Workbook Introduction

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WORKBOOK INTRODUCTION

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IPM IMPLEMENTATION ON REFUGE LEASED LANDS

This workbook covers IPM for five Refuge-grown crops (potatoes, small grains, sugarbeets, onions, and alfalfa); for weeds of these crops; for vertebrate pests, such as mice and voles; and for berms. Each crop section can be used independently, even taken into the field, once this introductory section is understood. A separate weed section has been prepared since many weeds are a problem for more than one crop.

The workbook was designed to provide a good understanding of the life cycle and biology of priority pests and their natural enemies, as well as to give regionally specific "how-to" IPM recommendations. It is hoped that the information in this workbook will be used to learn about key pests and to plan ahead for pest prevention, as well as for making day-to-day decisions about pest control.

Under each crop, the life cycle of the pest is described, monitoring measures are recommended, and specific management

recommendations are made. Major and minor pests are denoted by the following symbols: **Major ; Minor •**. Important text headings, particularly management recommendations, are set out and marked with the following symbol: **L** .

"A convergence of technical, environmental and social forces is moving agriculture towards more non-pesticide pest management alternatives like biological control, host plant resistance and cultural management."

Michael Fitzner, National IPM Program Leader, USDA Extension Service

As in this introductory section, the numbers in ( ) at the end of sentences refer the reader to citations listed at the end of the text. Numbers at sentence endings without ( ) refer to footnotes at the bottom of the page.

A copy of *Beneficial Organisms Associated with Pacific Northwest Crops* also is provided with each IPM Plan in the binder's back pocket. *Note: this publication is not available. See the Executive Summary for further information.* This U.C. Extension Service publication contains color photographs and life-cycle information for common predators and parasites found in the region, and should be a useful resource for enhancing biological pest control.

Growers and Refuge managers are the primary audiences for this workbook. Pest control advisors (PCAs), the IPM coordinator, crop scouts, and other Agency personnel also will use the workbook. PCAs will find it useful for determining action threshold guidelines for key pests. The IPM Coordinator will use it when cooperating with growers to develop and implement IPM in their fields. Other Agency personnel will review workbook suggestions when considering lease agreement changes and pesticide use approvals.

Role of the IPM Coordinator

The IPM coordinator will work with growers to develop and fine-tune IPM controls. The IPM coordinator also will help with field trials when appropriate. He or she will work to coordinate IPM efforts with PCAs, growers, agency personnel, and potentially an IPM Advisory Group, and will periodically double-check scouting data and subsequent control recommendations.

Role of Scouting for IPM on Refuge Leased Lands

Scouting to monitor pests is the cornerstone for all IPM decisions. The following describes how the scouting process might work on the leased lands:

- local PCAs hire crop scouts to monitor leased lands and record pest and beneficial population levels, crop development stage, weather, and other useful information;

- scouts give copy of scouting form to PCA and send copy to IPM coordinator;

< PCA determines if control action is required, and recommends treatment if action thresholds are reached;

< IPM coordinator works with PCAs to ensure that pesticide or other recommendations are compatible with the IPM Plan; and

< growers working with local Extension staff and IPM coordinator will determine appropriate action thresholds where thresholds are unknown.

Emergency Pest Control Situations and New Pests

More intensive scouting of Refuge leased lands and adjacent non-cropland will provide an "early warning system" that should reduce the risk of pest outbreaks requiring emergency action and would alert growers to new pests quickly. Scouting will enable growers and PCAs to recognize a pest problem early, and to be more prepared to respond if a population increases to damaging levels. Better forewarning will give Agency personnel more time to evaluate emergency pesticide or other options, resulting in approval of necessary actions before crop damage is sustained. IPM on the Refuge should reduce growers' risk by enabling them to be more prepared. Information gained from scouting may also enable farm managers to plan future strategies that would prevent the pest from reaching damaging levels again, thus reducing the chances of future emergency situations.

WHAT IS IPM?

With the advent of new technologies and regulations, agriculture is undergoing increasingly rapid change. In order to develop practical pest management alternatives that present less risk to the environment, researchers, Extension Service personnel, PCAs, and growers across the country have begun to develop and implement regionally specific IPM programs.

> *"IPM is a sustainable approach to managing pests by combining biological, cultural, physical, and chemical tools in a way that minimizes economic and environmental risks."*
>
> National Coalition on IPM, January 1994

IPM can be a flexible and valuable tool when used as a *concept* with which to approach pest management. IPM isn't a cookbook recipe for pest control and if approached as such, loses its flexibility for dealing with agriculture's ever-changing financial and physical environment.

IPM treats pests as part of a crop production system that includes not only the crop and its pests and natural enemies, but also the crop's entire biological and physical setting. A good IPM program coordinates pest management activities *with each other* and *with production methods* to reach cost-saving, long-lasting solutions to pest problems; ***the emphasis is on knowing about and preventing problems before they occur.***

An IPM program may not eliminate pesticide use, but attempts to use chemicals as a last line of defense against pests, not as the first choice. In

practice, a grower implementing IPM will integrate several pest control strategies to avoid crop loss and to reduce risk to natural resources. These include cultural, biological, mechanical, physical and chemical controls. An option is selected based on knowledge of the crop, the local pests, and the pests' natural enemies.

There are many definitions of IPM in use around the country, including the U.C. Statewide IPM Program definition used as a basis for preparing this Plan. Despite some minor differences in emphasis, all IPM definitions have the following aspects in common:

< A conception of the farm as a component of a larger, functioning system. Actions are taken to restore, preserve, or augment checks and balances in the system, not solely to eliminate pests.

< An understanding that the presence of a pest does not necessarily mean significant economic damage is occurring.

< A determination that, before a control method is used, economic injury levels, action thresholds or some other appropriate decision-making criterion is used. Monitoring is done to evaluate populations of pest and beneficial organisms. Efforts are made to avoid or limit the disruption of natural pest controls.

< A consideration of all possible pest control options (e.g., cultural, biological, mechanical, physical and chemical) before taking action. Some IPM techniques are incompatible; consideration must be given to assure that chosen techniques do not negate the benefits of one another.

WHY USE IPM?

One of the main goals of IPM is to provide clear guidelines to growers for the management of crop pests in a manner compatible with fish and wildlife and other non-target organisms. Growers can use IPM guidelines to decrease the potential for pest problems *before* a crop is planted, and plan pest management activities and inputs during the growing season.

> *"Systems such as IPM are based on extensive collection and interpretation of field level data to determine pest infestation thresholds, protect non-target and beneficial species, utilize predators and parasites, and rely on synthetic pesticide use only as a last resort."*
>
> Rick Rominger, 1993. California Farmer, USDA Deputy Secretary

A farm is a dynamic system. Factors that influence a farm include (but are not limited to) weather, crop prices, neighboring farm activities, government regulations, soil fertility, and interest rates. A pest management system (and any cropping system) must take into account as many factors as possible in order to be sustainable. IPM typically takes into consideration more factors than does conventional pest management.

There are several advantages to the IPM approach:

< ***Prevention is generally cheaper than a cure—***

IPM seeks to prevent pest problems from developing in the first place. Making small changes in the way a crop is grown can sometimes prevent a pest problem simply by eliminating hosts (such as by controlling weeds in borders surrounding fields).

< ***IPM can help decrease farming costs in the long-term—***

In the short-term, farming costs may increase due to purchase of different equipment and supplies. Long-term costs can be reduced if chemicals are used only when it makes economic sense and not according to a fixed, pre-determined schedule. Chemical treatments are often reduced. For example, results of 18 economic evaluations of IPM on cotton showed a decrease in production costs of seven percent and an average decrease in pesticide use of 15 percent. Two IPM studies on potato production reported a reduction in pesticide costs with the same or better crop quality.

< ***IPM can reduce chemical use in the long term—***

For the past 30 to 40 years, various chemical pesticides have been the primary tool for controlling the spectrum of pests that confront agriculture. However, chemical pesticides have some disadvantages that make their exclusive use expensive and problematic, including problems with pesticide resistance, residues in food and the environment, and outbreaks of minor pests, and killing of various non-target organisms.

Long-term Aspects of Chemical Use

Resistance. Pesticide use selects for the individuals most able to survive chemical applications, thus changing the genetic make-up of a pest population. Survivors and their offspring have a much higher percentage of individuals resistant to one or more pesticides. Over 800 species of pests are now resistant to one or more pesticides.

Resurgence. Pesticides often kill natural enemies along with the pest. Once pest populations recover, there is little to prevent them from exploding to higher, more damaging numbers except more pesticides.

Minor Pests. Populations of some pests, normally kept under control by natural enemies, can increase to economically damaging levels once their natural enemies are destroyed. Aphid outbreaks following pesticide applications for alfalfa weevils are an example of this problem.

Residues. Only a minute portion of any pesticide application will contact the target organism. The remainder may degrade harmlessly; but too often water, wind, and soil will carry pesticides to non-target areas and organisms, possibly affecting the health of human, fish, and wildlife populations.

Role of the Farm Manager in IPM

The grower or farm manager is the most important link in a successful IPM program. This person must know the biology of the pest, the crop, and the farm environment. He or she must integrate this knowledge with tools and techniques of IPM to manage not one, but several pests, and must pay close attention to the pulse of the managed ecosystem, stay abreast of developments in IPM, and be aware of crop and pest biology.

A successful IPM program takes time, money, patience, short- and long-term planning, flexibility, and commitment. Certain IPM strategies, such as increasing beneficial insect habitat, may take more than a year—enough time to support an adequate number of predators and parasites to lower the need for pesticides and thus save money. A good monitoring system may require a larger initial outlay of time and money than a conventional chemical spray program. (Monitoring should occur on a continual basis during the growing season. Results need ongoing analysis and consideration.) In the long run, however, a successful IPM program will pay for itself. Direct pesticide application costs are saved and equipment wear and tear may be reduced.

The grower/manager will probably spend time talking to other growers and making contacts with Extension and research personnel to discuss integrated farming techniques. In addition, the following traits are important:

- *Patience*. The grower implementing IPM must expect setbacks and unforeseen developments. Many factors that affect pests and crop production, such as weather, are beyond human control.

- *Flexibility*. The program should be flexible enough to adjust to changes that occur year to year and field by field.

- *Commitment*. IPM has been successfully implemented in many crops in spite of all the unpredictable setbacks that are part of any farming operation. A grower/manager must be willing to commit the time, money, and effort necessary for the successful implementation of IPM.

Key Elements of IPM

Any successful IPM program involves the following:

- *identifying* pests and their natural enemies;

- *understanding* the physical and biological factors that affect the number and distribution of pests and their natural enemies;

- *monitoring* pests and their natural enemies for damage and biological control;

- determining *if and when a treatment is needed* to prevent economic damage;

- integrating a combination of cultural methods, biological controls, and chemical treatments to keep pests from causing economically significant crop damage in a way that reduces consequences to the environment;

- follow-up with monitoring to see how well control measures work and to see if further action is needed; and

- use of *field trials* to test and gain new information critical to implementing IPM successfully.

< Identifying Pests and Beneficials. Accurate pest and beneficials (natural enemies) identification is a crucial step of IPM. The effectiveness of subsequent pest management depends on correct identification. Misidentification may be worse than useless; it may actually be harmful and waste time and money.

< Understanding the Factors that Affect the Pest and Its Natural Enemies. To manage a pest, the grower must first understand its interactions with other organisms and with factors such as the weather and soils. As knowledge of the pest evolves, weak links in its life cycle become apparent. Knowing a pest's life cycle helps to pinpoint when the pest is most vulnerable to control actions.

Another key to healthy plants and pest prevention is healthy soil. Maintaining a balanced soil environment enables beneficial soil microorganisms (such as fungi, bacteria and nematodes) to control plant pests. The more the agricultural field mimics natural systems, the less chance there is for soil-dwelling pests (such as plant-feeding nematodes, and disease-causing fungi and bacteria) to gain the upper hand. Thus, the more the grower understands the dynamics of the soil, the more pest problems can be prevented.

< Scouting and Monitoring. Scouting a crop to monitor pest and beneficials levels and activities is another basic tool of IPM. Scouting provides the best information possible for making pest management decisions. Monitoring helps determine if a pest or its natural enemies are increasing or decreasing, or if a control action worked or not. Monitoring of beneficials is important because it provides information on how well natural controls are working and whether or not to consider other pest suppression actions.

Proper timing of monitoring is important because it is inefficient to scout and sample for pests when they are not active or present. Conversely, delayed sampling is financially risky because economic damage can occur before a control action is taken.

The more often a crop is scouted, the more knowledge the grower has about it. Balancing the frequency of monitoring against its cost is important too. Frequency may vary with temperature, crop type, growth stage, and pest. If, for example, a pest is approaching damaging levels, a grower will want to scout more often. Scouting field borders more frequently than other areas may also be warranted. *Usually sampling is done weekly to stay vigilant of pest populations.*

Check each field weekly when pests are likely to occur. More frequent monitoring (two to three times a week) is necessary when previous counts show populations approaching damaging levels. Pest levels may vary greatly within a single field. Therefore, it is important to take at least four random sample—one in each quadrant of the field—on each visit to assure a

representative reading. Avoid taking samples from field edges (but keep them under observation). Pests in high and low spots, wet areas, borders, and in weedy spots may not represent the average population in the field. Watch these “trouble spots” for unusual insect activity, and consider localized spot treatments if action thresholds are reached.

Monitoring for diseases requires a slightly different strategy than for other pests, such as insects. Insect populations can be monitored and treated if their numbers are increasing toward economically damaging levels. Treatments for diseases, however, must often occur *before* symptoms are observed since most fungicides only work to prevent infection. Once disease symptoms are obvious to field scouts, it is too late to prevent economic damage. Therefore, the aim of disease monitoring during the growing season is to determine if conditions are conducive for disease development and to apply fungicides to prevent infection before it occurs. Some newer-generation fungicides do have “kickback” action and can be applied after an infection period has occurred. Still, proper monitoring is helpful to determine exactly when treatments are best employed.

Scouts monitoring for disease should:

1) know the life cycle and potential infection periods for all diseases of the crop. If spores are produced at a specific temperature and humidity range, then scouts should monitor for and record when these conditions occur;

2) use weather monitoring equipment to collect temperature, humidity, and other climate data. In some cases, computer-driven models have been developed that incorporate regionally specific weather data and pathogen life cycle factors to predict likely infection periods. For many diseases, these models have yet to be developed.

3) know the symptoms of the disease. This allows for early detection and is useful for determining and recording the effectiveness of preventative treatments, such as use of resistant varieties, cultural practices, or fungicides; and

4) know the field history, and how cultural practices, such as irrigation or low spots in the field, may interact with weather conditions to promote or discourage disease.

< Predicting Pest Activity Using Degree Days. Temperatures and food supply determine the rate at which insects develop. Insects will not develop below a certain minimum temperature called a developmental threshold. To a certain point, the higher the temperature is above the threshold, the faster the insect develops.[(2)]

The rate of insect development can be determined by calculating accumulated "degree days". IPM programs often use degree-day[1] accumulations to time pest control activities, begin monitoring, or predict pest development stages, such as adult flights or egg hatch. It is important to verify degree-day predictions of pest activity with actual monitoring results, such as with trap or stem counts, or with visual observations of the pest. The Cooperative Extension Service often will issue degree-day accumulations for key insect pests.

< Scouting Tools. Tools used to monitor pests vary with the crop and the pest. Sweep nets, sex-attractant (pheromone), or colored sticky traps are often used, as are stem counts and visual observations. A 10X hand lens is often used for counting insects and examining disease symptoms. Often, scouting is accomplished by sampling a field following a specific pattern. Population levels are then determined by taking an average of the number of pests counted throughout the field.

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[1] The following is a simplified method for calculating degree days:

$$\text{degree days} = \frac{\text{high temp.} + \text{low temp.}}{2} - \text{developmental threshold}$$

For example: To calculate the number of degree days accumulated for an insect with a developmental threshold of 50 degrees F on a day when the high is 80 degrees F and the low is 60 degrees F: $\frac{80 + 60}{2} - 50 =$

20 degree days. In this example, if it is important to accumulate 100 degree days before considering treatment for the pest, then the number of degree days would be calculated each day and added to the previous total. As 100 degree days were approached, it would be time to monitor to determine what action, if any, is needed.

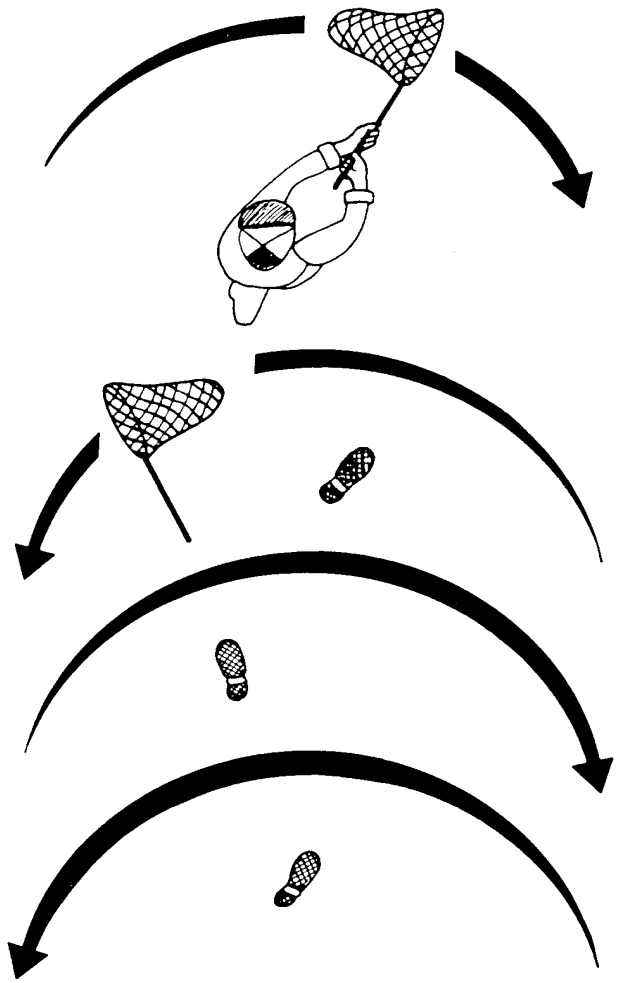

Figure 1.
A single sweep is one 180-degree arc taken as you step forward. A sweep can be made singly or consecutively. To calculate the average number of insects per sweep, simply divide the total number of insects caught by the number of 180-degree sweeps.
(*Intermountain Alfalfa Management*)

A standard insect sweep net is constructed of a 15-inch diameter wire loop fitted with a net bag that is attached to a 26-inch-long handle. Each sweep of the net consists of one 180-degree arc taken with each step of the field scout. The net typically is held vertically so that the lower rim is 1 to 2 inches ahead of the upper rim and at least 4 inches into the crop foliage. This position allows the scout to catch any insects that fall from the plants. Single or consecutive sweeps can be taken.

< Economic Injury Level and Action Threshold. Economic injury level is a term used to describe a pest population level that causes damage equal in value to the cost of controlling it, and is the highest density of the pest that can be tolerated without significant crop loss. Economic injury levels will vary with cultivar, crop vigor, market, and time of year.

Because it is important to act before a pest reaches the injury level, IPM programs often use the concept of an economic or action threshold level. This is the level at which controls should be used to prevent a pest population from exceeding injury levels. Though useful, many crops have no established economic injury or threshold levels. Growers must then rely on their own experience and unique market demands for deciding when a pest is approaching economically damaging levels, and must determine their own action thresholds.

Sampling Terms

Economic injury level. The lowest number of insects or mites that will cause economic damage—expressed as a number of insects per leaf, or per plant part.

Action threshold, or economic threshold level. The population level at which control measures are needed to prevent pest populations from reaching the economic injury level. The action threshold is lower than the economic injury level, to allow for control measures to take effect before the population reaches economic damage.

< Record Keeping. Monitoring goes hand-in-hand with record keeping. It is important to keep records of when and where pest problems occur, as well as cultural practices used (e.g., irrigation, cultivation, fertilization), and varieties planted. The effect of weather on pest and beneficial populations also should be recorded. Record keeping is a systematic approach to learning from experience.

< Field Trials. Field trial recommendations are given in each workbook section. These provide good potential for new IPM techniques, but need testing to evaluate local effectiveness. There are two types of field trials suggested in this document. Growers can conduct the suggested trials on their own private lands or on the leased lands, but on leased land they will be required to contact the IPM coordinator, and encouraged to contact experiment station researchers about the trial.

The second type of field trial will be required as a special lease stipulation, with scientific protocols. All field trials should include good record keeping so the results (both cost and extent, and success or failure) will help build a reference resource for use in developing field-specific IPM strategies.

Trial recommendations, such as crop rotations, growing beneficials, and seed treatments, are included to encourage and enable ongoing refinement of preventative as well as reactive responses to pests, grounded in local knowledge and experience.

New crop rotations/cover crop combinations show promise of helping to control perennial pests such as nematodes and soil-borne diseases. Any use of alternative crops on the leased lands would require coordination with and approval by the IPM coordinator, however. Conservation tillage, such as strip tillage, has been adopted in a wide range of crops for a variety of reasons: it is generally cheaper than conventional tillage; it protects against wind and rain erosion of soil; and by helping conserve soil moisture and provide a better microclimate for the seedling, the crop can establish itself faster with few pest problems.

Providing on-farm habitat for beneficial organisms, known by some as farmscaping, looks at managing the entire farming system to enhance habitat and food sources for organisms beneficial in natural pest control. The benefits of increasing beneficial habitat are lower pesticide and labor costs. However, these "miniature livestock," which is how these organisms should be viewed, are more effective and long-lived if provided with food sources, such as nectar.

Biological seed treatments are becoming more important and effective as science begins to understand more about soil ecology and how soil organisms interact. Seed treatments and other biological pesticides show promise in controlling economically damaging diseases, such as white mold.

Some of the chemicals or products mentioned for field trials may not be registered in California, or may not be registered on the crop for which a field trial is recommended. In such cases, a Research Authorization (RA) is required prior to using the product in California. RAs are a simple procedure, administered by the State of California. A one-page application form is sent to and administered by Dr. Don Koehler (916) 324-3950 of Cal EPA, Department of Pesticide Regulation. RAs are presented to County Ag. Commissioners and then a report card is sent by Cal EPA (a postcard) so that the researcher can notify CAL EPA when research is finished.

U.C. researchers working on their own property do not require RAs—they have blanket RAs. But for work on Service land, U.C. researchers would have to file an RA. RAs can usually be granted within 1 week. They are normally used for 10-acre plots, but can be applied on trials up to 200 acres.

Field trials are critical to implementing IPM. Farming systems are dynamic and constantly change due to weather, and the introduction of new pests, research results, production techniques, and crop varieties. Trials are necessary for learning how to cope with these changes and how to best incorporate them into the farming system. They are the "life blood" of IPM and are often the source of innovative ideas that can be subsequently

tested for their usefulness. The results of trials, both successful and unsuccessful, serve to increase the ability of IPM to meet local needs.

A Day in the Life of a Grower Using IPM—

Grower John and his PCA meet in the evening to discuss the current crop scouting report for John's small grains. The PCA notes that most of his acreage is "clean" but that the southwest corner of one field has some Russian wheat aphids just about at the action threshold. The PCA suggests that only the corner part of the field requires spraying—a total of about 5 acres. Since the field is 80 acres, spraying only a small portion represents significant savings in time, labor and money. The PCA also notes that it's too early in the season for beneficials to be a factor in aphid control, so John will be able to avoid exposing beneficials to the chemical treatment as well. John agrees that a spot treatment would be the best approach, and the two decide to use this strategy.

The PCA also mentions noticing some low-lying areas of two grain fields that have spotty stands. John remarks he typically has this problem whenever heavy rains come early in the spring. This year after harvest he'll rip the areas and put in a couple tons of mature compost in the low spots to help the drainage and increase yields.

The PCA tells John that he'll sample the corner again for Russian wheat aphids after treatment to determine how well the insecticide worked and pass the information along to him. John then says goodbye to the PCA and drives over to his potato crop where he has placed metal sheeting to exclude voles. So far, no damage. He heads home and enters the PCA's scouting report into his computer for future reference on that field.

PEST CONTROL OPTIONS—AN INTEGRATED APPROACH

Growers implementing IPM consider all available cultural, biological, physical, mechanical and chemical control options for each crop pest (including weeds, diseases, nematodes, insects, and vertebrates) and make informed decisions about how best to control them while also considering crop development stage, market demands, pest levels, and weather conditions. Growers in the Klamath Basin already are implementing many of these IPM techniques.

CULTURAL CONTROLS

Non-chemical strategies that give an advantage to the crop rather than the pest are often categorized as cultural controls. Various tillage methods, crop rotations, sanitation, exclusion (of pests from a field), altered planting dates for pest avoidance, increased row spacing, and bed shaping are examples of techniques that modify the cropping environment and help control pests. Resistant varieties give the crop an advantage over the pest, so their use is often considered a cultural control.

Mechanical and physical control options are often grouped with cultural controls. Tillage used to control weed seedlings is technically a mechanical control method, but one that also modifies the crop environment to the detriment of the weeds. Physical barriers that prevent pest entry into a crop can likewise be grouped under the larger heading of cultural controls.

Cultural controls can be either preventive, used *before* the crop is planted, or they can be curative, done during the growing season to control an increasing pest population and keep it from reaching a level that causes economic damage. *Both the short- and long-term benefits of each action should be considered before making a control decision.*

Examples of preventative cultural controls include:

< selecting a disease-resistant crop variety;
< improving field drainage to reduce root rot diseases;
< using crop rotations to starve a pest that has a narrow host range;
< installing a barrier around a potato field to exclude mice and voles;
< harvesting alfalfa in strips to conserve beneficials;
< planting a windbreak that also improves habitat for insect predators and parasites; and
< using wider or narrower row spacings or planting density.

Examples of cultural controls used to “cure” a problem during the season are:

< early cutting of alfalfa to avoid excessive alfalfa weevil damage;
< tillage to destroy weed seedlings; and
< flaming small weed seedlings before crop emergence.

Crop Rotations

Example of importance of crop rotation in pest prevention

A potato rotation program has been used for many years on Refuge leased lands. Under this program, potatoes are grown the first year of the rotation, and are followed for 2 years with other crops. This rotation has reduced the severity of pests, including barley root-knot nematodes.

Crop rotations radically alter the environment both above and below ground, usually to the disadvantage of pests of the previous crop. The same crop grown year after year on the same field will inevitably build up populations of pests that have a life cycle similar to that of the crop. More diversity also helps attract beneficial insects to the field. When managed well, a good crop rotation will help manage diseases, weeds, and insects with a minimum of inputs which then provides for maximum profits.

There are many variables that must be considered when developing a profitable crop rotation. For example, a green manure crop may provide nitrogen and increased tilth to a field, but will the benefits of a green manure, which may include lower pest pressure and a more marketable subsequent crop, outweigh the costs, which might entail losing a cash crop for a season? It is important, then, to consider the costs and benefits of the whole 3-to-4-year rotation when evaluating the economics of the system.

Crop rotations help prevent soil infertility by building soil organic matter. Maintaining and even increasing soil organic matter is important, as this is the skeleton on which a healthy soil is built. Organic matter has immense water storage capacity, and acts as a buffer to sudden changes in soil pH associated with application of some fertilizers. Organic matter provides soil with good structure and tilth, which in turn increases drainage and helps prevent diseases associated with pooling of water around roots.

Sanitation

Sanitation involves the removal and destruction of overwintering or breeding sites of the pest, and/or preventing the disease from entering the field. Methods would include using Refuge wash stations to clean equipment and tilling or removing crop residues from the field. In some crops, although sanitation is an important pest management tool, there is a tradeoff between the destruction of pest overwintering sites in crop residues and the preservation of crop residues to protect against soil erosion and/or to provide wildlife habitat.

Exclusion

Exclusion is used to prevent a pest from entering a field. Planting only disease or weed-free seed, or washing equipment when moving from one field to another are examples of exclusion techniques for preventing pest problems. Barriers around crops also exclude pests (e.g., voles).

Other

Researchers have discovered that the development of plant diseases is heavily influenced by ***plant spacing***, row spacing, the shape of the bed and the height of the plant. These factors influence air flow across the crop which in turn determines how long the leaves remain damp from rain and morning dew.

Generally speaking, better air flow will decrease the incidence of plant disease. This is another instance in which detailed knowledge of the crop is necessary to determine the best pest management strategies.

Farmers across the country are testing a wide variety of other cultural control options. ***Flame weeding*** (searing weed seedlings) before crop emergence is becoming an alternative to chemical herbicides. Large, multi-row ***vacuum machines*** (trade named Bug- Vac) are used commercially for pest management in several crops.

BIOLOGICAL CONTROLS

Naturally occurring biological control is the cheapest and most efficient form of pest management available. Biological control occurs when predators, parasites, or diseases of pests keep their hosts' populations from building to economically damaging levels.

Biological control is supported by the maintenance of cover crops, hedgerows, water reservoirs and other diverse habitats in or near crop fields. This habitat supplies food (mostly nectar and pollen) and shelter for pest predators and parasites. By providing alternative sources of food and shelter, such habitats help to provide a ready source of beneficial predators and parasites for neighboring fields when crop pests appear. Habitat in and around crop fields can be manipulated to increase plant diversity, disrupt pest life cycles, and confuse pests.

> *"When we kill off the natural enemies of a pest we inherit their work."*
>
> Carl B. Huffaker,
> Prof. of Entomology
> U.C. Berkeley

As biological control increases, pesticide use may decrease. However, biological control is not a magic cure for pest problems. The use of habitat enhancement to increase beneficial organisms must be understood within the context of overall crop management.

Care must be taken when selecting plants for habitat enhancement because some may favor pest populations over beneficial organisms. It is important

to choose only those plants (and planting situations) that best support beneficials without negatively impacting soils or the crop. For example, when considering cover crops as a habitat enhancement tool, the first consideration should be the potential effects on soil fertility and on soil-borne pests (particularly nematodes and diseases). These considerations may take precedence over the potential ability of a particular cover crop to attract and support beneficials. Ideally, all these considerations can be integrated into a cover crop (or other habitat-enhancing strategy) that is managed relatively easily, maintains and improves soil, and does not interfere significantly with the growth or management of the intended crop.

Habitat enhancement strategies can be divided into ***annual practices***, such as ground covers, strip planting and crop rotation, and ***permanent*** features, such as hedgerows and fencerows. Some practices are much easier to implement than others, usually due to labor or specialized equipment.

Planting more than one crop on the same land in one year is a useful annual practice for enhancing habitat. For example, ***interplanting*** is the seeding of one crop into an already established stand of another crop, as with overseeding a cover crop into a grain stand. ***Intercropping*** is another example, and is the practice of simultaneously growing rows of two or more crops within the same field. ***Strip cropping*** is the practice of growing two or more crops in different strips across a field wide enough for independent cultivation. Like intercropping, strip cropping increases the diversity of a field, which in turn may help "disguise" the crop from pests.

A variation of strip cropping, trialed successfully in California, is the use of ***pest break strips.***[3] Pest strips are created by sowing a mix of habitat plants such as clovers, alfalfa, and various wildflower seed in 40-foot-wide strips. These strips are planted at 350-foot intervals across the field. They have proven effective for enhancing biological control in potatoes and several other row crops. Good-to-excellent control of aphids, caterpillars, leafhoppers, and leafminers is reported with this method.

Permanent habitat enhancement includes using ***windbreaks***, or ***shelterbelts***. These long barriers reduce windspeed and, as a result, modify the microclimate in the protected area. Aside from making the area more favorable to beneficials, shelterbelts also protect the soil from wind erosion, decrease the drying effects of winds on crops, and provide wildlife habitat.

CHEMICAL CONTROLS

Included in this category are both synthetic pesticides, insecticidal soaps, oils, and plant-derived botanical pesticides (such as neem). Ideally, pesticides are the option of last resort in IPM programs because of their negative impact on non-target species, including beneficial organisms. They should be used only when other control measures, such as cultural or biological controls, have failed to prevent a pest from reaching an economically damaging level. If pesticides must be used, it is advantageous to select the least toxic pesticide available that will avoid harm to the wide variety of other organisms in the field such as birds, fish, soil microorganisms, molds, fungi, bacteria, and mammals, and the pests' natural enemies.

Pesticide Application Techniques

As monetary and environmental costs of chemical pesticides escalate, it makes sense to increase the efficiency of chemical applications. Correct ***nozzle placement*** and ***nozzle type*** are very important considerations. Misdirected sprays, inappropriate or old or worn nozzles will ultimately cost the grower money and increase environmental risk/damage.

If the monitoring program indicates that the pest outbreak is isolated in a particular location, ***spot treatment*** of the infested area will not only save time and money, but will conserve natural enemies located in other parts of the field. For example, growers may want to treat just the field edge if scouting results show that only the borders are infested to a level requiring a control action. Treating just the edge may prevent pests in the rest of the field from reaching economically damaging levels by conserving natural enemies, and thus encouraging biological control. Another example of a spot treatment would be controlling patches of perennial weeds that have only invaded a few sites in a field. Decisions to spot spray should be made between the grower and the crop scout, and the IPM coordinator should be notified.

The grower should also ***time treatments*** to be least disruptive to pest predators. Knowledge of the beneficial organisms associated with the crop (such as their preferred food sources and when they are most active) avoids unnecessary chemical treatments and conserves beneficials. These will provide future pest control and may add to the grower's "bottom line" by limiting the number of chemical treatments.

One way to increase pesticide application efficiency and decrease costs is through ***band applications***. An example of the technique on the Refuge would be positive displacement application of Lorsban only in the onion seed-bed at planting. For weeds, herbicides are band applied only along the top of the seed-bed.

HOW TO GET STARTED WITH IPM

Good planning must precede IPM program implementation. Planning should be done *before* planting because many pest strategies require steps or inputs that must be considered well in advance. Attempting to implement an IPM program in the middle of a cropping season generally does not work.

The following table provides some ideas about technical and information needs that should be considered when implementing an IPM program.

Table 1.
Technical information needs

Technical/Information need	Comments and considerations
Pest-resistant cultivars	Should: < be resistant to major pest(s) < have appropriate mode of resistance < be a cultivar appropriate for the area < be commercially available < be marketable
IPM program	< Check with state or county Extension, researchers, Bio-Integral Resource Center (BIRC), Appropriate Technology Transfer for Rural Areas (ATTRA) and PCAs for the latest IPM program information. < Determine Economic Injury Levels (EIL) , or action thresholds, for major pests. < Consider how EILs may change with time and how this could influence management practices.
Monitoring options	< Determine who will do the scouting (e.g., will the grower do it, or will a PCA hire a scout to do it). < Calculate estimated cost per acre for scouting. < Is the purpose of monitoring to determine: pest populations, natural enemy populations, injury levels, if pesticide treatments will be necessary, timing of treatments? < Identify which pests and beneficials will be sampled. What are the key pests and their natural enemies? < Decide what sampling tools will be used (e.g., sweep nets, visual observations, stem counts). < Consider what other factors should be monitored and recorded, including soil moisture or nutrient conditions, temperature, humidity, rainfall, as these will affect pest management decisions.
Record-keeping	< Keep field maps and record field history. Note fields with recurrent problems, or sections with pest infestations such as nematodes, weeds, or soil-borne diseases. < Develop a record-keeping system that is easy to use and maintain. < Develop a method of displaying monitoring information that will facilitate decision making.
Pest identification: Who can help?	< PCA, county/state Cooperative Extension, university researchers, suppliers, and crop scouts.

Technical/Information need	Comments and considerations
Pest monitoring equipment	< Find and select monitoring equipment (e.g., pheromone traps, sweepnets, handlens, baited traps) PCAs will have much of this information.
Farm equipment	< Will IPM increase or decrease equipment use and maintenance? < What specialized equipment is needed (e.g., mowers, cultivators, no-till drills, flame weeders) ? < Availability of pesticide spray equipment? Timing of applications is often critical for good pest control. Will the necessary equipment be available when it is needed?
Pest prevention and control options	Research and determine pest management options and "fallback" positions in advance. < What cultural or habitat options can be implemented before the crop is planted? < What are potential crop rotation options and their effect on pest management? < What are cover crop options and their effect on pest management? < What are least-toxic alternatives (and sources of chemicals) that can inhibit pests? < If pesticides are necessary, what are the best times for treatment in order to conserve beneficials? < What weed-free period does the crop require to prevent yield loss due to competition?
IPM program evaluation	< Evaluate all components of the IPM system including monitoring, action thresholds, and treatment options for overall effectiveness. < Select field trials to help modify and continually fine-tune the IPM program.

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4. Figure 1: *Integrated Pest Management for Alfalfa Hay* (Publication 3312), edited by Charles G. Summers, David G. Gilchrist, and Robert F. Norris. Oakland, CA: University of California, Statewide Integrated Pest Management Project, Division of Agriculture and Natural Resources. Copyright: 1985, University of California board of Regents. Used with permission.