American Journal of Potato Research (2021) 98:5–11
https://doi.org/10.1007/s12230-020-09813-0

SYMPOSIUM

Decision Support for Potato Growers using a Pest Monitoring Network

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Accepted: 23 November 2020 / Published online: 6 January 2021

Abstract

Pest monitoring networks form the foundation of many integrated pest management programs in agroecosystems throughout the world. These monitoring networks tend to focus on widely dispersed and highly variable insect pest populations that can cause significant crop loss without intervention. By assessing the distribution and abundance of insects over growing seasons, pest monitoring networks help growers anticipate problems and use proactive rather than reactive management tactics; this promotes timely decision making that usually leads to more effective and cost-efficient pest management. There are several key considerations for developing and operating a successful pest monitoring network: (1) they can be costly and require a regular funding source; (2) the monitoring methods must be appropriate for the pest and adequately distributed (spatially and temporally) to locate infestations; (3) the monitoring data must be provided through timely communications that can be easily accessed by growers or other decision makers; (4) monitoring results should be explained so they can be easily interpreted; and (5) communications should include recommendations for next steps, such as guidance in identifying and scouting for the pest, cultural management approaches, and appropriate use of chemical controls. In this paper, we relate our experiences operating an insect pest monitoring network in potato crops grown in the Columbia Basin of Washington in the United States. We discuss our efforts to fund the program, operate more effectively, and continually improve the content of our communications.

Resumen

Las redes para monitorear plagas forman los cimientos de muchos programas de manejo integrado de plagas en agroecosistemas en el mundo. Estas redes de monitoreo tienen la tendencia de enfocarse en poblaciones de insectos plaga dispersadas ampliamente y altamente variables, que pueden causar pérdidas significativas de los cultivos si no hay intervención. Mediante el análisis de la distribución y abundancia de insectos a lo largo de los ciclos de cultivo, las redes de monitoreo de plagas ayudan a los productores a anticipar problemas y el uso de tácticas de manejo proactivas en vez de reactivas; esto promueve la toma de decisiones a tiempo, que generalmente conduce a un manejo de plagas mas efectivo y eficiente en costos. Hay varias consideraciones clave para el desarrollo y operación de una red de monitoreo de plagas exitosa: (1) Pueden ser costosas y requerir de una fuente regular de financiamiento; (2) Los métodos de monitoreo deben se apropiados para la plaga y distribuirse adecuadamente (espacio-temporalmente) para localizar infestaciones; (3) los datos del monitoreo deben ser suministrados a través de comunicaciones a tiempo que pudieran ser fácilmente accesibles por los productores u otros que toman decisiones; (4) los resultados del monitoreo deberían explicarse, de manera que puedan ser fácilmente interpretados; y (5) las comunicaciones deben incluir recomendaciones para pasos siguientes, como guía en la identificación y vigilancia de la plaga, estrategias de manejo cultural, y uso apropiado de controles químicos. En este artículo relatamos nuestras experiencias en la operación de una red de monitoreo de insectos plaga en cultivos de papa en la rivera del Columbia en Washington, Estados Unidos de Norteamérica. Discutimos nuestros esfuerzos para encontrar el programa, operar más efectivamente, y el mejoramiento continuo del contenido de nuestras comunicaciones.

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Keywords Pest monitoring · Pest management · Scouting · Aphid · Beet leafhopper · Potato tuberworm · Potato psyllid

Introduction

Pest monitoring is an essential part of a grower's integrated pest management (IPM) plan. Most pest problems are sporadic and unpredictable, but effective scouting for pests can confirm their presence and help growers decide when and where control measures are needed. Identifying pest problems early, before significant economic damage has been done to plants, usually leads to more effective management that mitigates crop losses and limits control costs. Moreover, effective pest monitoring allows growers to time their control measures to coincide with a specific pest life stage or level of pest abundance, which can be useful in promoting more effective control. For many growers, however, pest monitoring can be a laborious, expensive, and imprecise activity.

Pest monitoring networks operate in agricultural regions in many parts of the world (Faust 2008). Such networks involve sampling at many sites over space and time, providing information about the temporal and spatial distribution of pests across large areas. Monitoring networks are often used to detect early infestations and identify areas within a larger region where pests are most abundant. These programs help growers know when and where to anticipate infestations, scout for pests, and implement pest management activities. Pest monitoring networks tend to focus on widely dispersed and highly variable insect populations that can give rise to major outbreaks and crop losses when left unchecked. They are particularly useful for informing regional IPM programs, where local interventions of pest problems help to lessen the impact of pest outbreaks at broader scales. The observations from regional pest monitoring networks, when gathered over multiple seasons, also offer insight into the phenology and seasonal population dynamics of insect pests; this includes information about migratory patterns, timing of pest arrivals, number of generations in a season, population size, and seasonal disparity in population size. These data can be used to forecast or predict pest infestations, and when communicated to growers, can provide early warning about imminent pest outbreaks.

Pest monitoring programs ought to do more than collect pests and report their numbers, however, if they are meant to guide growers and keep pest outbreaks in check. There are many aspects to managing a successful pest monitoring network and operators should consider: (1) funding; (2) pest monitoring methods; (3) means of communicating results with growers; (4) interpreting results; and (5) making subsequent pest management recommendations. In this paper, we relate our experiences operating an insect pest monitoring network in potato crops of the Columbia Basin of Washington in the United States (U.S.). We discuss our efforts to fund the program, operate more effectively, and improve the content of our communications with each season.

Discussion

Study System

Washington's growers produce more than 20% of the U.S. potato crop on about 165,000 acres annually (USDA 2018). The vast majority of potato production in Washington is in the irrigated parts of the Columbia Basin in the center of the state. Potato growers in the Columbia Basin depend on reliable yields of marketable tubers to realize profits and maintain economic viability (Galinato and Tozer 2016). They invest large sums in the crop and tend to take a risk-averse approach to pest management to protect their investment, meaning they are often willing to spend more to aggressively manage pests rather than risk the uncertainty of yield or quality losses. The penalties for crop losses and failure are high. Potato processing contracts reduce payments for crops that fail to meet predetermined yield and quality expectations, and processors can refuse to take a crop if defects exceed specified amounts. Potato growers in the Columbia Basin walk a tight line between profit and loss; the net return for processed potatoes is around \$187 per acre, which is only 3.6% over total costs (Galinato and Tozer 2016). In the recent past, potato growers in this region relied primarily on calendar-based applications of broad-spectrum insecticides (i.e., those that control many kinds of insects) to control an array of important potato pests. However, growers face increasing pressure from distributors and consumers to reduce pesticide inputs and are increasingly turning to more selective insecticides for pest management. These products are usually more expensive than broad-spectrum chemicals, and pest management costs have further increased due to new and emerging pest problems (Greenway and Rondon 2018).

As a result, the potato industry is shifting to a more information-driven approach to pest management. To assist potato growers, personnel at Washington State University (WSU) established an insect pest monitoring network in the Columbia Basin (Wohleb 2013). When the program started in 2009, we targeted three insect pests that have caused considerable crop losses in the region: aphid (*Myzus persicae* and other spp.), beet leafhopper (*Circulifer tenellus*), and potato tuberworm (*Phthorimaea operculella*). Shortly after, we added our observations of other pests that were sometimes encountered while sampling plants for aphids, including Colorado potato beetle (*Leptinotarsa decemlineata*), lygus bug (various *Lygus* spp.), and two-spotted spider mites

(*Tetranychus urticae*). Another important pest, potato psyllid (*Bactericera cockerelli*) was added in 2012 (Wohleb and Waters 2018) following the initial outbreak of zebra chip disease in the Pacific Northwest the previous year (zebra chip is vectored by potato psyllids) (Crosslin et al. 2012a, b; Munyaneza 2012). The insect monitoring program provides potato growers in the Columbia Basin with current information about the distribution and prevalence of these important pests. This information is communicated, along with pest management recommendations, in an emailed newsletter, *WSU Potato Pest Alerts*, which is sent to subscribers weekly during the growing season. Information is also posted on our new *Potato Decision Aid System* website (https://potatoes.decisionaid.systems/).

Expenses and Funding

Pest monitoring networks require funding to operate. Funds are needed for pest monitoring equipment and supplies, personnel salary and benefits, and other operating costs like mileage and vehicle maintenance. They may require initial investments for permanent or reusable equipment, such as suction traps or water pan traps that are used to collect aphids, while other supplies, like pheromone lures or sticky cards used to attract and trap insects, need to be purchased regularly. Sticky cards are inexpensive, but we deploy thousands of them in a season to operate our *Potato Pest Monitoring Network* (PPMN) in the Columbia Basin, and those costs add up; in fact, we spend almost $9000 USD on yellow sticky cards each year for monitoring potato psyllids and beet leafhoppers. It takes people to deploy and manage insect traps, collect samples, sort through and identify insect pests, record findings, and write reports. Wages and benefits for personnel who perform many of these tasks are the largest expense for our PPMN. Some pest monitoring programs limit personnel expenses by using volunteer assistance. For instance, the *Aphid Alert Network* in Minnesota and North Dakota developed a system of solar powered suction traps that are maintained and serviced by volunteer grower-cooperators (MacRae 2017). This reduces their operating expenses considerably, but they still pay laboratory technicians to sort through samples and identify aphid species. In our case, some insect identification is done in the field and requires training and strict adherence to a protocol, so we prefer not to rely on volunteers. The use of volunteer assistance also limits the *Aphid Alert Network's* expenses for travel to monitoring sites. The PPMN's second largest expense is for mileage and vehicle maintenance; we drive about 25,000 miles each season (950 miles per week for 27 weeks) to collect samples in potato fields and collect and maintain insect traps that are widely distributed across a large geographic region (encompassing about 4600 mile^2).

Some pest monitoring programs also incur costs for testing insect vectors to determine if they carry important plant pathogens. For example, all of the potato psyllids we collect via the PPMN are assayed using polymerase chain reaction to determine whether they carry the zebra chip pathogen (*Candidatus* Liberibacter solanacearum). This involves removing psyllids from sticky cards, placing them in microcentrifuge tubes, and mailing them to the USDA-ARS Yakima Agricultural Research Laboratory (YARL) for analysis (scientists at the YARL have performed these tests for us since 2012). Other programs perform similar assays in their own laboratories, so they have added expenses for testing apparatus, reagents and other supplies, and laboratory personnel. These tests, whether outsourced or done in-house, require a source of funding.

There are also fees associated with communicating pest monitoring results to growers, whether it is via mailings, phone-in hotlines, text alerts, e-newsletters, apps, or website postings. Website and app development usually requires paid technical support and may also involve maintenance costs. Subscription fees may be owed to web-based newsletter platforms, such as MailChimp® and Campaigner®; some offer free services if the subscriber list is relatively small and a limited number of emails are sent. Communications via blogs and social media (e.g., Twitter and Facebook) may be free, but as with all information outlets, paid personnel have to write the announcements and reports and ensure they reach the target audience.

There are many ways to fund pest monitoring programs. Our program is mainly supported by potato growers through an annual grant of the Washington State Potato Commission (WSPC). This is supplemented with state-based funds for the salaries and benefits of university faculty who contribute their time and effort to the program. Occasionally, we acquire additional state or federal grants to expand the program, improve program outputs, and learn more about the pests we monitor. Over the years we have secured additional grants and partnerships to (1) create and validate GIS (geographic information system) maps (i.e., heat maps) that show interpolated insect pest densities across the region (Crowder and Wohleb 2017); (2) develop phenology models for the insects we target (D'Auria et al. 2016); (3) develop a potato decision-support website; (4) expand our insect monitoring network to include potato psyllids and assay them for the zebra chip pathogen (Wohleb and Waters 2018); (5) explore alternate and overwintering host plants for potato psyllids (Cooper et al. 2019; Thinakaran et al. 2017); (6) map and compare genetically distinct potato psyllid populations in the region (Cueva et al. 2018); and (7) determine which species of lygus bug (*Lygus* spp.) are found in potato in the Columbia Basin, and learn whether species composition is influenced by surrounding crops.

Some pest monitoring programs receive support through private company sponsorships in return for advertisement. The advertisements, however, do not usually constitute product endorsements. Other web-based decision-support systems for pest management are fee-based (i.e., partially funded through paid subscriptions to access the website).

Monitoring Methods

Various methods and tools are used for pest monitoring. Insects may be sampled with the help of beat sheets, sweep nets, or vacuums, and by collecting leaf samples. Some examples of trapping devices include suction samplers, light traps, pitfall traps, baited traps, or sticky traps used in combination with an insect attractant like a sex pheromone or color (yellow is the most common, though some insects are more attracted to blue or other colors). Identifying the best method for detecting infestations early, or for estimating insect population size, usually requires some trial and comparison, and includes procedural considerations, such as trap positioning and location. The beat bucket method (a modification of beat sheet sampling) we use to monitor aphids was developed by Keith S. Pike, Emeritus WSU Professor of Entomology. He established an aphid monitoring program in the Columbia Basin in the 1990's to help potato growers control green peach aphids (*Myzus persicae*) and potato aphids (*Macrosiphum euphorbiae*) and limit the spread of *Potato Leafroll Virus*. He managed the *Aphid Monitoring Program and Hotline* in Washington for almost two decades. The methods we use to monitor beet leafhoppers, with yellow sticky cards (Jensen 2008a), and potato tuberworm, using delta traps with pheromone lures and sticky liners (Jensen 2008b), were adapted by practitioners who dealt with important outbreaks of these pests in the early 2000's. We tried various methods for monitoring potato psyllids following the zebra chip outbreak of 2011, but eventually adopted the methods, using a combination of yellow sticky cards and leaf samples, that were recommended by the operators of a potato psyllid monitoring program in Idaho (Wenninger et al. 2017).

Monitoring activities should be adequately distributed, both spatially and temporally, to locate infestations in the region. Knowing when and where to monitor an insect pest requires careful observation of the pest's migratory pattern and an understanding of potato production in the region. For instance, we deploy traps for monitoring beet leafhoppers in April, because we know that the first generation of beet leafhoppers migrates towards potatoes in late May and early June. We pay particular attention to traps located on the western edge of the region at this time, because this is where they usually make their first appearance and in the largest numbers. Potato tuberworm infestations typically occur first in the southernmost part of the Columbia Basin and extend northward as temperatures warm. Thus, an important consideration of our monitoring efforts is to work with personnel from Oregon State University who conduct monitoring in northern Oregon (directly south of the Columbia Basin in Washington); pest monitoring often is most effective when coordinated across human-made borders.

It is also important to comprehend the limitations of your monitoring methods. We deploy sticky cards near field edges to intercept pests like aphids or potato psyllids when they are migrating into (or out of) potato fields. However, this method does not help us know if a field has become infested or if control measures are working after these pests have entered the field. That usually requires examining plants for insects within fields. So, we collect leaf samples and beat bucket samples to look for colonizing potato psyllids and aphids respectively.

Communicating with Growers

We put a lot of effort into our weekly communications with growers and allied potato industry personnel (crop consultants, processing company representatives, etc.). Results from monitoring should be delivered in timely reports that are easily accessible to growers; the information is less likely to benefit them when it is delayed, and may not be conveyed at all if the reports are difficult to find or inconvenient to retrieve. When we started the PPMN in 2009, weekly monitoring results were posted to a website. The following year, we started sending updates via email as a more expedient way to reach busy potato growers and let them know the results were in. A typical comment from one of our growers was, "I like the emails because I don't have to look up a website or make a phone call". The emails gradually evolved into an e-newsletter called *WSU Potato Pest Alert*s. The e-newsletter includes a summary of weekly monitoring results, education about the pests and the problems they cause, and management recommendations that combine scouting, conservation of beneficial pest predators, and guided use of insecticides. *WSU Potato Pest Alerts* also include GIS-maps that show predicted pest densities for aphids, beet leafhoppers, potato tuberworm, and potato psyllids across the region. The maps are made by incorporating our data into a model that uses inverse distance weighting to interpolate pest densities for the entire region (Crowder and Wohleb 2017). The maps are color-coded to represent different pest density ranges: none detected > low density > moderate density > high density > and very high density. The maps are very popular with growers because they indicate, at a glance, where insects are being found and how their numbers vary across the region. We usually display maps from the current and previous week side-by-side and often show several maps in a time series (Fig. 1) because they reveal changing insect population densities in the region over time.

Interpreting Results

Results from pest monitoring need to be provided with context so growers know how to interpret them. For example, a grower needs context to know if a management action is needed

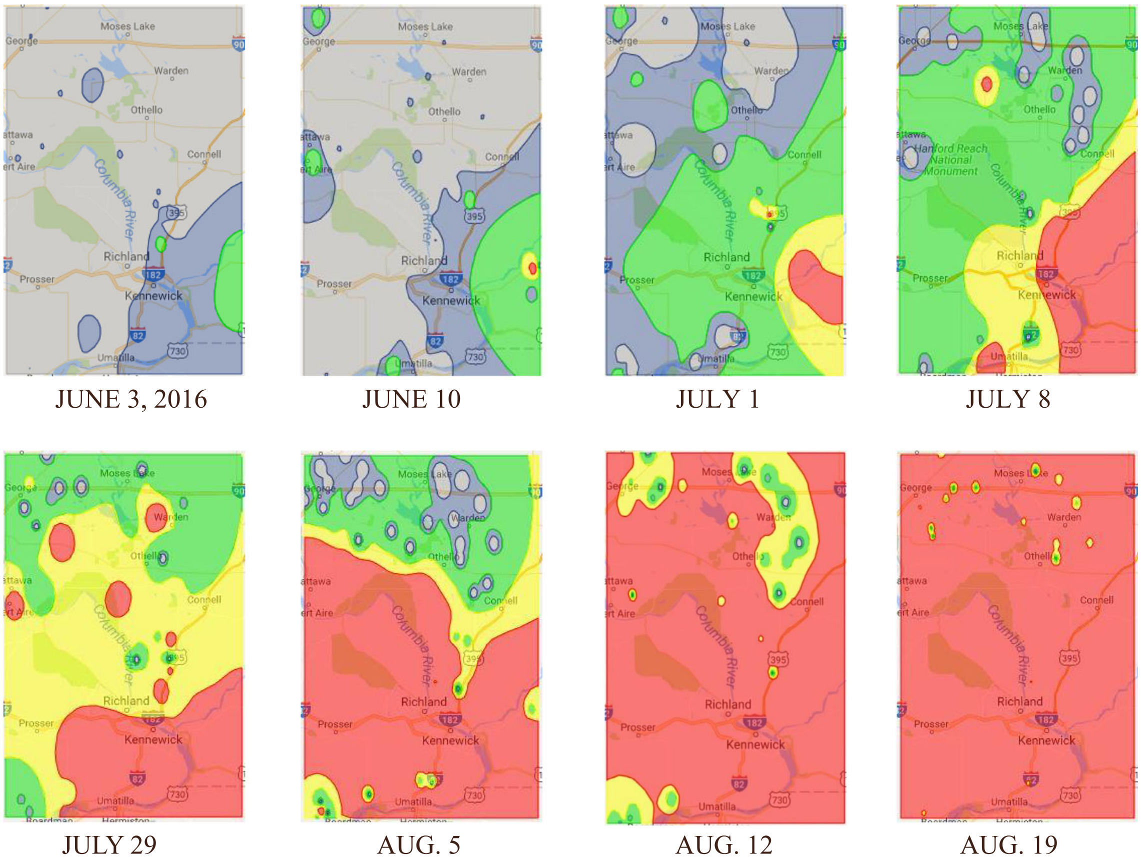

Fig. 1 Potato psyllid population density maps from June through August in 2016. Pest density ranges are color-coded: Gray = None, Blue = 0.1–0.5 psyllids, Green = 0.6–1.5 psyllids, Yellow = 1.6–2.5 psyllids, and Red = 2.6+ psyllids per trap

when we report that traps near their crop averaged 10 beet leafhoppers for the week. Ideally, monitoring data are associated with economic action thresholds for pests that prompt management activities to prevent pest populations from rising to the economic injury level. Unfortunately, none of the insect pests we monitor has recognized economic thresholds for potatoes in the Columbia Basin as they are difficult to establish in complex systems with many management options and variables, such as broad-specturm vs. selective insecticide options and cultivar-specific responses (tolerance or resistance) to pests and insect-transmitted diseases. Instead, we interpret our results by comparing them to historical pest monitoring records and by relating them to important outbreaks that resulted in crop losses. Therefore, we can report that 10 beet leafhoppers per week is a low population density that does not usually correlate with problems in the crop.

We often display graphs that show seasonal comparisons of pest monitoring results in *WSU Potato Pest Alerts*. They have been useful for illustrating the risk posed by insect pests each season (i.e., whether we anticipate problems or not). For instance, very large numbers of beet leafhoppers were collected on our traps in early 2013 and they were significantly higher than in other seasons. We displayed a chart of seasonal beet leafhopper monitoring results to illustrate to growers that beet leafhoppers might pose a greater problem that year (Fig. 2). In fact, there were many incidences of potato purple top, a disease caused by a beet leafhopper-transmitted pathogen, in 2013, but damage was limited mostly to the field edges.

Recommendations

Comprehensive programs that report pest monitoring results and make recommendations for next steps, including guidance in identifying and scouting for pests, cultural management approaches, and optimal use of chemical controls, can be particularly helpful to growers. We provide specific recommendations in the *WSU Potato Pest Alerts* to help potato growers in the Columbia Basin control aphids, beet leafhoppers, potato tuberworm, and potato psyllids. But, we also offer general pest management advice. Some of the things we emphasize are: (1) scouting before making insecticide applications; (2) insecticide resistance management strategies; (3) avoidance of broad-spectrum insecticides, like pyrethroids and organic pyrethrins, that may kill beneficial insects that help to keep pests like aphids, psyllids, and two-spotted spider mites in check; and (4) using the right kind of surfactant for the product being applied, adjusting the pH of spray solution if recommended by the label, and making sure products in a tank mix are compatible.

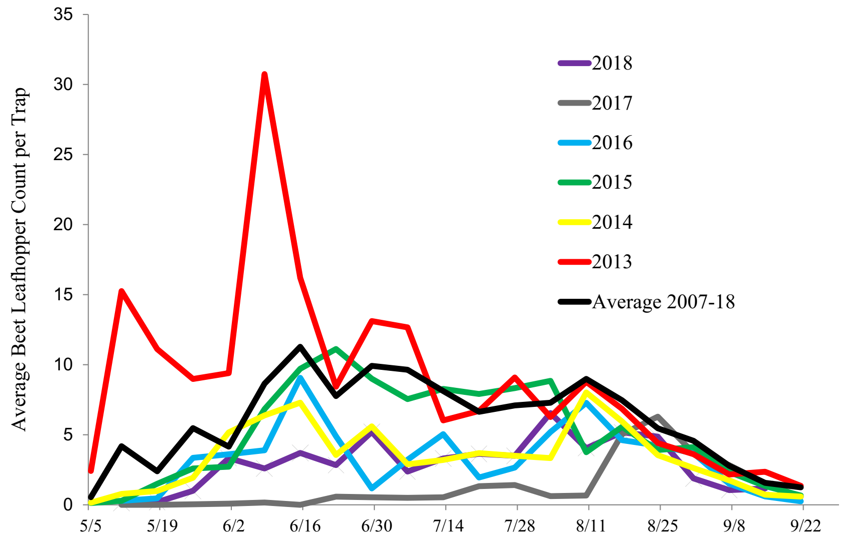

Fig. 2 Average weekly beet leafhopper trap counts in the years 2013–2018 and the average weekly trap count averaged across twelve years (2007–18)

Other Considerations

Pest monitoring programs are often initiated by researchers at state and federal agencies or universities as a way to understand the biology and migratory habits of a new or emerging pest. These programs are usually popular with growers who are also learning how to deal with a new pest problem. Sometimes growers request the continuation of these programs when they prove useful in informing scouting plans and pest management decisions. These efforts may not be sustainable, however, when the service components of these programs fall to personnel whose primary responsibility is to conduct research (Radcliffe et al. 2008). This was a recognized limitation of the *Aphid Monitoring Program and Hotline* managed by Dr. Pike, who had a research appointment with the university, and is one reason why he encouraged WSU Extension personnel to eventually adopt the program and develop the PPMN. Extension workers tend to focus on service-oriented activities. Connecting agricultural producers to information that advances their knowledge and economic well-being is one of the original missions of the Cooperative Extension System in the U.S.

Conclusion

The Columbia Basin PPMN and *WSU Potato Pest Alerts* is one of the most widely used sources of decision support for potato growers in the Columbia Basin of Washington. *WSU Potato Pest Alerts* emails are sent to more than 900 subscribers, including potato growers, crop consultants, and processing company representatives who are responsible for about 165,000 acres of potatoes in the Columbia Basin of Washington. We conducted surveys in 2013, 2015, and 2019 to learn more about our subscribers, what they like and dislike about *WSU Potato Pest Alerts*, and to know how they use the information the emails contain. About 85% have recommended or forwarded the emails to others, which explains the considerable growth in our subscriber list that started with just 90 email addresses in 2010. Roughly 20% of *WSU Potato Pest Alerts* subscribers work outside of the region, but follow the program out of general interest or to learn more about insect pest management in potatoes. Almost all of the subscribers (99% in surveys) believe that *WSU Potato Pest Alerts* play an important role in minimizing regional pest outbreaks that could otherwise result in major industry losses. When asked to rank the usefulness of *WSU Potato Pest Alerts* on a sliding scale (1 = not very useful, 5 = very useful), the mean rating was (4.41). Surveys returned by subscribers who make management decisions indicate that information in *WSU Potato Pest Alerts* helps them know when to expect pests in their fields and begin scouting activities, and often results in their making fewer (and more timely) insecticide applications because of the information they receive about regional pest populations and problems. We estimate that a cost savings of $35 per acre (the average cost of a single insecticide application) saves Washington's growers about $5.8 million per year.

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