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IPM: overcoming conflicts in adoption

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The diversity of competing interests in North America provides a remarkable series of divergent messages to growers. Depending on what crop they produce or how they farm, they may be heroes or villains, loyal or unpatriotic, or stewards or ravagers of the environment. Even relatively minor changes in farming practices can result in significant public or political response. Considering that growers may risk 100% of their crop yield on a potential savings of 10% (or less) for investment in pesticides, it is not surprising that growers are slow to adopt IPM programs. Well-intentioned appeals to eliminate pesticides, or save the environment at all costs, are usually not effective. Likewise, a high failure rate can be expected from attempts to legislate IPM, implement programs that focus on only part of a pest complex, or adoption strategies that do not include on-farm testing and extensive educational efforts. However, some strategies have proven effective. Growers who have experienced loss of pesticides due to resistance are receptive to management programs which avoid or delay resistance. Many programs have been adopted piecemeal, starting with sampling programs followed by treatment thresholds and modified pesticide use. One of the most successful approaches has been an economic comparison of grower standard and IPM programs using partial budgets. Increased net profits provide powerful incentives for program adoption.

Keywords: integrated pest management; economics; partial budget; sustainable agriculture

Introduction, definitions, goals

This discussion focuses on the problems and techniques for implementing sustainable integrated pest management (IPM) programs in large-scale, commercial agriculture. The literature is replete with reports about how to develop specific aspects of these programs such as sampling or chemical tactics. However, relatively little information is available on why apparently viable programs have not been adopted or on approaches for convincing businesses to embrace these practices (Hamilton *et al*., 1997). A first objective therefore is to discuss some of the reasons why growers are reluctant to rapidly implement IPM programs. A second objective is to identify specific techniques which have been effective, those which have not worked, and those that remain unproven but have promise. To achieve these objectives, the meaning of IPM must be clarified.

There are many different definitions for IPM and for sustainability. For the purpose of this review, such programs can be defined as using the minimum amount of pesticide to achieve an acceptable profit. In addition, this goal should be accomplished with the least damage to the environment while mitigating potential for human health concerns. One further goal is to reduce, and as much as possible eliminate, the development of pesticide resistance. Achieving such goals may require the use of beneficial arthropods, resistant varieties, a reduction of soil compaction and fossil fuel use by minimizing the number of trips through the field, reduced water use and improved water reclamation strategies, etc. Not all such strategies may be necessary in every cropping system, so the definition is intentionally broad.

In order to understand the difficulties in implementing sustainable programs, it is necessary to examine the issues from the farmer's perspective. As a group, farmers are receiving wildly divergent messages from our society. Summarized in their simplest form, some messages categorically state that farmers are heroes, others castigate them as villains. Often, the same special interest groups are providing both messages. These mixed messages are predictably confusing, often leading growers to maintain the status quo rather than take perceived risks in farming practices which might result in another barrage of media stories, journal articles, lawsuits, and reports which are critical of their actions. A few examples of these groups and their messages follow.

Agricultural scientists and ecologists. Concerned scientists are telling farmers (and anyone that will listen) that the worlds food supply is inadequate to feed the developing human populations. In spite of the impressive gains in productivity during the green revolution of the past few decades, over one billion of the six billion people in the world are undernourished (Abernathy and Pimentel, 1995). During the green revolution period in the 1950s and 1960s, introductions of new fertilizers, novel pest control strategies, hybrid grains, etc. greatly expanded the worlds food supplies. However, there are limits to this technology: the addition of over 250 thousand people each day has out

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paced food production (Pimentel, 1996). As an inevitable result, the per capita world food supply has been in decline for at least 10 years (Abernathy and Pimentel, 1995). Farming, therefore, will only increase in importance as the survival of huge portions of humanity becomes an acute problem, dependent on dwindling food reserves. In this situation, overproduction of basic foodstuffs will be a thing of the past. Farmers are aware that the knowledge and abilities they possess will be instrumental in minimizing this impending catastrophe. Thus, pressure will be mounting to produce more food. While it will be desirable to produce more with less, which is consistent with an IPM philosophy, critical food shortages can be expected to promote a doctrine of more production at any cost.

Economists. In many states, agriculture is a major economic force which not only produces income, but serves as a major employer. In California alone, gross farm revenue exceeds $20 billion per year, which adds approximately $65 billion annually to the state's economy (Carter and Goldman, 1996). With $11 billion in exports to other countries, farmers are an important component in our balance of trade. Although less than 1% of the human population are farmers, even California's agriculture generates nearly 1.2 million jobs (Carter and Goldman, 1996). While some of these jobs are seasonal, many are full-time positions with substantial income. Thus, as a group, farmers recognize that they are indispensable to the economic well-being of any country. In this context, acceptance of IPM practices will require documentation that broadly adverse economic implications will not result.

Politicians. In a disturbing trend, food is increasingly being used as a weapon. During 1997, the population in North Korea was facing famine after many years of poor harvests (Satterwhite, 1997; Tomlinson, 1997). The chronic food shortage had even reduced the physical stature of the average military recruit as compared to the genetically similar South Koreans. Gifts of food were badly needed. Both sides have now used food as a weapon (Dorn and Fulton, 1997). North Korean military officials began demanding food subsidies before they would agree to join in any peace treaty discussions. In essence, any chance at peace was held hostage until a food 'bribe' was forthcoming. Similarly, South Korea and her allies withheld food until a promise of attendance at peace treaty talks was made. While the use of food aid as a political tool to gain favor is not new, the use of food as a critical resource to be held or provided dependent on negotiations has rarely been employed in the past century. In this scenario, the farmer is critical to the peace process, and serves as an important national asset in international politics. It logically follows that more food production means more national power: therefore, food production is patriotic.

Scientists and environmentalists. Many scientists and environmentalists are warning of too much consumption of fossil fuels (we burn more than 40% more fossil fuel than the total amount of energy captured by plants we grow) (Pimentel, 1996). Fertilizers, which are responsible for much of the last green revolution, allowed people to move from farming to other livelihoods but apparently are responsible for significant petroleum use and for the present concerns with nitrification (Vitousek *et al*., 1997). In addition, farmers are being told they are responsible for much of the documented soil erosion; 30% of the worlds arable land has been reportedly lost to erosion associated with farming (Kerns, 1997; Pimentel, 1996). Thus, farming has been vilified in the scientific press and in the mass media as one of the primary causes of our current environmental problems. Such concerns may provide an impetus for acceptance of sustainable IPM practices by some growers. Other farmers may find the barrage of negative publicity so annoying that they ignore any environmental messages.

Urban populations. In spite of an absolute dependence on farm production, urban populations often discover they are in direct conflict with growers. In some cases this takes the form of competition for resources. For example, on a worldwide basis, approximately 85% of the fresh water needed by humans is used in agriculture (Pimentel *et al*., 1996). Increasing urban populations, and the comparatively large number of representatives they elect, frequently assert pressure for 'their fair share' of limited water supplies (Moore and Dinar, 1995; Rosegrant *et al*., 1995; White, 1994). Land use and availability can also be an issue. Local governments in urbanized areas are enacting 'green belt' laws to limit loss of agricultural land, but as urbanization in surrounding areas develops, the probability of having a housing tract next to an agricultural area is increasing. This urban-agriculture interface is a fertile source of contention. Many children and adults from urban backgrounds are attracted to large expanses of green crops, occasionally with undesirable consequences. Although fields adjacent to homes can be visually attractive, nearly every farmer who has a field at the urban-agriculture boundary can recite a litany of stories regarding lawsuits filed against them by their neighbors for perceived health or property damage. That's not to say that spray drift or misuse of pesticides does not occur. However, anecdotal evidence suggests that many of these concerns are not well grounded in reality. Regardless, a persistent concern from neighbors can promote the use of control strategies which are less toxic to mammals, if only for protection against litigation.

If, at some point, a grower determines that the land cannot be farmed profitably, and attempts to generate a final income through housing or business development, they are often sued to prevent the process. Most farmer-landowners take these responsibilities seriously, but many civic groups can cite examples of large growers unscrupulously dividing the land into tiny parcels in an area surrounded by much larger lots. This usually lowers the appeal, and thus the value, of the larger lots. The resulting animosity can be substantial. Such contentious relationships do not foster the acceptance of IPM practices as part of an effort to promote good neighbor policies.

Such issues can be complicated. Some people feel that we can no longer afford to lose arable farmland, and government agencies should step in to act as brokers or even caretakers to prevent such losses. Others have strong opinions that the local, state, and federal governments have no responsibility in this matter, and should not spend public monies on such undertakings.

State and Federal governments. Both state and federal governments are constantly adding new regulations and revising old laws to be more stringent. Keeping abreast of the changes is daunting for state and local officials, much less for a farmer who is already working well over a 40 hour week. California, which has its own Environmental Protection Agency, as well as a Department of Worker Health and Safety, has some of the most stringent regulations in the U.S.A. It has been estimated that over 20 pesticide-related bills per year are submitted to the legislature (Trumble, 1989). Some of these regulations inadvertently require the use of more petroleum-based fuels (digging and maintaining water catchment basins), or the use of additional water (leaching selenium from agricultural soils, etc.). Thus, they are sometimes in conflict with the goal of reducing consumption.

In the case of pesticides, a major law in CA that was introduced to reduce pesticide has just the opposite effect (Trumble and Parrella, 1987). The original intent of the law was apparently to foster biological control through limitations on pesticides. However, by limiting the registration of pesticides to a single pesticide for a particular insect on a given crop, growers were forced onto a pesticide treadmill. As resistance to the pesticide increased, control was reduced, and growers did not have the option of switching to other materials until control was demonstrably ineffective. In addition, they did not have the option of switching to materials which were not harmful to the natural control agents for other pests on the same crops. Thus, they applied the materials at higher and higher rates and with increasing frequency. Greater consumption resulted: the inevitable result was an increased pesticide load on both the crops and the environment. Not surprisingly, a secondary effect has been to cycle through pesticides rather rapidly.

Given (1) the potential for scientists, politicians and governments to appear friendly one day, and hostile the next, (2) the litigious nature of the U.S. society and (3) the love-hate relationship of the urbanized public, it is no wonder that farmers react cautiously to reports of new and often conflicting concerns. The tendency for many growers is to minimize their responses to new and untested strategies until proven effective. Thus, a self-defeating rationale develops; new ideas wont be used until commercially tested, and they cannot be tested commercially because growers are hesitant to try new strategies. However, this is not to suggest that growers will never try new approaches. The following sections highlight some of the approaches that have been attempted with variable degrees of success.

Implementation approaches with a low probability of success

Most farms are operated as businesses; owners must make a living for their families or a profit for their shareholders. In this context, it is unreasonable in most cases to expect strong responses to altruistic requests such as the following.

Appeals to protect the environment. Many farmers consider themselves to be better at assessing environmental problems on their farms than government agencies, any firm consisting of environmental lawyers, most university professors, and local environmental activists. With a few exceptions, these relationships are typically adversarial. Such interactions are occasionally elevated to the national level by the news media. Frequently the media reports on a plausible but poorly substantiated accusation against a chemical or even an agricultural commodity, which generates widespread concern. Unfortunately, the determination of cause and effect, which may follow a year or more of investigation, is not always widely reported to the public. For example, U.S. strawberry growers saw shipments decline dramatically in 1996 when media reports incorrectly attributed a *Cyclospora* spp. contamination problem with strawberries. Ultimately, the problem was found to be related to foreign imports of raspberries (Herwalt and Ackers, 1997). However, by the time the story was corrected, the strawberry season was nearly over and millions of dollars had been lost.

Appeals to eliminate pesticides. The general populace has a fear of pesticides, so appeals to protect human health by eliminating pesticides are popular and often gain support from elected officials. In several surveys, consumers have indicated that pesticides and pesticide residues are their most important concern in regard to food safety (Cuperus *et al.*, 1996; Pomerantz, 1995). This fear is exacerbated by disasters associated with pesticides. A metham sodium spill in the Sacramento River Basin which threatened drinking water supplies, the mrthyl-isothiocyanate release in Bhopal, India which killed thousands, and the ground water contamination in the central and northeastern United States, all have contributed to this fear. A National Academy of Sciences Report (Council, 1986) highlighting the potential for pesticidal contamination in vegetables, has brought this concern into nearly every household in the country. Our ability to detect residues at the parts per trillion level has aggravated this problem. Many consumers do not recognize differences in risk levels between parts per hundred and parts per trillion; they only recognize that no level of risk is acceptable. As a result, the percentage of the public responding positively to trusting production regulations for providing safe food dropped precipitously from 97.7% in 1965 to 45.8% in 1984–85 (Sach *et al.*, 1987). Not surprisingly there has been a resurgence in environmental concern by the general population.

Despite increased potential for health concerns from working directly with pesticides, most farmers have much less fear of these materials. This may be because they more frequently see the benefit of enhanced pest control. Growers often must wait years for a new pesticide to clear the safety analyses evaluated by EPA, and this agency assures growers that when used as directed the product is safe. Not surprisingly, a typical response to an appeal to reduce or eliminate pesticides is that the regulating agencies in the government have spent many years and a great deal of public money ensuring that the materials they use are safe. Because most growers are heavily invested in their business, they hope to remain in operation for an extended period of time. To insinuate that they are a threat to life if they use any pesticides is a sure way to alienate a farmer. Use of this strategy is likely to be interpreted to mean that they do not care for the welfare of themselves, their families, the people who work for them, and the people who eat their food. A hostile response should be expected.

Implementing IPM through legislative fiat. The difficulty in this approach relates to the definition of IPM. For example, the Clinton administration has a stated policy designed to foster IPM (joint U.S. EPA, USDA and FDA news release 0815093 on 21 September 1993). Under this policy, 75% of crop land in the U.S.A. should be managed using IPM strategies by the year 2000. However, the problem one faces is the definition of what constitutes IPM. Although there are many different definitions of what composes IPM, most have a recurring theme of maximum production or profit with minimal pesticide use and damage to the environment. Using just this portion of the definition, it would be easy to argue that wheat is already grown using IPM strategies because of the extensive use of resistant varieties against the Hessian fly. Undoubtably this practice reduces pesticide use dramatically. In alfalfa, many of the larger growers use strip cropping techniques developed by Stern *et al.* (1967), which maximize the benefits of biocontrol agents and thereby reduce pesticide application. For cotton, much of the acreage in the southern USA has been planted with transgenic varieties containing *Bacillus thuringiensis* toxin (Halcomb *et al.*, 1996). Similar field trials are in progress for releases of transgenic corn (Orr and Landis, 1997). One could argue that this constituted a major new IPM approach.

In fact, you could argue that IPM includes ANY use of sampling techniques, economic or action thresholds, use of a biorational material (*B. thuringiensis*, sabadilla, etc.), resistant crop varieties, biocontrol agents, non-chemical weed control, low mammalian-toxicity chemicals, transgenic plants, pheromones, etc., even in combination with the more conventional chemicals. Employing this definition, much of the crop land in the U.S.A. is already using IPM.

However, if you define IPM, in part, as the lowest possible use of 'conventional' chemicals (organophosphates, carbamates, pyrethroids, and other similar materials), then the picture changes dramatically. It is quite unlikely that by the year 2000, 75% of our crop land will be under IPM programs which permit maximum production with the absolute minimum use of pesticides, fertilizers, etc.

This is not to say that legislative actions have no merit. Any approach that improves the grower's and public's awareness of IPM will be valuable. However, 'toothless' legislation will have little impact. As a group, even growers that profess to utilize IPM practices believe that legislative mandates to implement IPM are not appropriate (Hamilton *et al.*, 1997). As described previously, even well-intentioned legislation, if poorly designed, can result in increased pesticide applications (Trumble, 1989).

Programs with too narrow a focus. The scientific literature is rife with papers documenting IPM or biocontrol programs which will never be adopted. Many of these were developed for a specific pest on a crop, rather than for the entire complex of pests. The proposed program may work for the particular pest, but often the recommended control strategy is incompatible with other pests (Campbell *et al.*, 1991). For example, releasing *Trichogramma* spp. for control of *Trichoplusia ni* (Hübner) on tomatoes may provide adequate control of this pest, but the strategy is compromised by the need for repeated pesticide applications for *Spodoptera exigua* (Hübner), *Keiferia lycopersicella* (Walsingham), *Heliocoverpa zea* (Boddie), *Macrosiphum euphorbiae* (Thomas), and *Liriomyza trifolii* (Burgess) (Oatman *et al.*, 1983; Trumble *et al.*, 1994). Without the development of control strategies for these pests that do not interfere with the effectiveness of *Trichogramma* spp. releases, the adoption of a narrowly focused IPM program will almost certainly be minimal.

Programs based on scientific shortcuts. Because generating all of the data necessary for an IPM program is so time consuming and tedious, there is a strong tendency to adapt parts of a program developed (1) in a different geographic location, (2) for a similar pest species or, (3) for the same pest in a different crop. All of these approaches have a high probability of failure. For example, assuming that because a sampling program works in one geographic region it will work in another is a common mistake (Trumble *et al.*, 1989). Even assuming that sampling plans will not change with age of the insect (Trumble *et al.*, 1989) or plant architecture (Trumble, 1993) can lead to significant errors. Because the application of pesticides can alter how pests are distributed in a field, failing to validate sampling plans in fields treated with pesticides can result in substantial over-estimation of populations (Trumble, 1985). Such over-estimation can lead to excessive applications of pesticide and subsequent selection for pesticide resistance.

Inadequate presentation and commitment. Even an excellent IPM program is likely to fail if it is only published in the scientific literature. In fact, the literature contains many programs that appear to be scientifically sound, but have not been implemented because the researchers that developed the program did not have the means or inclination to take the program to a commercial operation for validation and demonstration. Even with this step, a lack of persistence in presenting the material to growers through association meetings and extension forums can result in a loss of visibility and a failure to implement the program. A great deal has been written on the value of incorporating extension activities in the development and promotion of IPM programs. The reader is referred to the work of Gray and Edwards (Gray and Edwards, 1993) for additional information on this topic.

The apparent complexity of many programs, particularly sampling schemes, can be daunting. In most cases, growers and pest control advisors (PCAs, a.k.a. field scouts) are limited in the amount of time available for sampling. Anything which simplifies and speeds this process will be welcome, but in my experience, presentation of the math used to generate and validate the sampling technique will give the impression of unacceptable complexity. Thus, while some programs that minutely divide fields for site-specific farming offer significant advantages in resistance management and maintenance of biocontrol agents (Midgarden *et al.*, 1997), the extra work inherent in dividing large fields into 0.04 ha ‘management’ blocks will require careful justification to growers. Using this approach even a 50 ha field would then have 1250 independently-supervised management blocks. Similarly, IPM programs that require expensive equipment for geographic information systems, remote sensing, and photogrammetric engineering (i.e., Usery *et al.*, 1995), may face an uphill battle for acceptance.

Implementation approaches which have proven successful

Discussion of the impacts of cultural factors specific to any particular growing regions is beyond the scope of this paper. However, regardless of the approach taken, you must have an agreement between the PCA’s and the grower/management that any potential failure of the project will not jeopardize the PCAs job status. PCAs have often told me they would like to institute an IPM program, but if it fails it will cost them their jobs. In contrast, if a crop is lost because they could not control the pest, yet they applied every reasonable material in an attempt to suppress pests, the grower is much less likely to respond negatively. Thus, it is necessary to arrange an agreement between the grower and the PCA to the effect that any losses incurred during a test trial of the IPM program will not be blamed on the PCA. Using this approach, growers and PCAs can scale up from trials of a few hectares, to tens of hectares, to entire farms with an increasing level of confidence.

Concerns regarding pesticide resistance. Farmers take economic risks every time they plant a crop. Individually or in combination, weather, insects, pathogens, market forces, and many other factors can cause a crop to be unprofitable. Not surprisingly, farmers attempt to minimize risk whenever possible. One place where risk appears easily minimized is insect control. Traditionally, the risk of crop failure due to arthropod pests has been reduced by the extensive use of highly toxic, broad spectrum pesticides. As recently as the 1980s these pesticides were relatively inexpensive, readily available, and generally effective against most vegetable pests. Over 45.4 million kg of pesticides are used annually in California, one of the highest usage rates in the world (Calif. Dept. Food and Agric., 1989).

Not surprisingly, California’s U.S. $20 billion agricultural industry has been increasingly threatened by the development of pesticide resistance by many destructive pests (Georghiou, 1986; Georghiou and Lagunes-Tejeda, 1991). Such resistance results in major economic losses, increased pesticide usage, and a greatly elevated potential for environmental contamination and human health problems. Unfortunately, the excessive use of pesticides has led to insecticide resistance in insect populations, environmental and health concerns, and legislative actions which have ultimately reduced the number of chemicals available for use. These problems, coupled with evidence that many pesticides cause damage to plants which is not visibly evident, have been instrumental in opening the door to development and implementation of IPM programs. It is unfortunate, but often true, that growers do not perceive the risk associated with pesticide resistance until no effective chemicals remain, and crop losses result. However, once a grower or group of growers have experienced this problem, they become very sensitive to resistance development. Fear of the loss of effective pest control can offer a powerful motivation to growers.

The $20 million loss documented by California’s celery industry in the mid 1980s following the development of resistance by the leafminer (*L. trifolii* (Burgess) (Diptera: Agromyzidae)) to all available pesticides provides an excellent example (Calif. Celery Research Advisory Board, 1986). Similar problems have been identified for the beet armyworm, *S. exigua*, which has become a major pest of most vegetable and many field crops in California (Brewer and Trumble, 1991). Thus, the need has been adequately demonstrated to the vegetable industry that a more prudent approach would include a move toward less insecticide intensive pest management practices.

Stepwise introduction. Developing all of the information necessary for an IPM program typically takes many years. Often, several years are required for the development and validation of sampling programs (more for systems with multiple insects) (Theunissen and den Ouden, 1987). Accurate assessment of plant tolerance or compensation for pest damage, which is critical to development of threshold levels, is difficult and time consuming (Pedigo *et al.*, 1986; Trumble *et al.*, 1993). Investigations documenting the effects of biological control agents on key pest species, including potential introductions of new natural enemies, usually require a minimum of three years (Hoffmann *et al.*, 1990; Van Driesche and Bellows, 1996). If studies are included that examine the effects on beneficials and pests of registered and new compounds (Bull and House, 1983; Narayana and Babu, 1992), as well as alternative horticultural strategies, the time needed to complete a program and then confirm the results in a commercial setting can easily exceed ten years. If multiple cultivars or locations must be examined (Eigenbrode and Trumble, 1994), the process can be extended almost exponentially.

Thus, it's not surprising that most IPM programs are developed and implemented incrementally. Fortunately, each of these components can stand alone as a time or money saving approach for the grower through reductions of labor costs and/or unnecessary pesticide applications. An example of this is provided by the series of studies by Schuster and his colleagues starting prior to 1980 with sampling for pests of tomatoes, and culminating in 1993 with a practical and functional IPM program (Schuster and Pohronezny, 1993).

The unique case of the introduction of transgenic plants containing *B. thuringiensis* toxins deserves special note. Acceptance by cotton growers in the U.S.A. has been high despite concerns of (1) environmental activists and legislators (Nap *et al.*, 1996), (2) scientists concerned with potentially deleterious effects of outcrossing (Keeler and Turner, 1991), (3) scientists predicting resistance development with loss of effectiveness of commercially available *B. thuringiensis* products (Holmes, 1993) and (4) researchers noting the untested effects of products with marker genes in transgenic plants (Ozcan *et al.*, 1993). For products that are not eaten by humans, the probability of accepatance appears high. Thus, growers have not shown an aversion to this technique. Ultimately, the acceptance of this specific approach for human food products may rest with the consumer.

Many other researchers have demonstrated how and why individual components add value to a farming operation, and their comments will not be repeated here (Kuhr *et al.*, 1974; Zehnder, 1994). The incremental approach does have the advantage of providing change in a gradual fashion with a minimum of risk.

Evaluation of economics/profitability. In my experience this approach can be very effective in getting growers to accept IPM as a viable strategy. However, one of the most difficult problems is getting accurate, reliable economic data on production costs. Most farms are operated as competitive businesses, and it is therefore necessary to ensure anonymity in production costs. An approach that has worked successfully in California and Mexico has been to convince growers to submit proprietary data on costs directly to a trusted third party (often a marketing board manager), who then removes all identifying information, thereby assuring anonymity (Trumble and Alvarado-Rodriguez, 1993; Trumble *et al.*, 1997; Trumble *et al.*, 1994; Trumble and Morse, 1993). These data are then sent to the researcher, who collates the information and provides putative 'industry averages' for various production costs While this may appear to be a somewhat cumbersome process, the resulting data are of high quality and any concerns that the researcher may inadvertently release a specific grower's costs are eliminated. It is important to determine the best average costs and to develop categories that growers can use to 'plug in' their specific costs to assess how the program would perform on their farms.

These cost data are then used to generate partial budgets based on statistical comparisons of current grower pesticide use strategies versus an IPM program. A simple partial budget allows growers to compare their actual costs against the costs of the IPM program and determine what the net profits/losses would be for their operation. An example of this technique is presented later in this article. One caveat applies; like most field studies, risk assessment analyses cannot be adequately addressed in a single year, and two years of data is minimal.

Use of a partial budget procedure addresses grower concerns about the perceived monetary risks of implementing an IPM program. This approach provides detailed data on the economic returns from the proposed strategies using the types of analyses the growers employ. Creation of these partial budgets often generates persuasive arguments for adoption of proposed IPM programs based on net profits resulting from specific control strategies. An example of this technique is provided in this review under the heading 'Economics of IPM in fresh market tomatoes'.

In addition, an economic analysis may prove useful in helping companies set pricing on new products. Generating comparisons of net profits for registered materials versus new unregistered compounds can provide substantial insight into outcomes of various marketing strategies.

However, not all of the benefits of an IPM strategy can be easily included in a partial budget. Potential losses due to development of pesticide resistance in a pesticide-based grower strategy are difficult to include. The possible benefits of an IPM approach include, (1) reduced soil compaction due to fewer trips through the field, (2) minimized worker health and safety problems with less pesticide application, (3) increased consumer acceptance with reduced pesticide use and (4) reduced environmental concerns with less solvent release in the atmosphere and generally less potential for environmental contamination (Trumble *et al*., 1997).

Economics of IPM in fresh market tomatoes

Introduction

A recent study in Californias fresh market tomato system provides an example of this economic evaluation strategy. The purpose of this work was to determine how to integrate some of the new compounds expecting registration into an existing IPM program (Trumble *et al*., 1994). Determining an optimal use strategy for such new materials can minimize resistance development and maximize existing control through natural agents. In addition, demonstrating an economic return from a specific use pattern appears to help growers and PCAs break the cycle of repeated prophylactic treatments and thereby extend the effective life of desirable compounds.

The fresh market tomato system serves as a moderately complicated example. Most growers transplant into raised beds on 1.5 m centers. Irrigation may be by sprinkler, furrow or drip lines. Regardless, the plants require approximately three months to mature fruit. Nearly all fruit are harvested by hand and then transferred to a packing house for cleaning, sorting and boxing. Growing seasons are variable by location, with central California producing during the summer/fall, and southern California producing all year on the coast and during the fall, winter and spring in the desert regions.

Insect pests are variable by geographic location, season and year. The only consistent insects are *S. exigua* and *H. zea*. Occasional pests include *Manduca* spp., *K. lycopersicella*, *T. ni*, *M. euphorbiae*, *Liriomyza* spp., russet mites, several stink bugs and *Lygus lineolaris* (Palisot de Beauvois). Of the pest complex, most damage is caused by *S. exigua*. Unlike *H. zea*, which feeds in only one or two fruit during larval development, *S. exigua* may damage 10 or 15 fruit, eating only a small amount of each. Unfortunately, any penetration of the skin results in access for bacteria and fungi, and these fruit are considered unmarketable. Thus, in most years, primary consideration is for control of *S. exigua*.

Methodology

An experimental planting of tomatoes (cultivar Petoseed 7718VFN) was established at the University of California's South Coast Research and Extension Center in Orange County, CA during the summer-fall seasons of 1996 and 1997. Tomatoes were transplanted on June 18 in both years and grown using local commercial practices.

During the season, leafminer and parasite populations were evaluated weekly by counting leafminer pupae and adult parasites in four 22.8×28 cm trays per replicate from mid-August through harvest (Zehnder and Trumble, 1985). Because the key parasitoid species in California kill the larvae before they emerge and drop to the ground to pupate, the trays can be used to provide information on the relative efficiency of the parasitoids: if numbers of leafmines per plant are increasing, but pupae are not being captured in the trays, then the biological control agents are responding and no treatment will be necessary (Trumble, 1990).

In 1996, five treatments were evaluated from four replicates in a randomized complete block design. Each replicate consisted of eight rows on 1.5 m centers by 20 m in length. Treatments included:

1. a chemical standard approach using eight scheduled treatments ($1.1\ \mathrm{kg\,ai\,ha^{-1}}$ of methomyl (Du Pont) plus $0.22\ \mathrm{kg\,ai\,ha^{-1}}$ permethrin (FMC)), which has been shown to economically optimize returns from pesticides (Wiesenborn *et al*., 1990)
2. an IPM approach using only 'as needed' applications of *B. thuringiensis* (hereafter BT) (Xentari, Abbott Labs) at $2.47\ \mathrm{kg\,ha^{-1}}$ and two applications of spinosad (Success, $0.077\ \mathrm{lb\,ai\,ha^{-1}}$; Dow-Elanco)
3. a similar program with a nuclear polyhedrosis virus (NPV) (Spod-X at 4.94×10^{11} occlusion bodies/ha, previously Biosys, now ThermoTrilogy) plus a neem formulation (Align at $0.5\ \mathrm{l\,ha^{-1}}$ from ThermoTrilogy)
4. a celery looper NPV at 4.94×10^{11} occlusion bodies/ha, from Biosys (now ThermoTrilogy)
5. an untreated control.

Nine weekly applications were made in the chemical standard program beginning July 25. In treatment 2, BT was used in the IPM program on July 25; spinosad was applied on August 8 and September 5. In the virus plus neem treatment, applications were made on July 25, August 8, August 29, and September 5. The celery looper NPV in treatment 4 was applied on the same dates. Applications of all pesticides were made with a tractor-mounted boom sprayer with 4–6 nozzles per row. Disc-type nozzles incorporated D3 orifice disks, #25 cores, and 50 mesh screens. Operating pressure was $7.03\ \mathrm{kg\,cm^{-2}}$ delivering $935\ \mathrm{l\,ha^{-1}}$. In an effort to increase efficacy by reducing potentially undesirable effects of UV radiation on pesticides

(Griego and Spence, 1978; Pozsgay *et al*., 1987), spray applications for all materials were made in the evening.

In 1997, three treatments were evaluated from four replicates in a randomized complete block design including:

(1) a chemical standard approach using ten scheduled treatments (1.1 kg ai ha^{-1} of methomyl [Du Pont] plus 0.22 kg ai ha^{-1} permethrin [FMC]), which has been shown to economically optimize returns from pesticides (Wiesenborn, 1990)
(2) an IPM approach using two 'as needed' applications of *Bacillus thuringiensis* (Xentari®, Abbott Labs) at 2.47 kg ha^{-1} and two applications of Success (0.077 kg ai ha^{-1}; Dow-Elanco)
(3) an untreated control.

All Chemical standard treatments received spreader sticker (Leaf Act 80A). Ten weekly applications were made in the chemical standard program beginning July 9. In treatment 1, Xentari was used in the IPM program on July 23 and August 28; Success was applied on August 7 and 21. All other conditions were the same as in 1996.

Harvest was on September 25 and September 15–16 in 1996 and 1997, respectively. At harvest, all fruit from the center two rows of each plot were harvested, counted, and weighed. Two hundred mature-green to red fruit per replicate were randomly collected (800 per treatment) and inspected for damage by key pests.

The costs associated with pesticide applications were calculated by determining commercial pesticide costs on a per hectare basis (from wholesale pesticide suppliers), then adding the labor and equipment costs for the application by ground rig (information from UC publications, (Anonymous, 1981; Anonymous, 1988); and growers, see Table 1) to costs needed to produce tomatoes. The horticultural, harvest and marketing costs associated with commercial production were provided by several growers; values were averaged to produce a standardized cost (Trumble *et al*. 1994). Unfortunately, cost data were not readily available for the celery looper NPV.

Results and discussion of the IPM study

The damage resulting from insect populations is presented in Table 2. The BT/spinosad and chemical standard programs did not differ significantly in fruit damage by specific pests in either year, but was about 3–3.75% higher in total damage. Both of these treatments had consistently lower damage than the other treatments. The virus + neem, the celery looper NPV, and the untreated control plots were not significantly different for levels of insect damage.

The treatment programs and the control treatment had significantly lower leafminer populations than the chemical standard on most sampling dates in both years (Fig. 1). In fact, relatively few leafminers were found in the control and IPM trials throughout the season. The trend for higher populations in the chemical standard is probably due to the adverse effect of pesticide applications on the leafminer parasites; an effect which has been demonstrated previously in several crops (Johnson *et al*., 1980; Oatman and Kennedy, 1976; Trumble, 1990). This effect was evident during most of September, when leafminer and parasite populations were at their highest.

Table 3 shows total productivity and productivity adjusted for insect damage from the five treatments. Although no major differences were evident in numbers of cartons/ha in either year, the BT/spinosad treatment and chemical standard approaches did produce similar numbers to the control. This suggests that (1) the

Table 1. Costs for production of fresh market tomatoes. Water costs based on 150.6 cm/hectare, seed and transplant costs based on 14 332 plants/hectare; labor includes some transplanting and watering costs. Miscellaneous category includes overhead, fertilizer, and several minor additional expenses. Cost of pesticide application includes only the tractor and driver, pesticides are listed separately; see text for chemicals used in each treatment and numbers of applications

Fixed costs	$/ha	Variable costs	$/carton
Water	494.20	Harvest	1.10
Seed	24.10	Sales	2.30
Transplants	401.29		
Scouting	35.00		
Labor	161.62		
Miscellaneous (incl. overhead)	260.79		
Spinosad (1996 and 1997)	101.60		
Spod-X NPV	32.64		
Neem	49.42		
Methomyl (1996 and 1997)	44.47		
Permethrin (1996 and 1997)	56.83		
Bacillus thuringiensis (1996 and 1997)	24.71		
Pesticide application (1996 and 1997)	62.73		

Table 2. Percent fruit damage by key pest insects from insect suppression programs in fresh market tomatoes. Percent of fruit damaged is from samples of 200 fruit per replicate. Numbers in columns followed by the same letter are not significantly different at the $P < 0.05$ level, Fisher's Protected LSD Test; analysis prior to conversion to percentages. Total damage includes losses to *Manduca* spp. and other relatively rare pests

	Mean % fruit damaged			
Treatments	*H. zea*	*S. exigua*	*K. lycopersicella*	Total damage
Insect Damage 1996				
Control	2.12^{b}	7.25^{b}	1.75^{b}	10.87^{c}
Chem Standard	0.13^{a}	2.88^{a}	0.13^{a}	3.13^{a}
Bt/spinosad	0.75^{a}	5.75^{a,b}	0.25^{a}	6.75^{b}
Virus + neem	2.87^{b}	7.25^{b}	1.25^{b}	10.87^{c}
Looper virus	2.37^{b}	7.25^{b}	1.50^{b}	11.87^{c}
Insect Damage 1997				
Control	4.25^{b}	11.00	1.75	17.25^{b}
Chem Standard	0.00^{a}	6.00	0.00	6.00^{a}
BT/spinosad	0.50^{a}	8.25	0.50	9.75^{a}

pesticides and rates of application were not having a significant negative impact on plant productivity such as that noted by Welter (1989) and, (2) the density of leafminers in this year's study was not high enough in the early season to cause any noticeable yield effects. However, after the yield loss from insect damage was factored in, the control treatment showed numerically lower yields than either the BT/spinosad or chemical standard programs.

The previous information provides necessary background on damage and marketable yields, but does not provide an accurate picture of net profits. To get net profits from a particular treatment program, you must determine the cost of growing the crop and subtract this from the harvested value of the crop. Finally, the costs of the pest control strategy can be subtracted to determine the net profit. For the 1996 trials, for example, the cost of pesticides and applications in the chemical standard was \$1468 ha. At \$6 carton, the harvested value of the crop (2894.71 marketable cartons × \$6/carton = \$17 368 ha gross profit) minus the horticultural costs from Table 1 (\$11 219 ha) was \$6149. Subtracting the pesticide and application costs (\$1468 ha) leads to a net profit of \$4681 ha (or approximately \$1896 ac).

Generating these data for the BT/spinosad program requires a similar process. Using the value of \$101.60 ha (\$40 ac) for spinosad, and \$24.71 ha for BT, and \$62.73 ha for each application (tractor, labor, container disposal, depreciation, etc.), the net profit of the BT/spinosad program can be calculated. At \$6 carton, the harvested value of the crop minus the horticultural costs to grow it was \$5307 in 1996. The cost of three applications (two of spinosad and one of BT) is approximately \$416. Subtracting \$416 from \$5307 equals \$4891. Thus, the net profit of \$4891 ha in the BT/spinosad program is \$210 ha higher than that seen in the chemical standard program.

For the virus-based programs, the economic results were not as encouraging. In the virus/neem treatment, at \$6 carton, the harvested value of the crop minus the horticultural costs to grow it was \$4388. The cost of four applications was approximately \$579 ha. Subtracting \$579 from \$4387 equals \$3808. Thus, the net profit attained is \$873 less than that that seen with the chemical standard, and nearly \$1200 ha below the net profit from the BT/spinosad treatment. Unfortunately, there appears to be little interest at this time in commercially developing the celery looper NPV, and pricing is therefore not available.

In most years, the Free on Board value of a carton of tomatoes (the amount received by growers on their loading docks) does not exceed \$6 (Trumble *et al*., 1994). However, in exceptional years the price can reach \$8 or more. Because the yields in the BT/spinosad plots were lower in 1996 and 1997 (numerically, not statistically) as compared to the chemical standard, the net profits are increasingly affected as prices rise. For example in 1996, at \$8/carton, net profits in the chemical standard increase to \$10 470 ha, while in the BT/spinosad treatment the profits increase to \$10 034 ha, approximately \$434 less. Nevertheless, the growers I discussed this with remained unconcerned; apparently when carton values pass \$8, and profits exceed \$10 000 ha, growers are making enough profit that they consider the differences to be negligible. Net profits of less than \$8245 ha in the virus/neem treatment dropped over \$2200 below the chemical standard, and were not competitive.

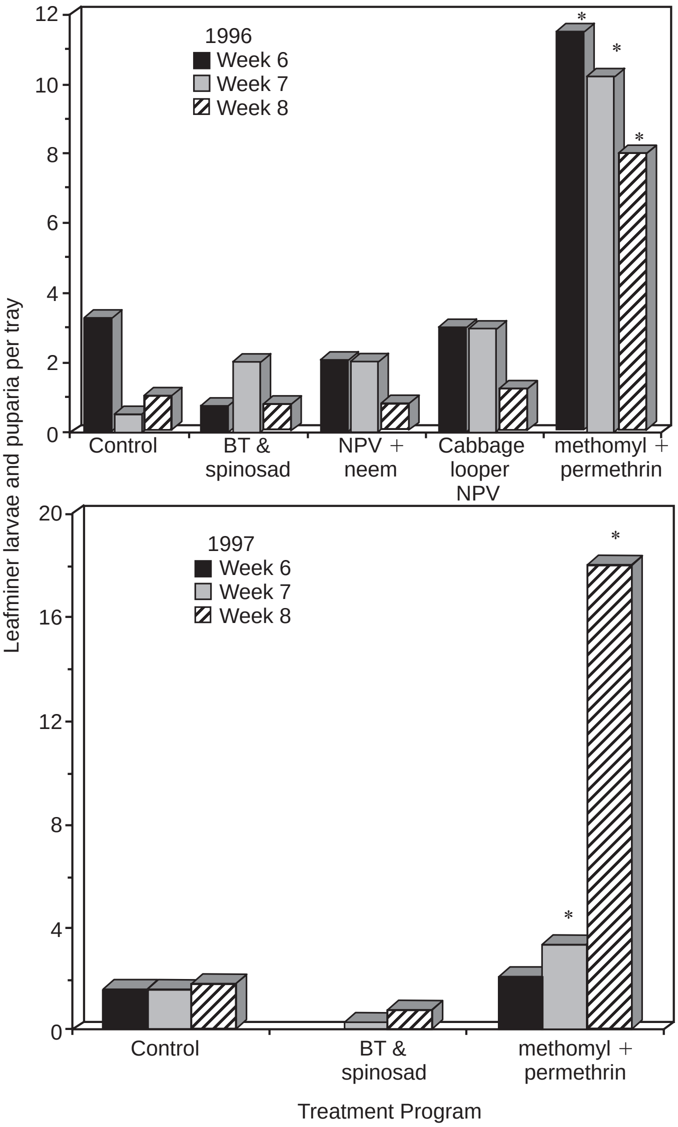

Fig. 1. Leafminer populations in weeks with the three highest counts during 1996 in the IPM trials. On all three dates, the methomyl + permethrin treatment had significantly more leafminers (Fisher's Protected LSD Test, $P < 0.05$) than any other treatment tested. See text for details on sampling procedures.

In 1997, the Bt/spinosad program performed somewhat better than the chemical standard at both the $6 and $8/carton. At $6/carton, where the IPM program net profits exceeded the chemical standard by $642 ha. The Bt/spinosad program was more profitable than the chemical standard at $8/carton by $260 ha. An example of the range of gross and net profits which could be expected in 1997 is presented in Fig. 2.

Unfortunately for the grower, the more typical prices fluctuate between $4 and $6/carton. At the lower values, the BT/spinosad program was more cost effective in both years. At a low price of $4/carton, growers lose money. Net losses in the chemical standard surpass $1100 ha, while in the BT/spinosad program growers are much closer to breaking even with losses below $250 ha. Balancing this potential additional loss of $850 ha at $4/carton ($1100 in the chemical standard minus $250 in the BT/spinosad treatment) versus a potential 3.2% additional profit at $8/carton ($330), may explain why growers are willing to adopt programs where comparative economic data are available.

Benefits of the IPM approach extend well beyond just the improvement in short term economic return. Potential reduction in the development of insecticide resistance has considerable long-term economic implications. Furthermore, the low input program requires no applications of insecticides that are highly toxic to mammals. Therefore, the potential hazards to applicators, harvesters and consumers would be reduced even further. In addition, because fewer trips through the field are required, reduced soil compaction and less pollution from fossil fuels would result. These problems also have substantial costs. Thus, because these factors were not included, the economic analysis presented here is conservative.

This illustration consists of only two years of data collection. The second year of field station experiments, if successful, would normally be followed by an on-farm comparison between the grower standard approach and the proposed IPM program. Additional, more complete examples of IPM program development and implementation using partial budgets are available (Trumble and Alvarado-Rodriguez, 1993; Trumble *et al.*, 1997; Trumble and Morse, 1993). In each of these cases, large portions (>50%) of the growers have adopted most if not all of the program, or have voted in grower cooperatives to move as an industry toward IPM-intensive tactics.

Conclusions

Given the contradictory messages our society sends to growers, it is not surprising that most farmers are slow to embrace new IPM programs. Because of these mixed messages, most growers do not readily respond to impassioned appeals to eliminate pesticide use, to protect the environment regardless of cost, to adopt IPM programs not validated on commercial farms, or to accept a program simply because it has been published in a scientific journal. In addition, the percieved economic risks associated with the possible loss of 100% of crop yield for a 10% (or less) investment in pesticides serves to slow adoption of new strategies. However, stressing reasonable and relatively simple arguments based on economic analyses of IPM can provide a very compelling argument to counteract perceived risks. Most growers, politicians, ecologists and environmentalists can agree that increasing net profits while decreasing potential negative effects on humans and the environment is a worthy goal.

Table 3. Productivity analyses from insect suppression treatments in fresh market tomatoes in the summer-fall plantings in 1996 and 1997. Numbers within years in columns are not significantly different at the $P < 0.05$ level, Fisher's Protected LSD Test. Adjusted cartons/ha refers to cartons/ha minus yield losses to insects

	Mean		
Treatments	No. fruit/plot	Cartons/ha	Adjusted cartons/ha
1996			
Control	2132.75	2853.84	2441.09
Chem standard	2341.00	3035.62	2894.71
BT/spinosad	2170.50	2870.98	2570.60
Virus + neem	1962.00	2619.45	2217.30
Looper NPV	2120.75	2771.57	2303.70
1997			
Control	2838.50	2635.85	2359.72
Chem standard	2972.75	2831.64	2742.81
BT/spinosad	2827.75	2683.76	2551.69

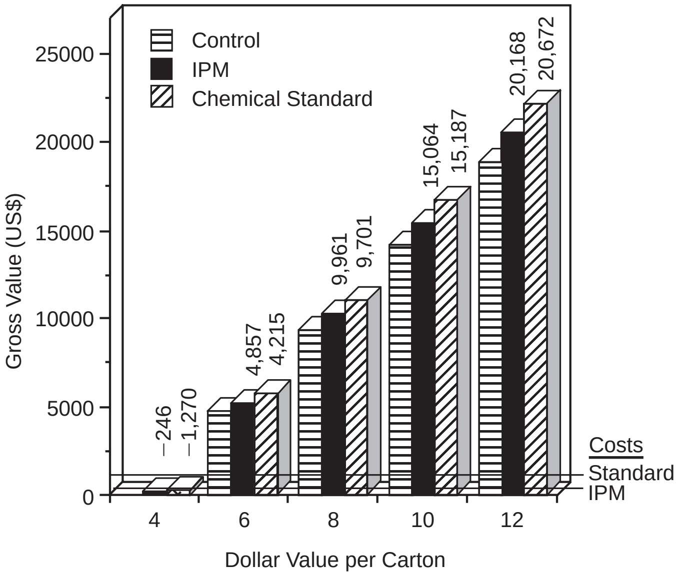

Fig. 2. Net profit analysis from a fresh market tomato plantings 1997. The height of the bars indicates the potential gross profit the crop when the market value (dollar value of the cartons) changes. Horizontal lines show the cost of the chemical and the IPM strategies. The net profit (gross profit from the crop minus the cost of pest control) are shown directly above the chemical standard and IPM program bars.

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