pesticides and increased costs for registration have greatly reduced insecticide availability.[1] This problem has been compounded by the development of pesticide resistance in many key pest species, increasing costs of pesticides to the grower, and a growing aversion of the public to pesticide use on food crops. In addition, until recently vegetable crops have been considered generally unsuitable for biological control efforts because of the high value, expectation of cosmetically perfect produce, and short-term nature of the plantings.[2] Thus, despite the high potential value, the reduced availability of pesticides and a relative lack of proven tactics using natural agents currently limit the available control strategies.

Limitations on the availability of control strategies have important implications for sampling and economic thresholds (ETs), which, in turn, will influence sampling strategy. For example, if all available controls are poor, then the ET will be low (e.g., locating the insect pests may be enough to trigger treatment), and a simple survey for presence/absence may be adequate. If the control strategies are good, and the ET is well defined (even if it is low), then a sampling program with a high level of precision

would be desirable. Similarly, if control costs are high, or if pesticide resistance potential is substantial, a highly precise sampling plan is needed. The possible combinations of sampling plans and ETs for vegetables are astronomical. One of the few certainties in sampling in vegetable crops is that the economic impact of sampling errors which underestimate insect populations or damage will be intolerable to producers. For this reason, most PCAs tend to be conservative when selecting sampling plans.

Basic knowledge of ETs for vegetable production systems is, unfortunately, quite limited. Interactions between plant compensatory/tolerance mechanisms and arthropod damage are only poorly understood.[112] Recognizing key types of damage which affect yield is critically important, but has been defined for very few vegetable crop systems. The influence of horticultural practices, geographic location, and environmental variation all interact to make predictions of plant compensation and insect distribution difficult. Nonetheless, some generalizations are possible and are discussed in this chapter where applicable. Anyone interested in assessing arthropod populations must consider the final goal of growers; producing an economic return on their investment. Further, questions on the specific program must be addressed; most importantly, is the information to be used for research into ETs, for efficacy of control strategies in small plot trials, as a practical procedure for determining pest infestation density on commercial plantings, or some combination of the above. For use in commercial operations, the programs must be validated in typical commercial situations. In general, sampling programs tend to evolve from intensive research-oriented procedures to less time- and labor-intensive methods suitable for commercial use. As examples of this process, some representative pests, their associated sampling programs, and related ETs are described in the next section.

II. KEY PESTS AND MAJOR TECHNIQUES USED IN SAMPLING VEGETABLE CROPS

The following insects are representative examples within selected guilds. Space does not permit the listing of all pest-plant systems. For life history and control information for other pest species, the reader is referred to McKinlay,[3] and Metcalf et al.[4] and the references therein. Rather than simply listing all sampling techniques, an attempt has been made to describe the rationale by which procedures were tested and, whenever applicable, adopted.

A. ROOT-FEEDING ARTHROPODS

Among the most difficult arthropods to quantify are those which feed below the soil surface. Extensive destructive sampling, designed to quantify population levels, is both tedious and economically damaging. Few growers are willing to tolerate removal of substantial numbers of plants in the absence of any evidence of plant stress. In some circumstances, destructive sampling may be used to detect the presence of the pests, particularly if some plants obviously have been stunted or are stressed by root loss. However, most current sampling programs focus on the presence/absence or movement of the above-ground stages of the insects.

An exception is the use of attractant bait traps for some arthropods (see Chapter 16 for examples in corn). This technique has proven particularly effective for wireworms (Coleoptera: Elateridae or Tenebrionidae). Generally, food baits such as corn, potatoes, or oats are placed in 15 × 15 × 10 cm holes and covered with soil and a layer of plastic. The plastic serves to retain moisture and elevate soil temperatures, both of which have been shown to improve collection efficiency.[5] However, in areas

where soil temperatures and moisture levels are normally high, the plastic covering may not be necessary.[6] Because the traps draw the insects from a variable area depending on climatic conditions and attractiveness of the bait, the resulting data provide an indication of presence or absence of the pests and a relative estimate of population intensity.

Arthropods feeding beneath the soil surface often can be separated into two categories; those feeding on the marketable portion of the plant and those causing economic losses through root damage. Sampling programs or representatives of each of these categories are discussed here, beginning with the potato tuberworm, *Phthorimaea operculella* (Zeller), which feeds on the potato tuber. A second pest, the lettuce root aphid, *Pemphigus bursarius* (L.), feeds on the roots of vegetable crops such as lettuce and celery, for which only the above-ground portions of the plants are marketed.

The potato tuberworm is a significant pest of potatoes throughout the world.[7] Although foliar damage can cause yield losses if stems are mined,[8] most economic losses occur when larvae infest the tubers.[9] Historically, pesticides have been used on a weekly or calendar spray schedule following visual detection of adults or larvae in the foliage. The development of more precise economic injury levels (EILs) and sampling plans have been hampered because visual counts of larval densities in the foliage are tedious and time consuming, and attempts to correlate bait traps and light traps with foliar infestations have been unsuccessful.[10] More recently, the documentation of an effective pheromone, and the development of a suitable pheromone trap, allowed PCAs to relate pheromone trap catches to foliage counts and tuber damage.[11,12] However, several drawbacks to pheromone trapping have been noted, including the lack of correlation between trap counts and tuber infestation which can occur if horticultural practices are altered. For example, increasing hill sizes and use of drip irrigation can reduce tuber exposure, eliminating statistical relationships between tuber infestation and trap catches. In addition, the use of pesticides may affect sampling efficacy; Bacon[13] reported that high levels of larval suppression in the foliage did not assure that tuber infestations would be proportionately reduced. Thus, in spite of the worldwide importance of potatoes as a staple food source, the variable impacts of diverse environmental and horticultural factors on potato tuberworm populations have severely limited the development of EILs and precise sampling plans.

An example of a more effective sampling program for a root-feeding insect can be provided for the cabbage maggot, *Hylema brassica* (Weidemann). This dipteran is an important pest of *Brassica* crops in much of the northern hemisphere, including Europe, Canada, the U.S., and the former USSR.[14] The cabbage maggot overwinters in the pupal stage, emerging in the spring to start a seasonal cycle of 2 to 4 generations, depending on location. The highly mobile adult females oviposit in cracks in the soil near the stems of young plants, and the resulting larvae burrow down to feed on the roots. A single plant may support hundreds of larvae, whose feeding causes stunting, wilting, and entryways for plant pathogens.

Predicting spring emergence of the adults is critical both for timing of adulticide treatments as well as effective implementation of additional sampling strategies. Several researchers have reported success using thermal summation techniques (e.g., accumulated degree-days).[15-17] The use of this technique for predicting emergence of subsequent generations is complicated by the occurrence of a summer aestivation of the pupal stage when soil temperatures exceed 21 to 22°C,[18] but this problem can be solved mathematically.[19] Procedures for developing thermal summation models are readily available.[20,21]

An alternative approach to calculating degree-day accumulation is to relate emergence to the phenology of common plant species in the region. This relatively simple method relies on the plant to integrate key environmental parameters such as temperature, daylength, and soil moisture, and has proven effective for *H. brassicae* in commercial situations.[22] In New York, the initial flowering of yellow rocket (*Barbarea vulgaris*) has been demonstrated to reliably coincide with spring emergence of the pests.[23]

Sampling plans are currently available for the eggs, pupae, and adults of the cabbage maggot. Harcourt,[24] using visual counts of the eggs on the soil surface near the base of cabbage plants, developed a sequential sampling plan based on the common 'k' of the negative binomial distribution (see Chapter 8 as well as Shelton and Trumble[25] for an explanation of sequential sampling designs). An ET of 20 or 30 eggs per plant was proposed, but not verified from field trials. The beauty of Harcourt's sequential technique is that decision making potential for sampling efforts is maximized. Unfortunately, when Finch et al.[26] conducted a more detailed evaluation of the negative binomial approach, they found the common 'k' could not be consistently fit to the data. Ultimately they created a sampling plan based on Taylor's Power Law (TPL), which was designed to determine the number of samples necessary to estimate population density with a fixed-precision level (see Chapter 10). However, because the sampling program had been changed from a visual estimate to a 5×2 cm core of soil washed through a screen to collect eggs, the ET used by Harcourt was no longer appropriate, but a new ET was not suggested. This situation is typical of many vegetable cropping systems; sampling plans have been developed but ETs have not been determined. Similarly, many proposed ETs have not been validated in commercial operations.

In a related study, Finch et al.[27] developed a fixed-precision level sampling scheme for *H. brassicae* pupae. This scheme required removing a 15-cm soil core from around plants, stirring each sample into a 9-l bucket of water, and rinsing the soil through a screen sized to collect the pupae. Interestingly, the distribution of the overwintering population was different from the summer populations, and therefore mandated a separate sampling program. In continental Europe, a threshold of ten pupae per plant has been proposed as an ET which will prevent more than 5% crop damage.[28] Unfortunately, like the egg sampling technique, the pupal method has proven impractical for large-scale field sampling. The time, materials, and effort in collecting and washing up to eight soil samples per hectare becomes prohibitive when a PCA has only 2 to 3 h to spend in a 150-ha field.

Adult trapping has proven to be one of the most effective monitoring tools for cabbage maggots. A variety of sticky traps, yellow, white, and blue water traps, and cone traps have been tested for adult capture.[29,30] The most effective design seems to be a "marigold" yellow water trap baited with the synthetic attractant, allylisothiocyanate.[31] The color was selected over the standard fluorescent yellow because *H. brassicae* counts were statistically equivalent and fewer nontarget arthropods were collected, making sorting of catches more rapid. When used in conjunction with the thermal summation model, the traps need be deployed only for a short period, coinciding with the predicted emergence dates, to determine if pesticide applications are warranted.

B. STEM-FEEDING ARTHROPODS

Cutworms are among the most difficult stem-feeding insects to sample. The larvae usually sever the stems of young plants at night and then hide beneath the soil surface during the day. Tomatoes, beans, celery, cole crops, and a host of other vegetable

species can be attacked. Two of the most common cutworms are the variegated cutworm, *Peridroma saucia* (Hübner), and the black or greasy cutworm, *Agrotis ipsilon* (Hufn.). These pests may appear in fields in several ways: (1) adults migrate in and oviposit throughout the field, (2) larvae may be present from a previous planting, or (3) larvae may migrate in from weed hosts along field margins.

Knowledge of the field entry mechanism is important, as this will affect the distribution of the pests and therefore the sampling program chosen. For immigrant moths or larvae remaining from the previous crop, the population will be dispersed throughout the field. For migrating larvae, the border rows will contain the bulk of the population, and sampling can therefore be concentrated on the edges of the field. Visual searches often can detect the population distribution; careful survey of the field for lines of cut or wilting plants is a necessary prerequisite to subsequent, more detailed searches. The University of California IPM Manual[32] for tomatoes suggests an ET for a visual search at dawn of one larvae per minute.

A baiting strategy can be useful for determining the presence of larvae remaining after a previous crop prior to planting of the next crop. A typical bait includes wheat bran plus molasses, and sometimes a pesticide.[33] The baits are placed in a pitfall trap such as the Missouri cutworm trap, a modified pitfall design developed by Story and Keaster.[34] This trap has since been altered to include a vertical screen for visual attraction, which has improved collections.[35] This technique represents a considerable saving in time and effort over the soil sieving approach used previously.[36] For some cutworm larvae, the sampling technique with the best relative net precision[37] is a piece of sacking (burlap) or black plastic which acts as refuge during the daylight hours.[38] Such materials are relatively inexpensive, and within-field distribution can be rapidly estimated with minimal effort.

Adult trapping has proven useful for documenting migrations and generation peaks. Because many vegetable crops are susceptible to stand loss by cutworms for only a relatively short period after germination or transplanting, detecting the arrival of immigrants just before or during the susceptible plant stage is of critical importance. Although blacklights have been used successfully for this purpose,[39] a variety of factors, including weather effects and lunar periodicity, can dramatically affect trap catches.[40] In addition, because of a notable lack of specificity, light trap collections often require substantial commitments in time for sorting and identifying the catches.

If the cutworm species is known, pheromone trapping can provide a more species-specific technique. A variety of pheromone blends and trap designs have been studied for many of the economically important cutworm species.[41-43] However, choice of trap color can affect both specificity and total catch. Hendrix and Showers[44] documented lower catches for *A. ipsilon* using green traps, and suggested that white traps would be more desirable than yellow traps in some locations due to lower attractiveness to nontarget insects such as bumblebees.

When selecting the trap design for a particular species, the sampler should consider the duration of sampling and the possible numbers of moths which may be collected. Some traps are capable of collecting large numbers of adults (bucket traps, some water traps), while other designs using adhesive surfaces may become "saturated" with moths and, although additional moths may be attracted, they may not be collected. Many commercially available traps are made from plastics or metal and will last for many years, while others have been designed for a single use or a single season. Selection of the appropriate trap therefore depends on the specific needs in each crop (efficiency, cost, convenience, etc.). Unfortunately, few ETs have been developed for insect pests of vegetable crops using pheromone traps; correlative relationships between adult catches and larval counts have been difficult to document.

C. FOLIAGE- AND FRUIT-FEEDING ARTHROPODS

Foliage- and fruit-feeding arthropods are among the most diverse and destructive pests occurring on vegetables. Virtually every order of insects, and most of the economically important groups of spider mites are represented. Of these pests, one of the most damaging and most studied insects is the diamondback moth, *Plutella xylostella* (L.) (Lepidoptera: Plutellidae). The diamondback moth is a pest of cruciferous crops throughout the world, causing millions of dollars in damage annually. Losses result when larval feeding destroys plants, causes imperfect heading or unacceptable produce for the consumer, or when the larvae or pupae become contaminants. The contamination problem is most acute for the frozen food processing industry, which is subject to strict limitations on insects or insect parts. The pupae, which are attached to the plant surface with silk, are a particularly important problem.

Some of the earliest sampling studies of *P. xylostella* were conducted by Harcourt.[45] He determined that the negative binomial distribution provided a better fit to larval count data than the Poisson distribution. These data were then used to develop a sequential sampling plan on cabbage.[46] Subsequently, Theunissen and den Ouden[47] compared a series of different sampling strategies, including systematic sampling (200 plants per hectare), simple random sampling (100 plants per hectare), cluster sampling (20 clusters of 5 plants per hectare) and pilot sampling (random sampling of 10 plants per hectare). They concluded that while systematic sampling produced the best estimate (tightest confidence intervals), "presampling" via pilot sampling to determine that the pest population is approaching a threshold level may be the most cost effective approach. Subsequently, they used this background information to generate sequential sampling programs for the major pest species in cabbage.[48] The sequential sampling technique integrates the efficiency of the rapid pilot sampling approach with the reduced confidence intervals provided by systematic sampling.

More recently, several significant efforts to improve sampling efficiency have been made. In numerous vegetable crops, studies on the within-plant distribution of insects have allowed efficient estimates of whole plant counts based on sampling a relatively small portion of the plant.[49-51] Sears et al.[52] tried a modified approach; instead of determining the distribution of *P. xylostella* within the plant, they based their sampling program on the portion of the plant to be harvested (e.g., the head + ten wrapper leaves as a buffer). Unfortunately, the correlation between this artificial, economically important sample and whole plant counts was not significant. Thus, experiences to date indicate that partial plant samples should be based on detailed within-plant studies using available information on the biology and behavior of the pests, rather than on the portion of the plant to be harvested.

Hoy et al.[53] noted that even sequential sampling programs using a plant subsample lose considerable practical application because such plans do not always allow an entire field to be surveyed. As a result, other arthropod, disease, or weed problems may be missed by the PCA. They developed a modified technique called variable-intensity sampling that uses an algorithm to select the most efficient number of plants to be sampled along a V-shaped transect through a field. The orientation of the transect is changed each time to ensure the entire field is seen at least every two samples. The precision of sampling is adjusted according to the mean and its importance to decision making. Like standard sequential sampling plans, decisions can easily be reached if populations are exceptionally high or exceptionally low. However, in the critical range where the standard approach requires additional sampling (often *ad infinitum*), the variable-intensity technique rapidly reaches a decision. Originally the technique was designed to be used with larval count data, but

since has been found to be useful with binomial (presence-absence) data.[54] Thus, a researcher or PCA can now walk the field in a preselected pattern and simply count the presence or absence of larvae on a minimum number of plants and reach a decision.

Unfortunately, as every PCA rapidly discovers, the diamondback moth is not the only pest in cabbage. The plants are usually infested with a complex of lepidopterous insects including the cabbage looper, *Trichoplusia ni* (Hübner), the imported cabbageworm, *Pieris rapae* (L.), and the beet armyworm, *Spodoptera exigua* (Hübner). Using separate sampling programs for each of these pests would be prohibitively complicated in most field situations. Therefore, many researchers have attempted to develop composite sampling plans for all caterpillars. Some of these plans require that all larvae be counted regardless of species.[55-58] Others minimized the sampling effort by developing presence-absence programs where plants with any lepidopterous larvae are counted as infested.[59] Because larvae are often cryptic, and detailed searches of large plants is tedious and time consuming, sampling plans were developed based on the percentage of plants with presence of new damage.[60-62] Although this methodology requires that the sampler learn to distinguish new from old damage, the use of a presence-absence sequential sampling plan permits decisions to be reached rapidly. Not surprisingly, presence-absence sampling plans seem to be strongly preferred by most PCAs.

On occasion, it may be necessary to sample *P. xylostella* larval populations for the development of pesticide resistance, which has been documented to occur at levels causing field failures.[63] Several techniques are available, including standard topical application, uniform droplet exposures, leaf dips, and residual assays in petri dishes or vials. Each of these approaches has advantages and disadvantages. For example, the topical application approach requires the purchase of an expensive microapplicator and is fairly labor intensive, but provides a high level of reliability. However, this technique is not suitable for those pesticides which must be ingested. Resistance evaluation with uniformly sized droplets sprayed onto the leaf substrate also requires the purchase of expensive equipment, a modified on-demand uniform droplet generator, but allows both residual (contact or ingestion) and topical assays.[64] This technique has the advantage of allowing larvae to encounter a dose distribution similar to that occurring in the field. Such distributions have been shown to affect larval behavior and development, two factors capable of influencing control efficacy and resistance development.[65,66] The leaf dip technique, where leaf material is dipped in solutions of pesticides and allowed to dry before the insect is given access, is relatively inexpensive. Like the uniform droplet technique, the residue permits contact and/or ingestion toxicity to be measured. However, tests which last beyond 24 h become increasingly labor intensive because the leaf material must be replaced.

Magaro and Edelson[67] used the leaf dip technique to determine dose response curves for *P. xylostella* larvae. They further simplified the assessment of resistance by modifying a residual vial technique[68] such that disposable cups were coated with a discriminating lethal dose for 90% of a susceptible population. Field-collected third instars are placed in these inexpensive cups and held for 4 h prior to calculating percent mortality. This provides a relatively simple, inexpensive, and extremely rapid resistance assessment which can be used by most PCAs. The drawbacks to this technique include the requirement for collection of larvae of a specific stage and the inability to measure larval resistance against those pesticides which must be ingested.

Although not yet available for the diamondback moth, attractant trap assays for monitoring both resistance development and population dynamics have been constructed for other vegetable crop pests. These traps are similar in that they have

pesticides impregnated in the polybutene sticker used to hold the adults captured. In addition, these techniques all require a substantial amount of developmental effort; effects of insect age, time of capture, and bioassay for mortality, etc. need to be determined. In some cases, if the adult is not the target stage, relationships between adult resistance and target stage resistance must be established. However, once available, they can provide a rapid and accurate assessment of resistance to contact pesticides. Like the residual vial technique, the attractant traps may be most efficient when used with a discriminating dose. Sanderson et al. developed such a technique for dipterous leafminers, *Liriomyza trifolii* (Burgess), using yellow sticky cards.[69] Pheromone-baited traps have been used successfully in vegetables to monitor insecticide resistance in *S. exigua*[70] and the tomato pinworm, *Keiferia lycopersicella* (Walsingham).[71] At least in the case of *S. exigua*, the attractant trap technique has been built into a sequential sampling program which maximizes the input effort by minimizing the numbers of traps and adult moths required to reach a decision on the potential effectiveness of a pesticide.[72]

III. REPRESENTATIVE PROGRAMS

A. TOMATOES: COMPARING SAMPLING PROGRAMS IN FLORIDA, CALIFORNIA, AND SINALOA

1. Economic, Horticultural, and Environmental Information

Tomatoes destined for the North American market are grown primarily in California, Florida, and in the state of Sinaloa on the west coast of Mexico. The value of the tomato crops in each of these areas exceeds $100 million annually; in Sinaloa alone the tomatoes grown on 50,000 ha are valued at nearly $1 billion each year.[73] Unlike Florida, where primarily fresh market tomatoes are produced, California and Sinaloa have extensive plantings of processing tomatoes. Although many arthropod pests feed on both processing and fresh market tomatoes, the impact of each specific pest can vary between the two types of tomatoes, and the following discussion focuses primarily on sampling programs in fresh market tomatoes.

Horticultural conditions which affect sampling strategies vary between locations. In Sinaloa and Florida, fresh market tomatoes are grown in a "staked" or "trellised" fashion. In addition, the tomatoes grown are indeterminate varieties, producing fruit continually over several months. While a few hundred acres are grown in a similar fashion in southern California, most tomatoes are bush-type (nonstaked) determinate cultivars, which are harvested only once. Thus, sampling strategies in Florida and Mexico need to take into account that all stages of fruit may be present at the same time. Most of the tomatoes in both California and Florida are produced during a single crop each year (summer in California, winter-spring in Florida; spring and fall tomatoes may still be planted, but on much less acreage), while most growers in Sinaloa plant three overlapping crops in the fall, winter, and spring. This pattern of cropping in Sinaloa allows exceptionally large pest populations to build up by the spring planting. Further, irrigation practices differ, with increasing acreage in California and Florida using drip systems, and Sinaloa growers relying on furrow irrigation. Environmental conditions also are variable, with Florida and Sinaloa experiencing occasional rainfall and high relative humidity, while California's tomatoes are grown during the dry season when rain is uncommon and humidity is low.

Selection of tomato cultivars is inconsistent within each area, and often does not overlap between locations. Several studies have documented variable susceptibility of selected cultivars to key arthropod pests.[74,75] Any factor which changes the acceptance or suitability of a crop has the potential to alter how the pests are distributed in the

field. This phenomenon, which has been described for environmental and cultivar effects in other vegetable crop systems, causes substantial changes in fixed-precision level sampling programs.[76]

In addition to the horticultural and environmental differences between tomato production areas, differing political and societal influences have substantial effects on sampling programs. In the U.S., considerable effort is made to increase the efficiency of each sampling procedure in an effort to cut sampling time (cost) to the bare minimum. In Sinaloa, the situation is quite different. Many of the tomato growers are subsidized by the government because they provide not only an important "balance of trade" item with the U.S. and Canada, but also because they hire a substantial proportion of the population in the region.[77] In fact, much of the labor force lives on site in villages established by the grower. In comparison to the U.S., labor costs are dramatically lower in Mexico. As a result, labor in Sinaloa for sampling is readily available. This availability of labor allows the employment of sampling procedures which would be economically prohibitive in the U.S.

2. Key Arthropod Pests of Tomatoes

a. Helicoverpa, Spodoptera, *and* Trichoplusia *Species*

Some of the key arthropod pests of tomatoes and their relative importance in each tomato production area are listed in Table 1. Interestingly, at some locations the armyworms, fruitworms, and loopers are often sampled as a group, probably in an effort to minimize the training and sampling time required for identification.[78] This occurs despite the different feeding behaviors exhibited by each of the species. Even though all of these species can feed and successfully mature on foliage alone, they have divergent feeding strategies on fruit. For example, the tomato fruitworm, *Helicoverpa zea* (Boddie) (Lepidoptera: Noctuidae), may penetrate a fruit as a first instar, completely hollow out the fruit, and later emerge as an adult. Most *H. zea* larvae probably feed in two or three fruit during development. In contrast, the beet armyworm feed on ten or more fruit, penetrating half a body length into each fruit one or more times. Once the epidermis of a fresh market fruit is injured, the fruit is essentially unmarketable. Thus, for fresh market tomatoes, *S. exigua* would seem more damaging. However, mortality rates for first instar *S. exigua* often exceed 95%, possibly due to their positively phototactic behavior and susceptibility to UV radiation.[79] For processing tomatoes, the internally feeding fruitworms become economically significant contaminants while injury caused by the beet armyworm frequently heals and allows normal harvest and processing.

Sampling programs for the immature stages of armyworms and fruitworms are quite variable between the three production areas. In Florida the fields are partitioned into 1-ha sections and six contiguous plants from each section are sampled twice weekly. The suggested action threshold (essentially equivalent to an ET) is one larva per six plants in the prebloom stage.[80] After bloom, detection of any eggs or larvae is enough to trigger treatment.[81] In California, fields are divided in 4-ha sections and 25 plants are arbitrarily selected and sampled weekly in each section.[82] The suggested ET for fruitworms is 5% of the plants with first to third instar present. For armyworms, the ET was set at 20% of the plants with first to third instar present. In all locations, most of the sampling effort is expended in finding the small larvae because (1) pesticidal control is more effective than for larger larvae, (2) damage potential increases with increasing size, and (3) large larvae of the beet armyworm become negatively phototactic, hiding below ground or in the densest foliage in the canopy.[83]

In Sinaloa, *S. exigua* eggs and larvae were sampled in large experimental plantings by examining 60 to 120 plants per hectare on a diagonal transect.[84] In large-scale

TABLE 1
Relative Importance of Insect Pests of Tomatoes in Florida and California, U.S., and Sinaloa, Mexico[a]

Pest species	Location		
	Florida	California	Sinaloa
Armyworms and fruitworms			
Beet armyworm *Spodoptea exigua* (Hübner)	XXX	XXXX	XXXX
Tomato fruitworm *Heliocoverpa zea* (Boddie)	XXXX	XXX	XXXX
Southern armyworm *Spodoptera eridania* (Cramer)	XXXX	X	X
Cabbage loopers			
Trichoplusia ni (Hübner)	XXX	XX	XX
Tomato pinworm			
Keiferia lycopersicella (Walsing.)	XXXX	XXXX	XXXX
Leafminers			
Liriomyza trifolii (Burgess)	XXXX	XXXX	XXXX
Liriomyza sativae Blanchard	XX	XX	XX
Aphids			
Potato aphid *M. euphorbiae* (Thomas)	XX	XXX	XXX
Green peach aphid *Myzus persicae* (Sulzer)	XX	XX	XXX
Thrips			
Western flower thrips *Frankliniella occidentalis* Pergande	X	XX	XX
Tobacco thrips *F. fusca* Hind.	XX	XX	XX
Stink bugs			
Southern green stink bug *Nezara viridula* L.	XX	XX	X
Whiteflys			
Sweetpotato white fly *Bemisa tabaci* (Gennadius)	XXXX	XXX	XXX

[a] XXXX = highly significant; X = nonexistent or unimportant; see text for documenting references.

commercial operations, current recommendations suggest monitoring 10 m of plants in rows 1, 5, and 10 on each side of the field, and a minimum of 100 plants from the central portion of the field.[85] An ET of one larvae per four plants is used. For *H. zea*, finding four or more viable eggs (not parasitized) in an arbitrary sample of 30 leaves from each station is enough to require implementation of pesticidal controls. Numbers of parasitized eggs from each station are also recorded as a measure of the effectiveness of *Trichogramma pretiosum* (Riley) releases. The sampling procedure in Sinaloa is the only fresh market program that routinely calls for assessment of egg parasitism.

Although the larval stages of *H. zea*, *S. exigua*, and *T. ni* are most commonly sampled, information on adult migrations and generational peaks also can be useful.[86,87] Regional trapping strategies provide information on the beginning and end points of emergence and flight activity.[88] Such data can be helpful in determining the probable onset of oviposition by *H. zea*[89] or *S. exigua*[90] in tomatoes. Often, the development and maintenance of regional trapping systems are not feasible given the resources of a single PCA. However, regional information may be available from state

or county offices, loose networks of cooperating PCAs, or from the larger grower operations. Even the use of individual traps can be beneficial, providing some information on adult appearance and movements.[91] However, many of the same caveats mentioned earlier (sorting time, multiple species catches, environmental effects, etc.) for adult sampling apply here.

Despite the availability of pheromone trapping technology for more than 10 years, relatively few statistically accurate sampling programs have been based on this technique. An exception is the program developed by Brewer and colleagues[92,93] to monitor the occurrence of pyrethroid resistance in *S. exigua*. The program required the development of a considerable amount of background information, including a discriminating dose of fenvalerate in the sticker of pheromone traps (that is, a dose which will kill nearly all susceptible adults but few of the resistant moths) and information of the relationship between adult and larval resistance. Using this information, a sequential sampling plan based on the sequential probability ratio test[94] was constructed. The technique allows populations to be rapidly categorized as resistant or susceptible with a high degree of reliability. Several significant advantages were realized with this approach: (1) determination of probable field failure of the pesticide could be made prior to application, (2) sample sizes, and thus cost and effort, could be minimized, and (3) the rapidity of the test provided more timely information on resistance levels than the use of a topical application method. The use of such techniques is likely to become increasingly important as the availability and use of pesticides declines. However, this approach has some substantial drawbacks that include the need for a large amount of developmental effort and the probability that a practical relationship between insecticide resistance levels in the adult stage and larval stage may not be available for many pest species.

b. Keiferia lycopersicella *(Walsingham)*

The tomato pinworm is frequently the single most damaging pest in tomatoes. High populations of this cosmopolitan gelichiid moth can result in the abandonment of entire fields prior to harvest. Although larval mining and folding of leaves cause substantial reductions in photosynthetic activity,[95] most of the injury is caused when the larvae penetrate the tomato fruit, often just beneath the calyx.

To date, attempts to model the population dynamics of *K. lycopersicella* in fresh market tomatoes have not been successful. Such models have been used effectively for many years in other crops to predict the occurrence and development of key pest species.[96] Despite considerable background information on the growth and development of *K. lycopersicella* at different temperatures and on various stages of plant growth,[97,98] and knowledge of temperature relationships between local weather stations and within the tomato canopy,[99] no models have been published. In southern California, variation in larval development and survival due to local environmental conditions has resulted in models too complicated for practical application (Trumble and Wiesenborn, unpublished). For example, air pollutants such as ozone dramatically affect plant chemistry, which will allow an increase in *K. lycopersicella* developmental rate by up to 10%; survival can more than double.[100] Interfield migration and large irregular immigrations also tend to confound efforts to model local populations.

Like the lepidopterous pests previously discussed, most sampling plans for *K. lycopersicella* rely on assessment of the larval stage. In Florida the fields are divided into approximately 1-ha sections and six plants are counted in each section. Initially, the number of larvae and mines are counted on all foliage when plants are small (with zero to three true leaves present), or the top three or four leaves (three or more true leaves present) as plants increase in size.[101] More recent recommendations have been modified to include whole-plant counts when zero to seven true leaves are present,

and leaf samples from the lower portion of the tomato canopy. The latter change was made in response to some within-plant distribution analyses conducted by Pena,[102] who determined that the most statistically reliable estimates of populations could be achieved from sampling the lower half of the canopy. The ETs currently proposed include 0.7 larvae per plant for whole plant samples (< 7 leaves), and 0.7 larvae per leaf for plants with more than seven true leaves.[103]

Recommended ETs are much lower in California and Sinaloa than in Florida. In California, several recommendations have been tested. Using the previously mentioned sampling procedures for California, Toscano et al.[104] field tested a threshold based on percent infestation: if 5% of the plants had live, unparasitized larvae, treatments were considered justified. The resulting savings over a weekly spray schedule were substantial. This provides an example of one of a small group of successful sampling plans that were designed for convenience and practicality, rather than on extensive previous research showing statistical relationships between insect counts and population density or damage. However, even this approach requires fairly extensive experience with the pest-crop relationship. The drawback of this method is that although the savings were substantial with the 5% infestation EIL, potential additional savings generated by higher EILs may have been lost. More traditional approaches also have proven successful in California. Wiesenborn et al.[105] determined that a threshold of 0.5 larvae per plant provided a superior economic return over weekly or biweekly treatments, or the use of higher or lower larval ETs. In Sinaloa, a modified treatment level of 0.25 larvae per plant along 10-m sections of row provided a significant reduction in *K. lycopersicella* damage over grower practices, leading to a substantial economic benefit.[106]

Unlike Florida and California, labor costs in Sinaloa allow sampling for *K. lycopersicella* eggs. Because the eggs are small, ~1 mm, and placed between trichomes on the abaxial side of the leaf, locating and counting them requires both patience and time. Random removal and examination of 30 leaves from rows 1, 5, and 10 for each side of a planting, as well as an additional sample from a central location, can provide useful information on the oviposition and parasitization rates occurring in the field. This type of datum can be particularly useful if a pheromone confusion control technique is being employed. When pheromones are applied over large areas, collections in pheromone-containing traps are often reduced, and insect pest populations may still be high in the foliage. This egg sampling strategy has proven effective in Sinaloa for determining the degree of success offered by a pheromone confusion program for *K. lycopersicella*.[107]

Pheromone traps as sampling tools for *K. lycopersicella* have been used with mixed success. Van Steenwyk et al. developed an ET of 20 moths per trap per night in California which worked in experimental plantings. A statistically significant relationship was presented between adult numbers in traps and larval numbers per plant. Unfortunately, when subsequently tested on large-scale plantings, no relationship could be established.[108] In Sinaloa, the potential use of an ET based on pheromone trap catches has not been considered practical because populations often exceed 20 moths per trap per night prior to transplanting.[109] Nonetheless, pheromone traps can be used to determine the onset and termination of major migrations and generational peaks. In addition, pheromone traps with insecticide-impregnated inserts have proven effective in documenting pesticide resistance levels in California and Sinaloa.[110]

c. Liriomyza *Species of Leafminers*

Few insects in tomatoes have been as intensively studied as the leafminers *Liriomyza trifolii* (Burgess) and *L. sativae* Blanchard. These insects damage tomatoes by mining in the palisade mesophyll tissue of the leaf. A single mine can cause a

reduction in photosynthetic output of a leaflet of more than 60%.[111] However, documenting an EIL for leafminers has proven difficult, partly due to an excess in photosynthate production by the plant (see Trumble et al.[112] and references therein). Regardless, high population densities can cause premature leaf abcission, resulting in excessive leaf loss, potential reduction in fruit size, and "sunburn" of the fruit.

Although these insects are frequently held below economic densities by a complex of parasitic Hymenoptera, the use of many agrichemicals for control of lepidopterous pests can selectively remove the natural control agents, allowing the *Liriomyza* species to increase dramatically.[113] Thus, the most effective sampling plans survey for both the leafminers and their associated parasites. The potential value of the parasites is such that a rapid resistance monitoring technique based on pesticide residues in vials has been developed for some key parasite species.[114]

Sampling programs based on the larval, pupal, and adult stages of leafminers are available. In Florida and California, the larval populations have been quantified using foliar searches. Initial attempts to use total numbers of mines per plant[115] have proven less practical than counting numbers of live larvae on just a portion of the plant.[116,117] Not only are whole-plant counts of all mines on large tomato plants time consuming, but first instar mines are difficult to detect. In addition, not all leaves with leafminer damage are abcissed; as a result, the irregular accumulation of empty leafmines or even new leafmines contained parasitized larvae can trigger an unnecessary treatment. In Florida, most scouts seemingly have adopted a sampling strategy whereby live larvae, or live and dead larvae, are counted on (1) all shoots if plants have zero to two true leaves, (2) the terminal trifoliate of the third fully expanded leaf from the top of the plant (prebloom), or (3) the terminal trifoliate of the fourth fully expanded leaf of each plant in a six-plant sample (postbloom).[118,119] The practicality of the latter program is increased by using these same leaf samples for counts of aphids and eggs of the lepidopterous pests.

The larval counting technique generally requires examining each larva with a hand lens or microscope, and can be time consuming until the observer becomes proficient in discriminating between live, dead, and parasitized larvae. However, Schuster and Beck[120] recently developed a presence-absence procedure which minimizes sampling time. A significant linear relationship ($R = 0.99$) between larval numbers and the proportion of infested leaf samples allows a rapid estimation of leafminer larval population density. The procedure is most effective when populations are < 1.6 larvae per the terminal three leaflets. Above this density, the regression is no longer linear.

In California and Sinaloa, a trapping system has been designed to take advantage of the leafminer larval behavior of dropping from the leaves to the ground just prior to pupation. Johnson et al.[121,122] determined that inexpensive styrofoam trays ($12'' \times 8''$, $\sim 1¢$ each) placed beneath tomato plants would capture larvae in proportion to the numbers of larvae in the foliage. Because the key parasite species in California kill the leafminer larvae before they exit the leaf,[123] the tray technique also integrates information on leafminer parasite activity. If new mines are developing in the foliage, but few leafminer larvae or pupae are found in the trays, then the parasites are effectively suppressing the leafminer populations.[124]

The efficiency of the tray technique has been refined by determining the spatial dispersion of the leafminers using Iwao's[125] and Taylor's[127] regression techniques.[127] Both regressions provided a good fit to the data, with no significant variation in slope coefficients between years. Using the coefficients from Taylor's regression, constant precision level sampling schemes were generated that can be used to obtain rapid and accurate estimates of larval density with minimal effort.

The tray technique is not without problems. In Florida, the parasite populations include some species that emerge from *Liriomyza* pupae.[128] Thus, overestimates of leafminer populations based on numbers of larvae and pupae in trays could result in an unjustified treatment. In California and Sinaloa, occasional high winds and/or rain may artificially reduce collections. The losses due to the overflow of rainwater can be mitigated by using a fine screen to allow water, but not larvae, to pass through the trap. However, a design suitable for the extensive rainfall in Hawaii has been developed (M. W. Johnson, personal communication) that will largely alleviate this problem.

Adult trapping with colored sticky cards has evolved substantially since the technique was first reported as suitable for rapid detection of leafminers by Musgrave et al.[129] in 1975. Several researchers established that yellow cards collected adults more efficiently than other colors.[130,131] The height of trap placement in the canopy and time of day were determined to influence trapping efficiency; *L. sativae* was trapped most often in the centrally located traps while *L. trifolii* was found more commonly on the lowest traps.[132] An unintentional selection of species by trap placement could be of considerable significance, as the pesticide resistance profiles of these two pests differ substantially.[133] In California, a relationship between larval/pupal numbers on trays and subsequent adult collections (2 weeks later) on sticky cards has proven suitable for predictive purposes ($R^2 = 0.77$ to 0.97).[134] More recent studies in Florida also have found a strong correlation between adult counts in the foliage and sticky trap collections ($R^2 = 0.87$ to 0.93).[135] However, the latter two studies were conducted on research plantings, and need to be validated for use in large-scale tomato production.

The usefulness of yellow sticky traps may be extended by employing the technique for pesticide resistance monitoring. This procedure, in which insecticides are incorporated in the polybutene sticker, has proven effective for several contact insecticides, including chlorpyriphos and permethrin.[136,137] However, development of this method is tedious, requiring information on effects of duration of exposure, amount of sticker needed, insect age, size and sex, and relationship to standard topical bioassay procedures. In addition, this approach still needs to be validated in large-scale tomato plantings.

Like other trapping systems utilizing polybutene stickers, yellow sticky traps are not without problems. The sticky material can lose effectiveness if large numbers of flies are caught, or if dust or debris collects on the trap. Many other insects, including aphids and thrips, are attracted to the color yellow, and may make counting difficult. Finally, the technique may meet resistance from some PCAs who dislike working with stickers or paying a premium for commercially available cards.

d. Other Arthropod Pests

A wide variety of additional pests attack tomatoes. Most of these use similar types of sampling programs, including visual searches of foliage, pheromone trapping, or colored sticky cards. Some insects, such as *Bemesia tabaci* (Gennadius), recently have become major pests, and have not had statistically valid sampling plans verified for commercial fields. Most of the effort to date has focused on providing control, rather than determining thresholds or population distributions. One sporadic pest, the tomato russet mite, *Aculops lycopersici* (Massee), can develop populations capable of killing tomato plants in a very short period of time. Because the pest is quite small, detection is usually made when mite populations have begun to cause noticeable plant stress. Other pests also occur intermittently, including thrips, stink bugs, flea beetles, etc. Because many of these pests can occur in localized areas in the field, most

vegetable crop PCAs vary the pattern of sample collection such that the entire field is surveyed a minimum of once every 2 weeks.

B. STRAWBERRIES: COMPARING SAMPLING PROGRAMS IN CANADA AND CALIFORNIA

1. Economic, Horticultural, and Environmental Information

Strawberries are grown throughout North America, including: Ontario and British Columbia, Canada; California, Florida, Louisiana, Michigan, Oregon, and Washington in the U.S.; and Baja, Mexico. California is the largest producer, with over 68% of the total market share.[138] With the exception of California, most strawberries are planted as multiple-year crops, often held for 3 to 6 years. Usually there is little production during the first year. Nonetheless, the plants must be protected from arthropod damage. In northern California, most plantings are maintained for just 1 or 2 years, with harvests during the late winter and spring. In southern California, plantings are annual, with most crops planted in October, harvested from December through May or June, and then removed. A second summer crop may be planted in June and harvested from August until early October, when they will be removed in preparation for the winter planting. Thus, the horticultural and environmental conditions are more diverse than for most other crops.

2. *Tetranychus urticae* (Koch)

The primary arthropod pest of strawberries throughout the world is the two-spotted spider mite, *Tetranychus urticae* (Koch) (Acari: Tetranychidae).[139-141] This pest, which feeds on the foliage and not the fruit, causes significant yield decline through a reduction in photosynthate production.[142] Other pests include a complex of aphid species, which can affect yields through plant stress, but primarily reduce yields by contaminating the fruit with honeydew.[143] Thrips, earwigs, tomato fruitworms, lygus bugs, and several other arthropods are occasionally of regional importance. Sequential sampling plans have been developed for a few of these pests.[144,145]

The potential profits from strawberry production justify a substantial research effort. However, most initial research focused on chemical control strategies. Subsequent studies were intended to document within-plant distributions for the purpose of building practical sampling strategies for commercial fields. As a result, the earliest sampling plans were designed for collecting foliar counts of *T. urticae* from small plots where intensive sampling could be used to determine population densities with a high degree of precision. Because foliar counts of all life stages generally require the use of microscopes, leaves are usually harvested, placed in bags either singly or in groups, and transported to the laboratory where they usually were held at 4°C.[146,147] Unfortunately, leaves in cold storage undergo a combination of dehydration and discoloration due to oxidation and hydrolysis of starches to sugars that can make counting difficult if leaves are held beyond 24 h.[148] In addition, movement of mites between leaves collected in groups either during transportation or after removal from cold storage, could confound results. Problems with spider mite movement and leaf deterioration were solved, in part, by dipping the leaves in inexpensive floor wax; the wax "fixed" the mites to the leaf, stopped development, and preserved the leaves for examination for at least 2 weeks.[149] However, the key complications of labor costs and slow data collection were not eliminated.

Attempts to reduce sampling effort by using mite brushing machines[150,151] or an imprinting technique[152,153] were not completely successful. The mite brushing machines, which use opposed, rotating bristles to brush the mites from detached leaves onto a collection plate, also accumulate plant hairs, dust, spider mite webbing, and

associated trash. Discriminating and counting all the mite stages can be difficult. In addition, the technique still requires separate samples for each location to prevent spider mite movement during transport, and examination under a microscope. Nonetheless, in many circumstances, the mite brushing machines provides a significant improvement in sampling efficiency over foliar counts.

Although the time-consuming use of a microscope could be eliminated with the imprinting technique, discrimination between life stages of the spider mites is not possible. For the imprinting procedure, leaves are pressed into a filterpaper disk impregnated with a protein sensitive dye (bromo phenol blue) and the protein from the crushed mites produces a green response on the yellow paper. This procedure, which is extremely rapid if flat plates capable of holding the filterpaper disks are mounted on pliers, has proven most effective for determining the presence or absence of pest populations. High numbers of *T. urticae* cause overlapping stains, making numerical determinations impossible.[154]

Not surprisingly, all of the techniques requiring spider mite counts on foliage are difficult to employ effectively on large-scale commercial plantings. However, several researchers have used these techniques to determine the distribution of *T. urticae* in strawberries. From this information, several binomial (presence-absence) sampling plans have been developed that seemingly have gained acceptance in commercial production. Raworth[155] initially used foliar counts in untreated experimental plots to determine the coefficients of Taylor's power law,[156] and then developed a binomial sampling approach using Nachman's[157] statistical procedures. A predictive relationship was found between spider mite density and the proportion of uninfested leaflets sampled. Because the PCA can simply pull leaflets and examine them for presence of the pests, and the time-consuming laboratory pest counts are eliminated, this technique allows rapid and timely estimates of population density.

Binomial sampling programs in strawberries have been refined further by accounting for within-plant variation in population distribution. Reports from New Zealand and California have agreed that *T. urticae* populations prefer mature leaflets on plants.[158,159] Selection of mature leaflets from a predetermined location (basal, middle, or upper strata of the canopy) provides a sampling unit that has a relatively constant proportion of the population to be sampled.[160] Therefore, variability (and thus sampling time and costs) can be reduced by selective choice of leaflet location. Both Butcher et al.[161] and Trumble[162] used this information to develop presence-absence sequential sampling plans based on thresholds of five to seven *T. urticae* per leaflet and the statistical procedures of Wilson and Room.[163]

The sampling program in California has been complicated by the determination that *T. urticae* populations change distribution over time and following pesticide application.[164] Initial immigrant females are dispersed randomly, but with the production of offspring, spider mite populations become highly aggregated; a few plants have substantial numbers of mites while most have none. The population distribution subsequently becomes increasingly random as populations continue to increase and the mites disperse, infesting more of the available plants. Following pesticide application, small numbers of mites typically survive on many plants, allowing population regeneration from a relatively randomly distribution. Because the dispersion changes following pesticide use, a second sequential sampling plan was devised for post-treatment assessment.

This latter example points out a common flaw in many sampling programs for vegetables. If sampling plans are developed from fields that are not treated using commercial practices, the assumptions (distribution coefficients) used to create the program may be in error. In the case of strawberries, the use of the sampling program

designed for aggregated, pretreatment populations would overestimate post-treatment spider mite density. As a result, additional and unnecessary pesticide applications would be recommended. In addition, many pesticides can dramatically affect pest behavior and development,[165-167] which in turn will impact distributions. Development of potentially inaccurate sampling programs is probably a common occurrence because many researchers do not have access to commercial application equipment or to the protective supplies needed to safely work in pesticide-treated fields. In terms of overuse of pesticides, environmental contamination, and human health concerns, the costs of overestimation of pest populations are probably quite significant.

The sampling programs that are employed in strawberries and many other crops probably need revision on a frequent basis. At every production location, different cultivars are used for a few years and then fall out of favor. This shift in cultivar preference by growers is of considerable importance because cultivars can vary substantially in their resistance to *T. urticae*.[168,169] While little is known of the impact of cultivar variability on pest dispersion, it seems reasonable that any factor that changes attractiveness, within-plant location, or suitability of a crop for a given pest has the potential to alter within-field distribution, thereby effecting sampling programs. This may explain in part why sampling plans developed at one location may not be transferable to another geographic area.[170,171]

IV. CONCLUSIONS

Universal sampling programs suitable for all vegetable cropping systems do not exist. Variation in environmental and horticultural conditions, the cultivars planted, pesticidal effects on arthropod distribution, and pesticide-induced behavioral changes, etc. can influence how pests are sampled. However, there is a clear trend toward development of binomial sampling procedures; these are the most readily accepted by crop protection consultants. Unfortunately, suitable relationships between infested and uninfested plants or plant parts cannot be, or have not been, documented for all pests. Therefore, many of the other methods described in this chapter are still in common use. Also, regardless of how sophisticated the sampling technique for the key pest or pests, the presence of a wide variety of other arthropods on most vegetable crops insures that failure to periodically examine the entire field will result in reduced productivity. Finally, the available literature is filled with papers describing sampling plans which will never be used commercially; failure to validate a proposed sampling plan in large-scale commercial operations is probably the single most important reason that such programs are not adopted.

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