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Pest Management Strategies for Potato Insect Pests in the Pacific Northwest of the United States

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1. Introduction

This publication addresses pest management guidelines for insects that attack potatoes in the Pacific Northwest of the United States (Fig. 1). Non-chemical control options are strongly encouraged; however, proper use of insecticides has proven effective when used as an additional tool in integrated pest management programs. In general terms, Integrated Pest Management (IPM) is defined as a comprehensive approach of pest control (the term pest includes insects, weeds, diseases) that when combined, reduces the number of pest densities to a level tolerable by the crop. Traditional management practices include the use of host-plant resistance, cultural, mechanical, biological and chemical means of control. Overall, scientific research-based knowledge is required to implement a successful and functional management program.

Fig. 1. The Pacific Northwest includes Washington and Oregon in the U.S. and the Canadian province of British Columbia. Geographical limits are indicated: California (south), the Pacific Ocean (west), and Idaho (east).

Insects, both as pests and beneficials, have been studied by entomologists for a very long time. Of the millions of insects on the planet, only a fraction causes problems for crops and humans. Specific to this discussion, fewer than a dozen species cause most of the insect damage to potato production in the Pacific Northwest. Many of these pests infest at a specific stage of crop growth (e.g., seed corn maggot damage is more severe at planting), while others are permanent residents before planting, at planting and during crop development (e.g., wireworms) (Fig. 2). A number of pests are important to all western U.S. regions such as aphids, especially green peach aphid and potato aphid, both important vectors of leafroll virus, and more recently PVY. Other pests are important in specific regions such as beet leafhoppers in northeastern Oregon and southeastern Washington. This chapter will briefly provide a general profile of the potato crop in the region and will also discuss the most important insect pests affecting potato production. A general description of the pest, biology, ecology, monitoring and control will be provided. No specific recommendations are made regarding insecticide compounds. To obtain more information refer to the most current version of the Pacific Northwest Insect Control Handbook located at http://uspest.org/pnw/insects or consult your local extension office.

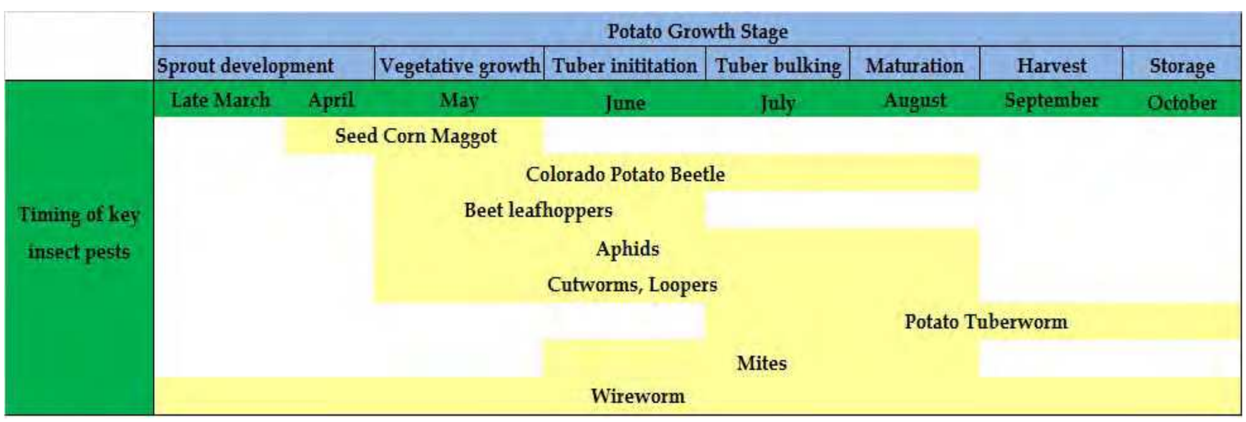

Fig. 2. Occurrence of potato insect pests in the Pacific Northwest of the United States.

2. Profile of the potato crop

The potato is one of the world's most important food crops, domesticated approximately 8,000-10,000 years ago by native Peruvians in South America (Hawkes, 1990; Ministry of Agriculture, 2008). The potato arrived in Europe in the late 1500s (Salaman, 1985) and since then potatoes have been widely cultivated in Europe, Africa, Asia/Oceania and North America. The top ten potato producers worldwide are China, Russia, India, United States, Ukraine, Poland, Germany, Belarus, Netherlands, and France (http://www. potato2008.org/en/world/index.html; source http://faostat.fao.org/default .aspx).

In the U.S., all 50 states cultivate potatoes; however, including Idaho, the Pacific Northwest produces nearly two thirds of the potatoes grown in North America. Idaho is consistently ranked first in potato production and acreage (28% of total U.S. production), followed by Washington State (23% of total U.S. production). Other top U.S. potato producing areas are Oregon, California, Montana, Colorado, North Dakota, Michigan, Wisconsin, and Maine (Fig. 3) (http://www.agcensus.usda.gov/index.asp). Florida and Texas can be included as leading farm cash receipts (http://usda.mannlib.cornell.edu/MannUsda/view DocumentInfo.do?documentID=1235).

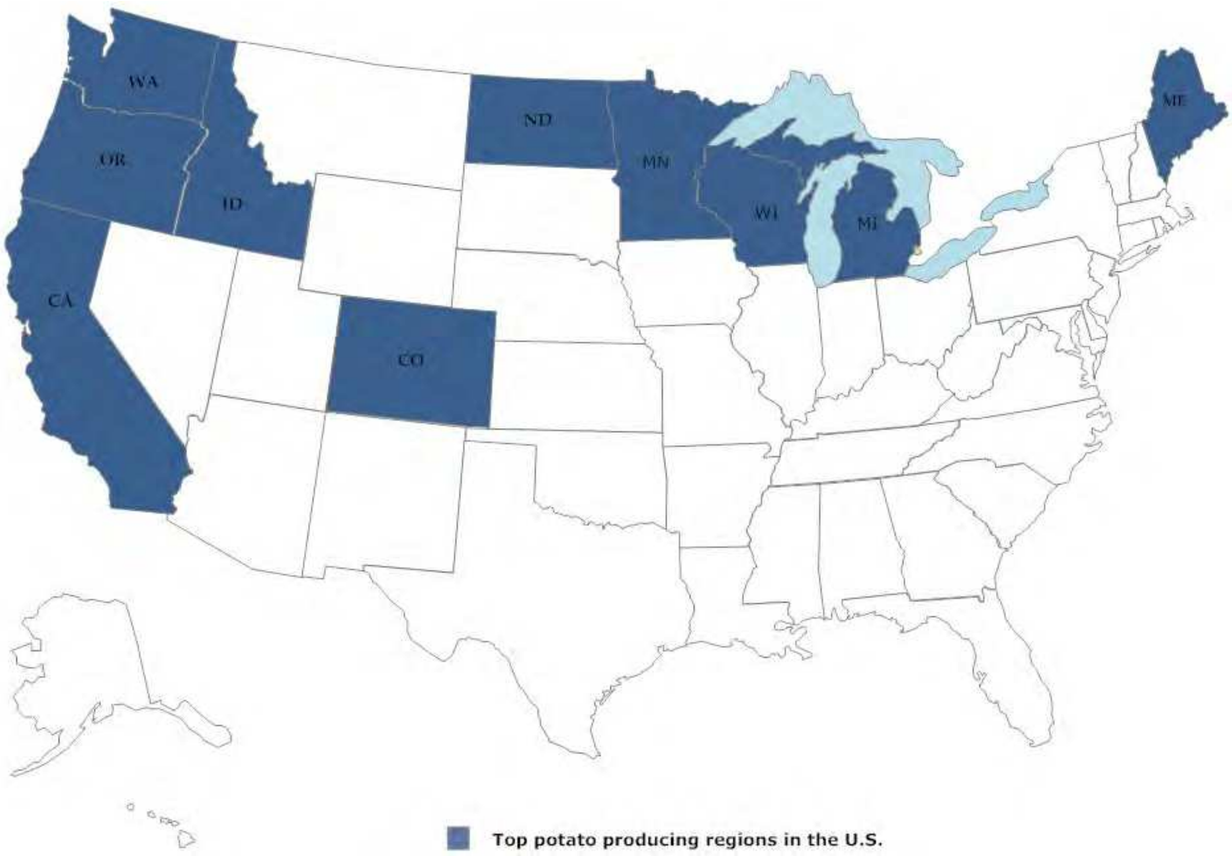

Fig. 3. Top potato producing regions in the U.S.

In the Pacific Northwest, potatoes are typically planted in the spring and harvested in late summer and fall. The growing season in most areas ranges from 120 to 140 days although high elevation areas have a 90 to 100 day season. In the Columbia Basin of Washington and Oregon, one of the most prolific regions in North America, potato production ranges between 160 to 180 days (University of California, 1986). Potatoes are produced as annual plants that grow from specialized underground stems called stolons later known as tubers (Gopal & Khurana, 2006). This vegetative propagation through the planting of tubers or part of tubers (seed pieces) is a common practice in the region (University of California, 1986; Wale et al., 2008). "Russet Burbank" is still a common variety in the region, followed by other Russet varieties such as Ranger Russet and Russet Norkotah (Table 1). Other varieties are available to producers in the region; many originated from the Tri-State potato breeding program (http://potatoes.wsu.edu/varieties/key.html). The Tri-State Program was created in the mid 1980's to intertwine researchers, scientists and stakeholders in the Pacific Northwest to promote and develop new potato varieties.

Thirty-seven Tri State releases has been released since the mid 1980's including the popular "Premier Russet", Western Russet" (both dual purposes fry and fresh packs), "Blazer Russet", "Umatilla Russet", and "Ranger Russet" (processing for fries), and "Alturas" (dehydration/processing) (Potato Variety Management Institute http://www.pvmi.org/varieties/varieties.htm).

Varieties	Year										
	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Russet Burbank	80	78	74	75	71	71	69	63	63	66	62
Russet Norkotah	5	5	8	8	8	8	10	14	12	10	10
Ranger Russet	7	6	4	4	4	3	1	2	1	-	1
Shepody	4	7	9	8	11	12	13	13	15	13	14
Umatilla	-	-	-	1	-	-	-	-	-	-	2
Alturas	-	-	-	-	-	-	1	3	3	2	2
Others	4	5	4	4	6	6	5	5	6	9	9

Table 1. Popular potato varieties (%) planted in Idaho, Washington and Oregon (Washington Potato Commission, 2007; National Agricultural Statistics Service, http://www.agcensus.usda.gov/index.asp).

After producers determine the nutritional needs of the crop (nitrogen, phosphorous, potassium), seed potatoes are cut uniformly, treated with fungicides and/or insecticides, and planted. Potatoes emerge 3-5 weeks after planting, depending on weather conditions, location and time of the year. After plant emergence, producers monitor crop needs regarding fertilization, pest control, and general management. Most potatoes in the area are grown under irrigation. Another common practice is desiccation or vine-killing (Hutchinson & Stall, 2007). Timely vine killing is essential for good tuber skin set, and efficient harvest. It is not clear if desiccation (naturally or artificially) of early season potatoes influences pest pressure in other nearby fields awaiting harvest. Johnson (2008) suggests a holistic plan for potato management combining management practices in the years prior to growing the potato crop, during the growing season, at harvest and during tuber storage. Miller and Hopkins (2008) specified that among many things, establishing appropriate long-term crop rotation, applying and alternating pesticides with different mode of action to avoid pesticide resistance, and improving soil microbial, physical and chemical health are necessary to achieve a healthy crop.

The potato plant develops through four clearly defined growth stages: (1) vegetative growth, (2) tuber initiation, (3) tuber growth and (4) plant maturation (Johnson, 2008). Each stage is affected by different groups of insect pests. The degree of the damage will depend on the timing of events, cultivar characteristics, and the intrinsic characteristics of each pest.

3. Managing insect pests in potatoes

The first step for managing insect pests is the timely detection of pest infestation. The goal is to manage the crop as a whole system, keeping pests at acceptable levels by utilizing several harmonizing strategies (Johnson, 2008). Earlier in this chapter, IPM was defined as a comprehensive pest control. Heitefuss (1989) defines IPM as a system in which all economically, ecologically and toxicologically suitable procedures are utilized in maximum harmony to maintain pests below the economic threshold. In the late 1990's, Luckmann and Metcalf (1994) defined IPM as an intelligent selection and use of pest control actions (or tactics) that will ensure favorable economic, ecological, and sociological consequences. IPM techniques include monitoring of pest populations, the judicious use of pesticides, and the effective communication regarding the necessity of implementing a control tactic or not. In a modern definition, the goal is to prevent and suppress pests with minimum impact on human health, the environment and non-target organisms (Dreistadt, 2004). According to Pedigo (1986), in order to use an IPM approach, an understanding of the following factors is required: (1) the biology of the pest and its natural enemies, (2) the response of crops to management practices, (3) the effect of pesticide application on pests and non-target organisms, and (4) the action threshold or level of damage tolerable by the plant.

3.1 Monitoring

Timing detection and monitoring is an essential long-term requirement against pest infestation in potatoes. Plants should be regularly checked for signs and symptoms of pest damage. During the height of the growing season, plants should be checked once or twice per week. The inspection of the undersides of leaves and the inner plant canopy is recommended since many pests prefer sheltered sites. A close look of any plant that has missing, absent or damaged leaves or flowers, or plants whose color, texture, or size looks different than healthy ones, can be a signs of a problem.

Some insect pests can be dislodged by laying a sheet, sturdy cardboard or paper below the infested plants and "beating" the canopy. Insects can be monitored with a hand lens or traps. Both techniques not only allow detection and monitoring of pest problems but also provide estimates of pest population density. The optimal timing of sampling depends upon the life history and behavior patterns of the pest and/or beneficial insects, as well as crop stage and state, and also environmental conditions. Some areas, such as field edges or fields next to main roads are more prone to pest problems (personal observations).

Different sampling procedures can be used depending on the crop, size of field, etc. In the Pacific Northwest, the majority of potatoes are planted in circles, under center-pivot irrigation, thus fields can be divided in quarters (e.g, north, east, west, south). Upon entering the field, quick visual examination of the field is recommended. Uncharacteristic areas with poor stands or patchy growth should be scouted thoroughly. In the Pacific North-western region traps are widely used. Some traps can be baited with a pheromone which is a chemical that usually attracts a single species (e.g., potato tuber moths). Traps can also be coated with adhesive material to "stick" the pest to the trap. Either natural (e.g., virgin females) or more often the synthetic pheromones are used to attract males (Roelofs et al., 1975; Persoons et al,. 1976; Voerman & Rothschild, 1978; Rothschild, 1986; Raman, 1988). Pheromones specifically disrupt the reproductive cycle of harmful insects. Pheromone traps are used extensively in commercial agriculture in the region helping farmers detect the presence of pest species (Merrill et al., 2011). Traps in general will work only for adult insects, as adults have developed wings and are more mobile. Yellow sticky traps attract fruit flies, winged aphids, thrips, psyllids, fungus gnats, wasps, numerous flies; many species collected in sticky cards belong to the same family or group (e.g., several moths in the Gelechiidae family can be found in traps meant to be for tuber moths, a member of the Gelechiidae family), thus correct identification of target pest(s) is needed.

3.2 Management

Before planting, selecting field location can minimize pest damage and improve predictability of pest problems (Hoy et al., 2008). Also circumventing planting dates when insects will emerge and inflict most damage is recommended. Certified seed should be used at all times. If available, the selection of cultivars resistant or tolerant to important pests is also desirable.

3.2.1 Seed quality and certification

High quality seed is essential for the production of a profitable crop (Love et al., 2003). Several diseases, some transmitted by insects and especially aphids, can be transmitted to infected seed such as viruses, bacterial ring rot, blackleg, late blight, scab, and wilt diseases (University of California, 1986). Disease-free seed tubers are available from certified nurseries where seed potatoes are grown for several generations before being commercially offered to producers. This process is regulated by each state's seed certification programs. The use of appropriate production practices is only half of the process of growing high quality potatoes (Love t al. 2003). Samples from seed growing areas are grown in field trial to establish disease problems. There is a range of tolerance from zero to 6% for certain viruses (University of California, 1986). For instance, Idaho inspection tolerance for post-harvest winter tests of seed destined for recertification range from 0.8% for leafroll, 2.0% mosaic, and 5% chemical injury (Love et al., 2003). Thus, (1) clean all equipment thoroughly before entering fields, (2) establish aphid control programs to prevent the development of aphid populations in potato seed fields, (3) control aphids in potato fields to prevent the movement of aphids to seed fields.

3.2.2 Resistant cultivars

Cultivars tolerant or resistant to pests can provide long-term protection for the potato crop. For a long time it has been recognized that the evaluation of potato germplasm for resistance is a valuable tool to developing IPM programs (Horgan et al., 2007). Although no commercial potato cultivar is completely resistant to insect damage, there are variations in the susceptibility of cultivars to the pest (Hoy et al., 2008). For example, tubers of the transgenic clone Spunta G2 are resistant to the potato tuberworm (Douches et al., 2002). Rondon et al., (2009) tested several cultivars including Spunta G2 with excellent results. However the public perception regarding genetically-modified organisms is still "blocking" the widely use of this type of resources.

3.2.3 Cultural practices

Proper management of field preparation, planting, harvesting and storage are essential for maximum yield and tuber quality (University of California, 1986). Pest infestation can be minimized by avoiding contaminated seed tubers, soil, and water, sanitation of machinery brought from infested areas, removing cull piles, and following rational fertilizer and irrigation programs. Crop rotation, which reduces certain pests by breaking their life cycle, should be an integral part of a holistic management program.

3.2.4 Biological control

In a sustainable ecosystem, insect pest populations may be kept in check by natural enemies such as other insects. Parasitoids, predators, pathogens, antagonists, or competitor populations that suppress pest populations are desirable in fields (Driesche & Bellows, 1996). Under current pest management programs in potatoes, especially with an intensive agricultural production system centered on frequent calendar sprays of broad-spectrum insecticides, the impact of natural enemies is relatively unknown (Koss, 2003; Rondon, 2010). In contrast, a lot of information regarding the biology and the potential of natural enemies (a.k.a., biological control agents) can be found in the literature (Rondon, 2010). The advantage of using biological control agents is that they have no pre-harvest intervals, and are safer for application personnel, consumers and non-target organisms.

In the Pacific Northwest region, a number of arthropod species attack insect pests at the egg, immature, and/or adult stage. Species of Heteroptera (former Hemiptera, Family Pentatomidae) such as *Podisus maculiventris* (Say) (spined soldier bug) and the *Perillus bioculatus* (Fabricius) (two-spotted stink bug), *Opolomus dichrosus* L. (no common name) can be found in potato fields feeding on *Leptinotarsa decemlineata* (Say) (Colorado potato beetle) (Ferro, 1994; Lacey et al., 2001). Tamaki et al., (1983) and Lopez et al., (1995) indicated that *Myiopharus doryphorae* L. (Tachinidae fly) and *Edovum puttleri* L. (Eulophidae wasp) are moderately efficient parasitoids of Colorado potato beetles. Nabidae (damsel bugs), Neuroptera (lace wings), Coccinellidae (lady bugs), Carabidae (ground beetles) and spiders are also common inhabitants in potato fields behaving as generalists feeding on aphids, thrips, small larvae and potato beetles.

3.2.5 Chemical methods

Traditional IPM text books recommend considering chemical controls only if other techniques do not result in adequate pest control. However, chemical controls can be effectively used with other techniques (e.g., cultural, physical, biological, etc.). When choosing a chemical, be sure to read the label and choose the right product; chemical selection can be the breaking point for success or failure in controlling target pests. Worldwide, the potato requires more pesticides than any other major food crop (CIP, 1994). Intense pesticide dependency has led to the development of pesticide resistance in cases such as the Colorado potato beetles in almost all potato-growing areas in the U.S. (Weisz et al.,1995). To date, the only exception of documented Colorado potato resistance to chemicals is in the Pacific Northwest (Schreiber et al., 2010). Management tactics that preserve susceptible genotypes and allow them to interbreed with resistant individuals have the greatest potential for resistance management according to Tabashnik (1989) and Weisz et al., (1996).

4. Potato pests in the Pacific Northwest

4.1 Wireworms (Order Coleoptera: Family Elateridae)

Wireworms are one of the most destructive insect pests in the Pacific Northwest. Nearly 40 species from 12 genera attack potato, but only a few are economically important (Hoy et al., 2008). In irrigated production, the most common wireworm species are the Pacific Coast wireworm *(Limonius canus* LeConte*)*, the sugar beet wireworm *(L. californicus* (Mannerheim)), the western field wireworm (*L. infuscatus* Motschulsky*)*, and the Columbia Basin wireworm (*L. subauratus* LeConte*)*. Areas with annual rainfall less than 15 inches may be infested with the Great Basin wireworm (*Ctenicera pruinina* (Horn)). West of the Cascade mountains *Agriotes* spp. is the most common pest. A complex of species may occur (Figure 4) (Andrew et al., 2008).

4.1.1 Pest description

Wireworms are the larval stage of click beetles. Adult click beetles are slender hard-shelled insects. They range in color from chocolate to dark brown and from about 0.8 – 1.9 cm long, depending on species. Click beetles get their name from their ability to snap a spine on their thorax that produces a "clicking" sound and allows them to jump in the air when distressed or disturbed. All beetles in the Elateridae family have this ability. This technique is used to avoid predation or to get back on their feet after falling on their backs. Depending on the

Fig. 4. Wireworms in the Pacific Northwest, from left: *Limonius canus*, *L. californicus*, *L. infuscatus*, *L. subauratus*, *Ctenicera pruinina*, and *Agriotes lineatus* (Photo by C.J. Marshall, Oregon State Arthropod Collection http://osac.science.oregonstate.edu).

species, each female after mating lays an average of 80 eggs, singly or in small clusters in the soil. Immature stages have a hardened and shiny shell and very few hairs (Fig. 5). They have three body regions with a distinct head, a thorax with 3 pairs of legs and a segmented abdomen with a tail-end (Jensen et al., 2011). Characteristics of the tail-end serve for identification purposes. Depending on species and age, wireworm larvae range from about 2 mm after hatching to 4 cm long or more at maturity. Wireworm pupae are first white, but later change to reddish-brown; they pupae in the soil.

Fig. 5. Wireworm larva (Photo by A. Jensen, Washington Potato Commission).

4.1.2 Damage
Wireworms can cause damage to potatoes by feeding upon potato seed pieces and sprouts in the spring, facilitating infection by pathogens or other insect pests. The latter damage can result in reduction in yield and/or rejection of the entire crop. In the U.S. there is zero tolerance for live larvae in tubers. Wireworms tend to be most damaging in potatoes that follow corn or small grains (wheat, barley) and on ground just entering cultivation. Wireworms damage potatoes both near planting time (damage to seed pieces) and during the growing season (damage to developing tubers). They can also be a problem at harvest and before entering storage.

4.1.3 Hosts
Potatoes, corn, wheat and grass are hosts for several species of wireworms in the Pacific Northwest. Also, beans, carrots, peas, and other annual crops may be infested; while melons, beet roots, and strawberry fruits are affected less frequently.

4.1.4 Biology
Adult click beetles emerge from pupae in the soil from late spring through late summer. In the Pacific Northwest, wireworms overwinter as larvae or adults. They can have up to a 7-year life cycle from egg to adult. Adults can fly, but usually remain in the areas where they developed as larvae. Eggs are laid in grassland or in cereal crops where larvae feed on grass roots and overwinter in the soil. Females tend to lay eggs in grassy areas. Larvae can live from 2-5 years in the soil, depending on the species. They require several years to mature and can overwinter at a depth of 30-100 cm or more in the soil, only to return near the surface in spring to resume feeding when soil temperatures exceed 50°F (10°C). Later in the season when temperatures reach 80°F (26.6°C) and above, the larvae tend to move deeper than 15 cm into the soil to escape the "heat" (Hoy et al., 2008; Schreiber et al., 2010). Wireworm larva can be confused with larvae of the family Tenebrionidae (false wireworms) or Tipulidae (crane fly). The Tenebrionidae group tends to be saprophagous while Tipulidae are associated with grassy crops.

4.1.5 Monitoring
Trapping should start early, especially in areas with history of wireworm problems. In the Pacific Northwest trapping starts mid to late March until April to May. Horton (2006) modeled the relationship between bait trap counts and crop damage by *L. canus* in Wapato, WA. Horton's model predicts tuber damage based on number of wireworms collected. Wireworm presence or absence in a field should be determined before using control measures. Unfortunately, current monitoring methods are time consuming, laborious and often do not accurately reflect field populations of this pest. Historically, wireworms have been monitored by extracting and sifting through soil cores to locate larvae. Since the distribution of wireworms in a field tends to be patchy and unpredictable, large numbers of samples are required to accurately estimate population size. Baits have largely replaced random soil sampling, since they are less labor intensive and may detect low wireworm populations. Baited traps can be constructed by placing 3-4 tablespoons of a mixed of wheat and corn seeds or rolled oats inside a fine mesh bag or nylon. The seed mixture should be soaked in water 24 hours prior to placement in the hole to facilitate germination. Dig a hole about 20-25 cm deep and 3.5- 4 cm wide at the soil surface (Horton, 2006). Bury the mixture

at the bottom of the hole. Fill the hole and mound a "soil dome" over the covered bait to serve as a solar collector and to prevent standing water. Cover each mound with a sheet of black plastic and cover the edges with soil to hold the plastic sheet down. The plastic collects solar radiation and speeds germination of the mixture. The germinating seeds attract wireworms. A few days later, remove the plastic and soil covering the bait and count the number of wireworm larvae found at each station. There are not specific recommendations as to how many traps per field should be placed, however, placement of the bait stations should represent different areas of a field (Campbell & Stone, 1939; Simmons et al., 1998)

4.1.6 Control

There are no effective natural enemies for wireworm. If one suspects wireworms are present in a field based on trapping, chemical control is the best management option (http://potatoes.com/Research-IPM.cfm). Fumigants are effective on wireworms that are present at the time of fumigation and within the zone of fumigation (Schreiber et al., 2010). Fumigants are sensitive to soil temperatures. In furrow applications are also effective; however, some rotational restrictions may apply (Schreiber et al., 2010). Use of contemporary chemicals in other crops suggests that stand protection and wireworm reduction are not covered with current chemicals available (Vernon et al., 2009).

4.2 Colorado Potato Beetle (Order Coleoptera: Family Chrysomelidae)

The Colorado potato beetle, *Leptinotarsa decemlineata* (Say), first described in 1824 by Thomas Say, is associated with potato plants and its solanaceous relatives such as nightshade. It is the most important defoliating insect pest of potato. Its remarkable ability to develop insecticide resistance, incredible reproductive potential and sustained feeding by larvae and adults, makes the management of this pest challenging (Hoy et al., 2008).

4.2.1 Pest description

The Colorado Potato Beetle (CPB) is a yellow and black striped beetle, about 1.3 cm long and 0.6 cm wide. They can be found in almost all U.S. potato regions. Larvae are reddish orange, with two rows of black spots on each side. Orange egg clusters are found mainly on the undersides of leaves, mostly in the top third of the plant. Eggs resemble ladybug eggs (Fig. 6).

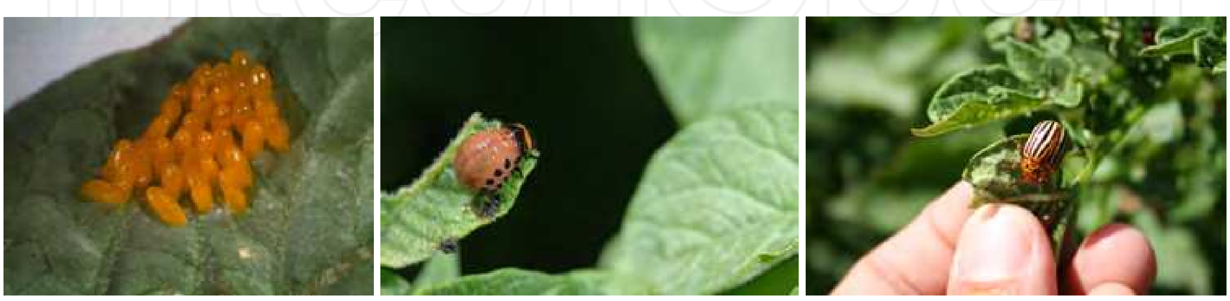

Fig. 6. Colorado potato beetle egg mass (left), larva (center), and adult (right). Photos by R. Marchosky (egg mass), L. Ketchum (larva), and S.I. Rondon (adult), OSU.

4.2.2 Damage
This beetle can cause complete defoliation and nearly complete crop loss if allowed to reproduce unchecked. Both larvae and adults feed on potato foliage throughout the season.

4.2.3 Hosts
Potatoes and other solanaceous plants such as eggplant, nightshade, horsenettle and buffalobur are preferred hosts of this pest.

4.2.4 Biology
Pupation and overwintering occur in the soil. Adults emerge from the soil to lay eggs in the spring. Depending on the region, this insect may have three generations in a season. Adult beetles spend the winter buried 10-25 cm in the soil and emerge in the spring just as the first volunteer potatoes appear. Recently emerged beetles either mate close to the overwintering sites or fly to new potato fields to find a mate. Usually first infestations occur around field margins. Eggs are deposited on potato foliage in masses. CPB eggs resemble lady beetle eggs. Larvae pass through four life stages and then burrow into the soil to pupate.

4.2.5 Monitoring
Start monitoring fields at crop emergence. There are no established treatment thresholds for CPB. Large CPB populations are harder to manage than small ones, thus the goal is to control this pest early in the season.

4.2.6 Control
Crop rotation may help in delaying or reducing CPB pressure. Colonizing beetles need to feed before laying eggs, so controlling volunteer potatoes and solanaceous weeds is important as are rotating crops and planting new potato fields far from the last year's potato fields (Schreiber et al., 2010). These practices will reduce the number of overwintering beetles migrating into the new field. This may not be a practical solution in the Pacific Northwest region since potatoes are use in rotation with other local crops such as wheat or corn. The use of "at planting" and systemic insecticides in early potatoes will contribute to the control of early-season CPB populations. The use of pyrethroid insecticides is not recommended since it has a direct effect on natural enemies. Targeting chemical applications to control eggs and young larvae when possible is recommended.

4.3 Green peach aphid and potato aphid (Order Heteroptera: Family Aphididae)
The aphid population in western North America, north of Mexico, is comprised of 1,020 species in 178 genera in 15 subfamilies (Pike et al., 2003). Several aphid species are known to be pests of potatoes, but the green peach aphid, *Myzus persicae* (Sulzer), and potato aphid, *Macrosiphum euphorbiae* (Thomas), are two of the most important vectors of diseases in the Pacific Northwest. Aphids are important due to their ability to transmit viruses. According to Hoy et al., (2008) there are six commonly found potato viruses transmitted by aphids: *Potato leafroll virus* (PLRV), multiple strains of *Potato virus Y* (PVY), *Potato virus A* (PVA), *Potato virus S* (PVS), *Potato virus M* (PVM), and *alfalfa mosaic virus* (AMV). PLRV and PVY are transmitted by several species of aphids but primarily by green peach aphid. The potato aphid transmits PVY and PVA.

4.3.1 Pest description

Green peach aphids are small, usually less than 0.3 cm long. The body varies in color from pink to green with three darker stripes down the back. The head has long antennae which have an inward pointing projection or tubercle at its base (Fig. 7). Potato aphids are larger than green peach aphids with a body somewhat elongated and wedge-shaped (Fig. 8). The adults of both species may be winged (alatae) or wingless (apterous). Winged forms are usually triggered by environmental changes (e.g., decreasing photoperiod or temperature, deterioration of the host plant or overcrowding) (Branson et al., 1966). On the back of the fifth abdominal segment, a pair of tube-like structures called "siphunculi", "cornicles", or "pipes" are present on most aphid species. The green peach aphid present a "swollen" cornicles with a dark tip, while the cornicles on the potato aphid are 1/3 of the length of the body and are usually curved slightly outward (Alvarez et al., 2003).

Fig. 7. Green peach aphid wingless adult (left) and alatae (right). Photos by A. Jensen, Washington Potato Commission.

Fig. 8. Potato aphid wingless adult and nymphs (left) and alatae (right). Photos by A. Jensen, Washington Potato Commission.

4.3.2 Damage

In general, aphids injure plants directly by removing sap juices from phloem tissues. They also reduce the aesthetic quality of infested plants by secreting a sugary liquid called "honeydew" on which a black-colored fungus called "sooty mold" grows. The "sooty mold" reduces the photosynthetic potential of the plant. Most importantly, aphids transmit plant diseases, particularly viruses. Aphids on potato are serious pests because of their ability to transmit several plant diseases such as PLRV (transmitted mainly by green peach aphid) and PVY (transmitted by several species of aphids). PLRV causes necrosis while strains of PVY can cause internal brown lesions in the tubers. Srinivasan & Alvarez (2007) reported that mixed viral infections of heterologous viruses occur regularly in potatoes.

4.3.3 Hosts

The green peach aphid, also known as tobacco or spinach aphid, survives the winter in the egg stage on peach trees. They can also overwinter on various perennial, biennial, and winter annual weeds, such as tumble mustard, flixweed, shepherd's-purse, chickweed, mallow, horseweed, pennycress and redstem filaree. Besides potatoes and peaches, other hosts include lettuce, spinach, tomatoes, other vegetables and ornamentals (Dickson & Laird, 1967; Wallis, 1967; Tamaki et al., 1980; Barry et al., 1982).

4.3.4 Biology

Green peach aphid migrates to potatoes in the spring from weeds and various crops where it has overwintered as nymphs and adults, or from peach and related trees where it overwinters as eggs. Most aphids reproduce sexually and develop through gradual metamorphosis (overwintering diapause egg, nymphs and winged or wingless adults) but also through a process called 'parthenogenesis' in which the production of offspring occurs without mating (Jensen et al., 2011). Potato aphids also overwinter as active nymphs, adults or eggs; eggs are laid on roses and sometimes other plants. Throughout the growing season aphids produce live young, all of which are female and can be either winged or wingless. In some instances, aphids undergo sexual, oviparous reproduction as a response of a change in photoperiod and temperature, or perhaps a lower food quantity or quality, where females produce sexual females and males. In the fall, winged males are produced which fly to overwintering hosts and mate with the egg-laying females produced on that host. Aphids found in the region undergo multiple overlapping generations per year (Jensen et al., 2011, Schreiber et al., 2010).

4.3.5 Monitoring

Fields should be checked for aphids at least once a week starting after emergence. The most effective scouting method is beating sheets, trays, buckets or white paper. There are no well-established treatment thresholds for aphids in potatoes in the Pacific Northwest but since aphids transmit viruses, producers are encouraged to control aphids early in the season, especially in seed potato producing areas. Schreiber et al., (2010) recommend a minimum sample size of ten locations per 100 acre field. For potatoes that are not to be stored, application of foliar aphidicide should begin when 5 aphids per 100 leaves or 5 aphids/plant are detected. Hoy et al., (2008) suggests some sampling methods and action thresholds for colonizing aphids on processing potatoes, table stock, and seed potato in different productions thresholds.

4.3.6 Control

Weed control and elimination of secondary hosts are critical. Early aphid infestations commonly occur on a number of weeds including species of mustards and nightshade; therefore, those weeds should be kept under control. Research in Idaho indicates that hairy nightshade is an excellent aphid and virus host (Srinivasan & Alvarez, 2007), thus, control of this weed is highly recommended. In some instances, the number of insects available to infest crops in the spring depends upon winter survival (DeBano et al., 2010). Thus, the elimination of overwintering sites is recommended if possible. Peach trees are the most common winter hosts, although apricots and several species of Prunus are sometimes infested (Schreiber et al., 2010). A large numbers of generalist predators feed on aphids including the minute pirate bugs, big-eyed bugs, damsel bugs, lady beetles and their larvae, lacewings, flower fly larvae, and aphid-specific parasitoid wasps. If aphids are present, use of insecticides in commercial fields should occur as soon as non-winged aphids are detected. In seed producing areas, preventive methods are recommended. Application of foliar aphidicide should begin just prior to the decline in performance of seed-treatment insecticides applied at planting (60 days after planting, Rondon unpublished). Schreiber et al., 2010 indicated that complete insect control from planting until aphid flights have ceased is the only means to manage diseases in full season potatoes.

4.4 Beet leafhopper (Order Heteroptera: Family Cicadellidae)

The beet leafhopper, *Circulifer tenellus* Baker, is the carrier of the beet leafhopper-transmitted virescence agent (BLTVA) phytoplasma (a.k.a., Columbia Basin potato purple top phytoplasma) that causes significant yield losses and a reduction in potato tuber quality.

4.4.1 Pest description

The beet leafhopper (BLH) is a wedge-shaped and pale green to gray or brown in color. It has several nymphal instars (Fig. 9). Adults may have dark markings on the upper surface of the body early and late in the season (”darker form”) or clear during the season (“clear form”) (Fig. 10).

Fig. 9. Beet leafhopper nymphs. Photos by A. Murphy, OSU.

4.4.2 Damage

Beet leafhoppers must feed in the phloem of the plant. Direct feeding can cause relatively minor damage (“hopperburn”); however, BLTVA is a very destructive and detrimental disease affecting potatoes. BLTVA can cause a wide range of symptoms in potatoes, including leaf curling and purpling, aerial tubers, chlorosis, and early senescence. Most BLTVA infection occurs early in the season, during May and June (Munyaneza, 2003; Munyaneza & Crosslin, 2006). Potato is not a preferred host for BLH and will not spend much time on the crop (however it does spend enough time to transmit BLTVA) (Schreiber et al., 2010).

4.4.3 Hosts

Among the favorite hosts are Kochia, Russian thistle, and various weedy mustard species such as tumble mustard. Beet leafhoppers are especially abundant on young, marginal, semi-dry and small weeds plants. They also thrive on radishes, sugar beet (Meyerdirk & Hessein, 1985), and carrots (Munyaneza, 2003).

4.4.4 Biology

The beet leafhopper overwinters on rangeland weeds and migrates to potatoes as early as May. They overwinter as adult females in weedy and native vegetation throughout most of the dry production areas. The beet leafhopper has three life stages: egg, nymph and adult. The adult can have a "darker form", early or late in the season; and a "clear form (during the season) (Fig. 10). Beet leafhoppers can transmit BLTVA as adults and nymphs. Eggs are laid in stems of host plants, and a new spring generation begins developing in March and April. Beet leafhopper begins to move from weeds to potatoes and potentially affect potatoes during the first spring generation, which matures in late May to early June (Jensen et al., 2011). Potatoes are most seriously affected by BLTVA infections that occur early in the growing season (Rondon unpublished). Beet leafhopper remains common through the summer, during which it goes through 2 to 3 overlapping generations. The final generation for the year matures during late October-early November. Total number of beet leafhoppers varies from year to year (Crosslin et al., 2011).

Fig. 10. "Clear form"(left) and "dark form" (right) of the beet leafhopper. Size of adults 2.5-3 mm. Photos by A. Jensen, Washington Potato Commission.

4.4.5 Monitoring

Because potatoes are not a preferred host of the BLH, in-field sampling is problematic. Most recommendations suggest the use of yellow sticky cards around field margins. It is important to keep traps close to the ground where hoppers mostly move. Check and replace traps at least once a week. Rondon (unpublished data) suggests the use of DVAC (modified leaf blowers) to collect leafhoppers.

4.4.6 Control

Weed control in areas surrounding the potato field can help reduce initial sources of BLTVA inoculum. Due to the nature of the pest, few biological control efforts have been taking place in the Pacific Northwest. However, a species of *Anagrus* (Hymenoptera Mymaridae), has been reported as a common egg parasitoid in California (Meyerdirk & Moratorio, 1987).
Foliar insecticides can reduce BLH populations and ergo, the incidence of the disease. Based on extensive research conducted in the Pacific Northwest, there are several foliar applied insecticides that are effective against BLH. Some evidence suggests that the use of some neonicotinoid insecticides at planting may provide control of BLTVA (Schreiber et al., 2010).

4.5 Potato Tuberworm (Order Lepidoptera: Family Gelechiidae)

The potato tuberworm, *Phthorimaea operculella* Zeller, is one of the most economically significant insect pests of cultivated potatoes worldwide. The first significant economic damage to potato crops in the Columbia Basin region occurred in 2002, when a field in Oregon showed high levels of tuber damage associated with potato tuberworm. By 2003, the pest was a major concern to all producers in the region after potatoes from several fields were rejected by processors because of tuber damage. Since then, potato tuberworm has cost growers in the Columbia Basin millions of dollars through increased pesticide application and unmarketable potatoes (Rondon, 2010).

4.5.1 Pest description

The potato tuberworm has four life stages: adult, egg, larva and pupa. Adults are small moths (approximately 0.94 cm long) with a wingspan of 1.27 cm. Forewings have dark spots (2-3 dots on males; “X” on females). Both pairs of wings have fringed edges (Rondon & Xue, 2010) (Fig. 11). Eggs are ≤ 0.1 cm spherical, translucent, and range in color from white or yellowish to light brown. Eggs are laid on foliage, soil and plant debris, or exposed tubers (Rondon et al., 2007); however, foliage is the preferred oviposition substrate (Varela, 1988). Adult female moths lays 150-200 eggs on the underside of leaves, on stems, and in tubers (Hoy et al., 2008). Larvae are usually light brown with a characteristic brown head. Mature larvae (approximately 0.94 cm long) may have a pink or greenish color (Fig. 12). Larvae close to pupation drop from infested foliage to the ground and may burrow into the tuber. Ultimately, larvae will spin silk cocoons and pupate on the soil surface or in debris under the plant.

Fig. 11. Forewings of potato tuberworm adult females present an “x” pattern (left); while male (right) present 2-3 dark spots. Photos by OSU (Rondon 2010).

Fig. 12. Potato tuberworm larva entering tuber. Photo by L. Ketchum, OSU.

4.5.2 Damage

Tuberworm larvae behave as leaf miners. They can also live inside stems or within groups of leaves tied together with silk. The most important damage is to tubers, also a food source for the larvae, especially exposed tubers, or those within centimeters of the soil surface. Larvae can infest tubers when foliage is vine killed or desiccated right before harvest (Clough et al, 2010). Tunnels left by tuber worms in tubers can be full of droppings or excrement that can be a potential source for secondary infections.

4.5.3 Hosts

Although the potato tuberworm host range includes a wide array of Solanaceous crops such as tomatoes, peppers, eggplants, tobacco, and weeds such as nightshade, the pest has been found only on potatoes in the Pacific Northwest region (Rondon, 2010).

4.5.4 Biology

Potato tuberworm adults emerge as early as April in the Pacific Northwest, and continue to threaten the crop through November. Populations build sharply later in the growing season (September and October). The potato tuberworm has been detected in all potato growing regions of Oregon and throughout the Columbia Basin of Washington. A limited number of adults have been trapped in western Idaho. No tuber damage has been reported in Idaho (Rondon, 2010). A recent study suggests that locations with higher spring, summer, or fall temperatures are associated with increased trapping rates in most seasons (DeBano et al., 2010). Occasionally potato tuberworm pupae can be found on the surface of tubers, most commonly associated with indentations around the tuber eyes, but usually are not found inside tubers (Rondon et al., 2007). Considering the duration period of each instar and its relationship to abiotic factors such as temperature, the potato tuberworm can undergo several generations per year in the Pacific Northwest region.

4.5.5 Monitoring

Pheromone-baited traps to catch adult male moths have been widely used in the region (Rondon et al., 2007). Unfortunately there are no established treatment thresholds. Another way is to check leaf mining. Most mines are found in the upper third of the plant canopy, suggesting that efficient scouting for foliar damage should focus on the top third of the plant (DeBano et al., 2010). The number of mines gives a good indication of the history of potato tuberworm infestation in a plant, but it does not necessarily indicate the severity of larval infestation at a point in time. The study also found that reasonably precise estimates of foliar damage for areas of 23 ft x 30 ft can be made by sampling 9 plants (DeBano et al., 2010).

4.5.6 Control

Control efforts should be directed toward tuberworm populations right before or at harvest. Females prefer to lay eggs on potato foliage, but when potato foliage starts to degrade and change color, or when it is vine-killed, the risk of tuber infestation increases greatly. The greatest risk for tuber infestation occurs between desiccation and harvest (Clough et al., 2010; Rondon, 2010). If tuberworm populations appear to be building prior to late season, additional control measures may be necessary. Other means of control include the elimination of cull piles and the elimination of volunteer potatoes. Daily irrigation that keeps the soil surface moist can also aid in the control of tuberworm populations. Most chemical products aim to reduce larva population in foliage but that technique does not provide 100% protection for the tubers.

4.6 Occasional pests

4.6.1 Mites

The two-spotted spider mite, *Tetranichus urticae* Koch, is the most abundant mite species found in potatoes in the Pacific Northwest. They can occasionally be considered pests of potatoes when crops such as beans, corn, alfalfa or clover seed are planted nearby (Hoy et al., 2008). Mites in general prefer hot and dry conditions; they also prefer stressed plants where irrigation is poorly managed. They damage plants by puncturing the leaf tissue to extract plant juices. Plants respond by changing color from green to brown. Spider mites overwinter in the area as adults in debris around field edges (Jensen et al., 2011). Females are very prolific; after emerging from overwinter, they mate and lay eggs on the underside of leaves. If temperatures are warm (75-80^{o}F or 23.8-26.6C), eggs can hatch in 3-5 days; nymphs to adults can take place in 7-9 days at those temperatures. When leaves get overcrowded, mites climb to the top of the plant and secrete silk that can be used as a "transport" device during light to moderate winds conditions (Fig. 13).

Sampling for mites requires a close visual inspection of leaves from different levels of the plants. Shaking potentially infested leaves above a piece of white paper helps to determine the presence of mites. Applications of miticides should be made upon early detection of mites. All potatoes should be surveyed for the presence of mites and mite eggs starting mid-season (Schreiber et al., 2010). Thorough coverage is essential for good control and it is suggested that foliage should be dry at the time of application. While a single application of a miticide will suffice, if a second application of a miticide is required, the use of a miticide with different chemistry should be considered as a resistance prevention strategy (Jensen et al., 2011).

4.6.2 Cutworm, armyworm and loopers

These are several species of moth larvae that affect potato crops. Cutworms, armyworms and loopers are the immature stages of lepidopteran moths. Moths' typically have four defined life stages: egg, larva, pupa and adult. The most common species in the Pacific

Fig. 13 Two spotted spider mite adults range in size from 0.25 mm to 0.5 mm long; eggs are around 0.1 mm. Adults and nymphs are pale yellow or light green with two dark spots on the abdomen (Photo by R.E. Berry, OSU).

Northwest regions are listed below (Table 2). Cutworms feed on potato seeds, cut stems, and foliage; armyworms and loopers feed on foliage throughout the season. Cutworms and armyworms have three pairs of true legs and five pairs of prolegs behind; loopers have only three pair of true legs and three pair of prolegs behind. At planting insecticides protect potato seed from cutworms; however, after the residual effect is gone, the crop is unprotected; in some years, a foliar chemical application may be needed. Potatoes can tolerate some worm defoliation without loss in marketable yield. The period of full bloom is the most sensitive plant growth stage, but even then defoliation on the order of 10% appears to cause little if any yield loss. Applications should be targeted to control small larvae (1st and 2nd instars), rather than larger larvae (Schreiber et al., 2010, Jensen et al., 2011).

Group	Common name	Scientific name
Cutworms	Spotted cutworms	*Xestia c-nigrum*
Western yellow striped armyworm	Bertha armyworm	*Mamestra configurata* Walker
Looper	Alfalfa looper	*Autographa californica* (Speyer)
	Cabbage looper	*Trichoplusia ni* (Hübner)

Table 2. Most common cutworm, armyworm, looper species in the Pacific Northwest (Zack. et al., 2010).

4.7 Resistance to insecticides

Insecticides are the most powerful tool available for use in pest management (Metcalf, 1994). However the misuse, overuse and historically unnecessary use of insecticides have been some of the most important factors in the increasing interest in integrated pest management (Von Rumker & Horay, 1972; Metcalf, 1994). In the last decades, the Insecticide Resistance Action Committee (IRAC), a group of technical experts that coordinates responses to prevent or delay the development of resistance in insect and mite pests, defined resistance to insecticides as a "heritable change in the sensitivity of a pest population that is reflected in the repeated failure of a product to achieve the expected level of control when used according to the label recommendations for that pest species" (http://www.irac-online.org/). In other words, it is the inherited ability of a pest population to survive a pesticide which is a result of a process of selection (Hamm et al., 2008). Some potato pests have developed resistance to certain groups of pesticides; however, significant insecticide resistance is not yet known to occur in the Pacific Northwest (University of California, 1986). For instance, while spider mite infesting potatoes has demonstrated the ability to readily develop resistance to miticides there appears to be no evidence of this problem developing in the U.S. Pacific region (Schreiber et al., 2010).

Pesticides such as pyrethroids that disturb natural enemies can cause a resurgence of primary or secondary pests, especially when applied mid to late season. In the past few years, package mixes of insecticide, some including pyrethroids have been available for use on potatoes. More research is needed to evaluate the real impact of this pesticide in the Pacific Northwest potato region. Seed and soil treatments with systemic insecticides have become a standard approach to control early "invaders" (Hoy et al., 2008). This approach may be less disruptive to predator and non-target insects than traditional foliar or ground chemical applications.

There are several key components to developing a resistance management program for insect pests: first, producers must employ non-chemical control tactics for control of pest problems, including irrigation, cultivation and proper fertilization management; second, producers must rotate insecticidal modes of action. This integrated pest management approach will lead producers to a sustainable production system with long term economic benefits. Alvarez et al., (2003) suggest keeping good records of chemical applications, rotating insecticide use changing not only the product but also the class of compound, applying insecticides at labeled rates, using newer insecticides with chemistries that are safer for applicators and non-target organisms, and reducing insecticide applications by scouting and making applications only as needed.

5. Conclusions

Potato is one of the most important food crops widely grown over many latitudes and elevations over the world. Increasing potato production in a sustainable manner requires an integrated approach covering a range of strategies. Combating pests is a continuous challenge that producers have to face as they intensify their production techniques to satisfy the increasing demands of the global market.

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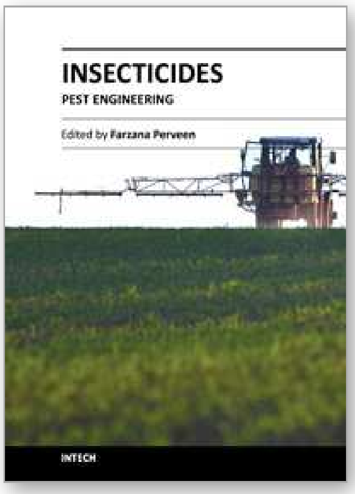

Insecticides - Pest Engineering
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This book is compiled of 24 Chapters divided into 4 Sections. Section A focuses on toxicity of organic and inorganic insecticides, organophosphorus insecticides, toxicity of fenitrothion and permethrin, and dichlorodiphenyltrichloroethane (DDT). Section B is dedicated to vector control using insecticides, biological control of mosquito larvae by Bacillus thuringiensis, metabolism of pyrethroids by mosquito cytochrome P40 susceptibility status of Aedes aegypti, etc. Section C describes bioactive natural products from sapindacea, management of potato pests, flower thrips, mango mealy bug, pear psylla, grapes pests, small fruit production, boll weevil and tsetse fly using insecticides. Section D provides information on insecticide resistance in natural population of malaria vector, role of Anopheles gambiae P450 cytochrome, genetic toxicological profile of carbofuran and pirimicarp carbamic insecticides, etc. The subject matter in this book should attract the reader's concern to support rational decisions regarding the use of pesticides.