Bio-intensive insect management
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The implementation of ecologically based or bio-intensive IPM programs in modern agriculture is based on a dynamic and interlinked set of management practices, which allow growers to monitor and manage pest populations efficiently. The success of such management practices is dependent on a thorough understanding of pest biology, ecology, behavior and interactions with biotic and abiotic factors in the ecosystem. Although an increasing body of knowledge continues to accumulate, new IPM programs are consistently lacking in one critical component; the site-specific or precise location of pest populations in the agricultural landscape. The lack of site-specific information has been responsible for much of the inefficiency of conventional IPM systems, which seek to use available databases efficiently among growers, consultants, industry and research. New technological advances in global positioning and geographic information systems over the past decade have made it possible to begin to link the existing knowledge base, which is critical to IPM, with precise in-field location. The concept of precision agriculture thus has the potential to maximize efficiency in agricultural production and pest management since the intent of precision agriculture can be simply stated as doing the right thing, in the right place, at the right time and in the right way.

One component of precision agriculture is using Geographic Information Systems (GIS) to geo-reference specific data. GIS is an organized collection of computer hardware, software, geographic data, and personnel designed to efficiently capture, store, update, manipulate, analyze, and display all forms of geographically referenced information. GIS computer technologies have extensive potential in agricultural production systems and can be used for pest management purposes and used for area-wide pest management programs.

Agricultural pests have not traditionally been widely incorporated into precision agriculture. Such pests are often characterized by extreme variability in both spatial and temporal distribution. While spatial variability is often effectively addressed by precision agriculture systems, temporal variability is not. Variability in population density is further complicated by variability in the genetic component of pest species. Geo-referenced sampling protocols and site-specific application of control measures have been shown to reduce the pesticide load in agricultural systems. In addition to reductions in pesticide load, the site specific application of pesticides has been shown to create temporally dynamic refugia for susceptible pest genotypes and natural enemies, which can lead to significantly less resistance to pesticides in target pests.

Crop rotation has been a widely used and effective pest management practice in U.S. agricultural systems. The ability of growers to rotate crops to avoid or reduce pest populations is significantly enhanced if pest distributions on a farm are geo-referenced. This ability is further strengthened at the area-wide level where large-scale crop landscapes can be manipulated to minimize pest impact. Geo-referenced risk maps depicting projected pest pressures, derived from information about previous crop locations and probabilities of immigration as a function of distance, have been developed for potatoes.

Resistance management strategies can also be more effective when used in area-wide pest management systems. Crop rotations on an area wide basis allow for the establishment of refugia of susceptible pest populations in a landscape of several contiguous farms that can ultimately delay onset of resistance for the area.
Examples of potential outputs from area-wide geo-referenced programs could include:

- Area-wide development and movement of pest populations.
- Economic performance of management approaches.
- Crop rotation design to manage pesticide resistance.
- Yield response to nutrient levels, pest thresholds, etc.
- Regional development and movement of pest populations.
- Impacts of rotation and management on pests and crop yield.

During the 1998 and 1999, two research projects implementing GIS systems for potato pest management were established in Central Wisconsin. A project in Coloma, WI was established to implement whole farm management of all potato pests using GIS and GPS Systems. In Plover, WI, a land area of 45,000 acres was mapped to determine the populations, movement and rotational scheme advantages in managing a single pest, the Colorado potato beetle.

**Whole Farm Management Using Geo-referenced Technology**

The utilization of geo-referenced information and databases in the potato production systems in Wisconsin has the potential to become a practical resource of useful production management information, which would enable growers to analyze and optimize their production practices. Pest management, which is one of the most dynamic elements in potato production, has received scant attention in the implementation of geo-referenced databases. However, pest density indicators in the form of geo-referenced maps instead of just an average and/or estimate number per field are now available. These maps show pest distribution patterns and quantitative information that is useful in implementing more efficient control practices. Thus, the possibility of in-site specific pest management becomes a feasible alternative that can prove to be an efficient and practical approach to controlling key pests in potato fields. Site-specific pest management strategies can also be extended beyond the whole farm context to encompass area-wide management involving multiple farms.

The study is being conducted in Waushara and Adams counties with the collaboration and participation of three potato farms located in the central area of the state of Wisconsin (Coloma Farms Inc., Wallendal Supply and Heartland Farms). Twelve potato fields, representing a total of 1200 A, were intensively scouted in order to obtain weekly data for pest populations in 1998 and 20 fields representing ca 2500 acres were scouted in 1999.

Figure 1: Location of Potato Fields for Whole Farm Management Project, Coloma, WI 1998
Field boundaries were digitized and mapped for each of the fields that were included in this study. Sampling points were based on a five-acre grid, and counts for insect pests at specific geo-referenced sites were conducted on a weekly basis, using plant counts, leaf counts, sweep nets and vacuum samples.

The software SST-Toolbox® was used to store, manipulate and analyze the data. Kriging, a method of analysis that serves as an interpolator, provided detailed estimates that represented the actual distribution of data samples in the study (Figure 2). Weekly map surfaces for each pest species and for each field were created to reveal statistical representations of data in order to make observations regarding insect pest distribution and population dynamics, which were used by growers to manage pest populations.

Figure 2. Colorado potato beetle small larvae and potato leafhopper adult populations found on Russet Burbank potatoes during July of the 1999-growing season. Coloma, WI.
The use of insect pest distribution maps was particularly useful in assessing the potential for partial vs. whole field treatment. Insect pests, which are relatively immobile (e.g. Colorado potato beetle), frequently infested fields from edges closest to previous infestations and their initial distribution was often strongly clumped and thus susceptible to spot treatment. Conversely, highly mobile pests (e.g. potato leafhopper) infested whole fields rapidly and their distribution within fields was more random and changed from week to week, requiring whole field treatment to achieve control. The database developed during 1998 and 1999 will provide a valuable resource in predicting future infestations and developing appropriate management strategies.

In 1999 fields were again mapped and sampled weekly for both insects and disease development. In addition 7 of the commercial fields in 1999 were sub-divided into large, replicated field plots (3-5 Acres) that were managed using a range of reduced risk management programs for insect and disease control. In each case, reduced risk programs were compared directly with standard commercial programs to provide growers with valuable performance data for reduced risk programs, which will be used in enabling the Wisconsin potato industry to comply with pending FQPA restrictions.

The large scale insect management trials enabled growers to directly compare the performance of conventional management with reduced risk alternatives on a commercial scale. The Home field in Coloma for example compared 5 insect management regimes in 3 A blocks replicated 4 times (Figure 3).

Figure 3. Pest management regimes evaluated on Russet Burbank potatoes and potato leafhopper adult distribution during July of the 1999-growing season. Coloma, WI
The regimes compared are listed in Table 1. All regimes provided good insect control. Colorado potato beetle pressure was moderate and all materials performed effectively against first generation. Extended oviposition resulted in higher than normal 2nd generation populations however and all regimes except the transgenic required re-treatment in July and August. Potato leafhopper populations were high with early infestations requiring treatment in early June in foliar regimes with 1-2 additional applications needed in all regimes. No significant aphid pressure was detected. The effectiveness of insect control was reflected in yield (Table 2), which did not differ significantly among management regimes although the transgenic regime yielded fewer large potatoes.

The reduced risk regimes evaluated in this trial are well suited for bio-intensive IPM where natural controls are preserved by the pest specific activity of the CPB control in the regimes. To evaluate the impact of regimes on non-target arthropods and beneficial insects, weekly vacuum suction counts were taken (Table 3). Populations of dipteran flies, which are a good indicator of non-target toxicity in potatoes, were enhanced in the systemic regimes and were negatively impacted by pyrethroid applications for leafhopper control. Predator and parasitoid populations were also negatively impacted by pyrethroids with significantly higher populations in the low-risk systemic, low-risk foliar and transgenic regimes (Table 3). Braconid parasites were the most numerous beneficial insects in these trials and although aphid populations were low, significant biological control of aphids was achieved in the transgenic regime.

Figure 4. Aphid and parasitoid populations found on NewLeaf Plus potatoes. Coloma, WI 1999.

The performance of the low-risk insect management regimes in insect control, which was equivalent to the conventional regimes while enhancing beneficial control, clearly demonstrated that reduced risk, bio-intensive IPM can be effective and economical. The large-scale evaluations further demonstrated the potential for bio-intensive IPM on a commercial scale.

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Conclusions

Geo-referenced information databases have a promising future in potato production systems. A complete database containing site specific information about pest distribution and movement is being built, which will allow growers and crop consultants to make observations and inferences on how to best implement insect management procedures. Improved crop production and profitability through more efficient management can also be expected. Migration patterns regarding distribution and habits of pests can be studied in more detailed ways because of graphic representations. Thus, pest management will be improved because of access to areawide information on pest movement and development, which will in turn result in a decrease use of pesticide inputs that will benefit the environmental and human health.

The graphic representations provided by geo-referenced maps also enable the grower to monitor their control practices more closely and evaluate which control measures are most effective. In the future geo-referenced whole farm management in agriculture will be applicable in monitoring and controlling large machinery for differential application of fertilizers, pesticides, and seed. In addition, geo-referenced whole farm management will aid in monitoring soil characteristics, irrigation, yield and fertility. Thus, growers will have the means to manipulate each variable individually to gain a greater insight into the causes of successes and/or failures. Precision agriculture will also help growers to monitor their crop rotation schedule. For instance, when high populations of CPB are detected along a hedgerow, growers may decide to abstain from planting potatoes close to that area the following year by adjusting the crop rotation and thereby reduce the CPB populations in that area by withdrawing their host plant completely. This approach will also aid growers in deploying crops and management programs, which will delay the onset of resistance.

Geo-referenced information databases are in the preliminary stages. However, they are already offering valuable support to management decisions in the farming context. In the future geo-referenced databases will become a useful platform for improved IPM and production practices. Thus, the potato industry and other high value fruit and vegetable crops can anticipate long-term benefits and stability as the use of geo-referenced information develops.

Area-wide Pest Management of the Colorado Potato Beetle

Colorado potato beetle movement in the spring and fall of each year are a concern to commercial potato growers in Wisconsin. Colorado potato beetles overwinter adults in sites adjacent to potato fields. In the spring, adults begin infesting, potato fields along field edges that are closest to the overwintering sites.

Crop rotation is an extremely important and effective control method for the Colorado potato beetle. Temporal crop rotation is important in reducing beetle populations, but spatial separation is an important consideration in optimizing the rotational effect as well. Long-distant rotations would be optimal in long-term reduction of CPB populations.

GIS systems allow for the precise geo-referencing and mapping of CPB populations moving into and out of potato fields and overwintering sites. This type of referencing thus allows for both visual and statistical analysis of population movement, which can be enhanced to manage and reduce CPB pressure.

During the summers of 1997-1999, an area in southern Portage county (Plover area) encompassing ca 45,000 acres was established to examine Colorado potato beetle population
distribution and movements. Potato fields in each growing season were identified and CPB populations were geo-referenced and determined. Data was inputted into the GIS software package SST-Toolbox® and surface maps were created to provide a visual representation of the CPB populations in space and time. A total of 44 potato fields (3500 acres) were identified in 1997 and 39 fields (2800 acres) were identified in 1998 and 1999. Figure 5 shows the distribution of the potato fields from 1997 and 1998.

![Figure 5: The distribution of potato fields from 1997 and 1998 – Plover, WI](image)

Grey Fields = 1997 potato fields  
White Fields = 1998 potato fields

Data was collected in the fall and the spring of each growing season. Sixteen geo-referenced sample points were established for each field (4 on each field edge) and 10 plants were counted at each sample point. The distance from each field edge to the nearest field edge in the following season was recorded and compared to the adult CPB movement. Analyses were run to determine which factors decreased CPB populations with correlation to determine the effect of distance, years in rotations, and management style on CPB populations.

The CPB management style varied from year to year between fields and growers. In 1997, 24 fields (56%) were treated with Admire, 16 fields (37%) were treated with a conventional foliar spray, and 3 fields (7%) used NewLeaf® potatoes as their CPB control method. In 1998, 27 fields (70%) used Admire, 11 fields (28%) used a conventional foliar spray, and 1 field (2%) used NewLeaf®. In 1999 28 fields (72%) used Admire while 11 (28%) were sprayed.

The results in central Wisconsin clearly demonstrate a strong negative correlation between crop infestation and distance to previous potato crops. Figure 6 shows the decrease in CPB population during spring infestation in relation to distance from a previous field edge. This trend was verified in all 3 years of the study.
Once a distance of over 400 meters was attained, the CPB spring infestation was greatly reduced. Populations were normally over 3.5 adults per 10 plants when potatoes were planted adjacent (less than 100 meters) to previous year’s potato crop. However, populations were reduced to less than 0.5 adults per 10 plants when long distance rotations (over 400 m) were utilized.

The number of adult Colorado potato beetles entering the fields during the spring infestation was also highly dependent on the management style used for CPB control in the previous year. Table 4 shows the number of beetles entering fields during the spring of 1998 in relation to the control strategy used for the Colorado potato beetle.

<table>
<thead>
<tr>
<th></th>
<th>Adults</th>
<th>Eggs</th>
<th>Small Larvae</th>
<th>Large Larvae</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional</td>
<td>2.82</td>
<td>9.25</td>
<td>32.4</td>
<td>6.5</td>
</tr>
<tr>
<td>Admire (10 to 16 oz)</td>
<td>2.14</td>
<td>2.14</td>
<td>1.87</td>
<td>0.5</td>
</tr>
<tr>
<td>Newleaf®</td>
<td>1.37</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

In each year, there were more beetles entering overwintering sites from the conventionally sprayed fields than when using the higher rates of Admire or NewLeaf®. This would affect the CPB populations that would infest fields planted adjacent to fields previously planted with potatoes. Therefore, the management style used in the previous year’s crop should be considered when deciding on the next year’s control strategy.

**Conclusions**

The distance between successive potato plantings in a rotation is extremely important in reducing CPB populations. The further the distance (greater than 400 meters), the greater the reduction in CPB populations. Area-wide rotations involving cooperating growers operating on contiguous farms would be the most effective. Management type also plays an important role in impacting CPB infestations, and a combination of rotated management approaches with distance rotation of the crop would both delay the onset of resistance and reduce population levels.