Managing Colorado potato beetle neonicotinoid resistance: new tools and strategies for the next decade of pest control in potato

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For the past 18 years, neonicotinoid insecticides have been the cornerstone of pest management in commercial potato. With the registration of imidacloprid (Admire, Bayer CropScience) in 1995, potato growers had access to a new class of water-soluble systemic insecticides that provided excellent control of piercing-sucking pests (green peach aphid, potato aphid, potato psyllid and potato leafhopper), below ground pests (wireworms) and leaf-feeding pests like Colorado potato beetle.[1,2] Since the registration of imidacloprid, new neonicotinoid insecticides (i.e., thiamethoxam and clothianidin) and several other formulations of those active ingredients have been registered for at-plant use in potato.[3-5] Benefits of the neonicotinoid mode of action group (IRAC MoA 4A, http://www.irac-online.org) include versatile application methods (e.g., foliar, seed-treatment, chemigation, drip, at-plant systemic, side-dress), long residual control of key pests when applied as a systemic, and limited non-target impacts.[3,4,6,7] The Environmental Protection Agency has designated several systemic neonicotinoids to be reduced-risk organophosphate alternatives, which limit impacts on non-target organisms, reduces acute and chronic exposure to farm workers, and decreases additional pesticide use.[2,8-11] Although the adoption of soil-applied neonicotinoid insecticides have been largely beneficial to the potato production industry, emergence of insecticide resistance (see Table 1) and other potential non-target impacts (e.g., colony collapse disorder) threaten the long-term sustainability of these compounds.[12-15]

Table 1. Colorado potato beetle resistance history Long Island, NY

Insecticide[a]	**Chemical group**	**1st labeled**	**1st failure**
carbaryl	carbamate	1957	1958
azinphosmethyl	OP	1959	1964
phosmet	OP	1973	1973
phorate	OP	1973	1974
carbofuran	carbamate	1974	1976
oxamyl	carbamate	1978	1978
fenvalerate	pyrethroid	1979	1981
permethrin	pyrethroid	1979	1981
fenvalerate +PBO	pyrethroid + synergist	1982	1983
imidacloprid	neonicotynl	1995	2000
spinosad	spinosyns	1997	2003
thiamethoxam	neonicotynl	1999	2003

[a] Resistance history can be found at the MSU Arthropod Pesticide Resistance Database[16]

Increasing concern about neonicotinoid resistance in Colorado potato beetle (CPB) and unknown environmental risks posed by this mode of action (MoA) group has elevated the importance of proactive pest management programs that integrate non-neonicotinoid insecticides.[12-15]

Transitioning from a continuous at-plant neonicotinoid pest management programs to one that incorporates newer, more reduced-risk insecticides will be a challenge for growers that are accustomed to uniform, broad-spectrum pest control provided by these systemic insecticides. Many of the alternative tools belong to different MoA groups (e.g., spinosyns, benzoylureas, diamides) that can effectively control specific CPB life stages; however, some have limited efficacy against other potato pests. Successful incorporation of these compounds will benefit neonicotinoid resistance management of CPB, but also increase the importance of scouting for other annual pests, such as potato leafhopper and colonizing aphid species. This article provides a brief review of the current status of neonicotinoid insecticide resistance in CPB and some recommendations for season-long CPB resistance management plans that incorporate new conventional insecticides to reduce reliance on at-plant neonicotinoids.

Insecticide resistance and Colorado potato beetle

Adaption of insect pests to grower management strategies (e.g., biological, cultural, or chemical control) is not a new problem. Pest population adaption (i.e., resistance) to management strategies are often most obvious when insecticides cannot control insect infestations in the field. More formally, insecticide resistance is defined as a genetic change in a pest population that results in repeated failure of an insecticide product when applied in a manner consistent with label recommendations.[14] Repeated product failure can result in additional insecticide applications, yield reduction, and economic loss for the grower.[15]

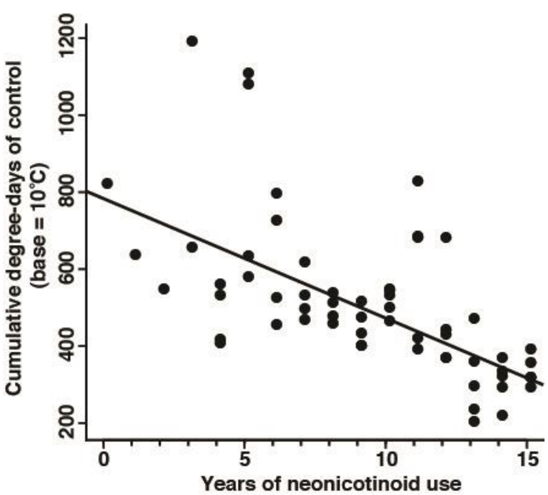

Figure 1. Duration of Colorado potato beetle control since registration of neonicotinoid insecticides in 1995 (i.e., year zero). Cumulative degree-days of control represent the period of time from at-plant neonicotinoid application until first foliar application for CPB control. Cumulative degree-days were calculated as summed growing degree-days where GDD = $[(Temp_{max}-Temp_{min})/2]-Temp_{base}$.

Colorado potato beetle has a long history of resistance development in the state of New York. Over the past 50 years, Long Island populations have become resistant to a nearly every labeled insecticide group (Table 1).[16] This pattern of rapid product failure is due, in part, to the isolation of this growing region from outside sources of beetles. Limited genetic mixing with other CPB populations combined with a high selection pressure has produced some of the most resistant beetles in the US. Although this is a single region, selection for resistant CPB occurs any time a control strategy (e.g., pesticide) is used.

Neonicotinoid resistance-perspectives from the field

Control of CPB populations with neonicotinoid insecticides has been declining nationally since the mid-2000's.[10-12] Laboratory bioassay estimates of thiamethoxam and imidacloprid have confirmed the suspicion that CPB resistance to neonicotinoids has increased throughout the Upper Northeastern and Midwestern potato production regions of the United States.[11,12,16] Although field-level failures are uncommon, the duration of beetle control within the growing season has declined significantly over time. Using a survey of several potato fields in Wisconsin, pesticide application history showed that the time between the at-plant neonicotinoid and first foliar application targeting CPB has declined steadily since 1995 (Fig. 1). On average, fields lost 35 growing degree-days of control per year since the registration of imidacloprid in 1995. Growing degree-day losses corresponded to approximately 3.3 fewer control days since 1995 or 50 days of lost control since registration of neonicotinoids.[17] Erosion of neonicotinoid control is representative of the broader Wisconsin potato production industry; moreover, similar control losses are likely in other potato production regions where resistance has historically been an issue. Reduced control of CPB with systemic neonicotinoids has motivated the use of extra foliar insecticides in addition to the at-plant application. Growers shifting to this pest management strategy are another indication that insecticide susceptibility has changed at a large spatial scale.[15] Although resistance is an emerging concern in some areas of the US, several other potato production regions continue to have adequate control of key pests with annual at-plant neonicotinoids. Growers at either end of the resistance spectrum will benefit by adopting preventative resistance management strategies that incorporate a more diverse set of insecticides as one tactic to maintain or improve the efficacy of the neonicotinoids.

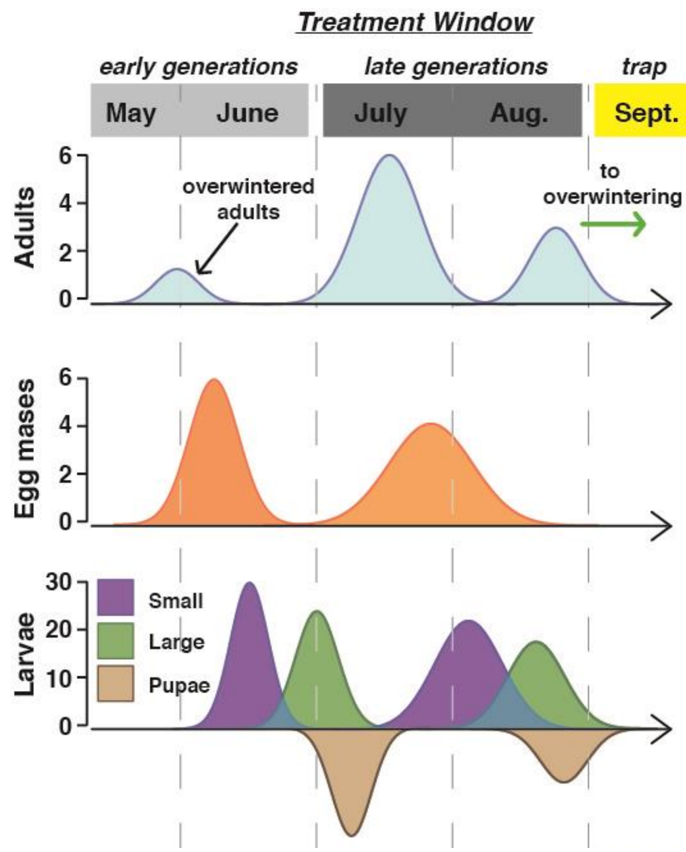

Figure 2. Insecticide application treatment windows for CPB larvae. Demographic curves represent a hypothetical pattern of life stages in commercial potato during an average growing season. Vertical axes show an average life stage count per ten plants. The light grey treatment window represents early CPB generations, dark grey is the late generation window, and yellow is the autumn trap crop window.

Using the entire toolbox-planning a three year resistance management program

Dynamic resistance management strategies that rotate chemistries in time and space are critical to maintaining the efficacy of each individual pesticide used in a production sequence. When successful, growers can prolong the longevity of useful insecticides which, in turn, improves profitability and minimizes need for additional insecticide inputs to manage problematic populations. Currently, potato growers have access to a diverse set of MoA groups, delivery methods, and formulations of insecticides to control CPB. Incorporation of newer MoA groups with an at-plant neonicotinoid program is an effective way to reduce selection pressure for resistance while spreading cost of newer, more expensive chemistries over several consecutive seasons. The following suggestions assume a two-generation CPB lifecycle common to the Northeastern US (Fig. 2). The growing season has been subdivided into three specific treatment windows, early generations, late generations, and autumn trap crop.

These treatment windows provide a general reference where specific MoA groups can be used to target larval generations in the crop. All compounds included have the greatest activity on small larval life stages (1st and 2nd instars). However, one compound (i.e., novaluron) has multiple life stage targets including larvae, reduced female CPB fertility and reduced viability of eggs that have not hatched.[18-20] Multiple-season CPB management plans are designed to limit exposure to MoA groups over consecutive insect generations. Here, populations are exposed to a given MoA group once every three to four generations (Fig. 3). Trap crop compounds (pesticides with activity on adult CPB) are presented as an optional resistance management strategy occurring outside the primary potato crop and are not included in the annual product sequence. At-plant neonicotinoids should be avoided in soils with high organic matter. These recommendations are not designed for seed potato production and will not adequately manage persistent or non-persistently transmitted viruses. Many foliar compounds included require repeated applications, specific spray tank conditions (e.g., pH, compatibility), companion adjuvants, and timing with pest life stages. Moreover, several of these compounds have less activity on other key potato pests (e.g., PLH and colonizing aphids); scouting and economic thresholds for secondary pests will remain a critical component of weekly field management activities. The decision to apply any insecticide (except prophylactic at-plant applications) should be completed for each field based on scouting results and economic injury levels observed in that individual management unit. For more information about specific scouting procedures, application rates, reapplication intervals, preharvest intervals, and other recommendations consult the Cornell Pest Management Guidelines[21] (http://veg-guidelines.cce.cornell.edu/) and the product label.

Suggested management program descriptions

*****Note see Fig. 4 for corresponding sequence. Programs in each group are ordered by estimated level of neonicotinoid resistance (high to low).

In-furrow + Foliar management programs

A. Neonicotinoid (F, IF, or ST) used in 2013 with very limited success. Management plan rotates away from the neonicotinoid group over four consecutive treatment windows. Replace Avaunt with Agri-Mek if eggs or early instar larvae are present in moderate to high numbers.

B. Neonicotinoid (F, IF, or ST) was used in prior year with limited success. Early season colonization has been historically high at specific field location. Endigo and Blackhawk could be switched if PLH and late season CPB numbers are low in 2015.

C. Populations easily controlled with at-plant neonicotinoids. Avaunt was placed behind Verimark to manage any adult insects that colonize the field late or persist through in-furrow diamide. Replace Avaunt with Radiant if eggs or larvae are present in moderate to high numbers.

D. Use only if neonicotinoid (F, IF, or ST) was not used in 2013 growing season and populations are still susceptible. Years 2 & 3 can be switched depending on in-furrow diamide availability. Replace Avaunt with neonicotinoid or Agri-Mek if eggs or larvae are present in moderate to high numbers.

<u>Foliar management programs</u>

E. Full foliar program if CPB resistance is suspected in a group of fields. If fields are relatively close use the same MoA rotation scheme uniformly to avoid selection over less than 4 generations.

F. Full foliar program if neonicotinoids have limited efficacy.

G. Neonicotinoids maintain satisfactory efficacy annually. Endigo can be switched with Platinum 75SG if PLH numbers are low in 2014.

<u>Short maturity-fresh market program</u>

H. Full foliar program for short maturing cultivars. In areas where colonization pressure is low, early window chemistries may be satisfactory to manage beetles until harvest. Follow up applications of another mode of action group (cross-hatched box) should be completed only if an economic injury level is likely to be reached. Companion groups could be foliar Actara, Endigo, or Agri-Mek. A foliar diamide should only be used in the late window of 2016.

Trap crops - Spring and Autumn trap crops can be used annually to reduce colonizing or overwintering beetle populations. Trap crops are typically located in lightly cultivated, buffer areas between the main crop and natural habitats (often wooded field boundaries). Spring trap crops should be planted 2-3 weeks earlier than the primary crop depending on weather conditions. Autumn trap crops should be planted early enough in the summer to have a full canopy before vine kill of the primary crop. Trap crops should be planted in a relatively concentrated area to be attractive enough to aggregate beetles. Adults can be killed either mechanically (flail/stalk chopper) or chemically with an insecticide when a sufficient number colonize the trap crop. Manage trap crops for foliar pathogens that could compromise the health of the primary crop (e.g., Late Blight).

Table 2. Product components to manage Colorado potato beetle larvae. Reduced-risk compounds with greater efficacy on uniform small larvae populations (Rimon) were placed early in management sequences assuming egg hatch would be most synchronous. Foliar neonicotinoid insecticides were reserved for multiple larval instars later in the season. Indoxacarb (Avaunt) has limited activity on larval instars and should be substituted when egg or larval counts are moderate to high. Prepack insecticides with pyrethroids (†, ‡) were reserved for situations when both CPB larvae and PLH reach threshold.

Treatment Window	Active ingredient	IRAC MoA group	Delivery[a]	Common trade names
early generations	abamectin	6	F	Agri-Mek, generics
	chlorantraniliprole	28	F	Coragen
	cyantraniliprole	28	F, IF	Exirel*, Verimark*
	imidacloprid	4A	IF, ST	Admire Pro, generics
	novaluron	15	F	Rimon
	spinetoram	5	F	Radiant
	spinosad	5	F	Blackhawk, Entrust
	thiamethoxam	4A	IF, ST	Platinum, Cruisier Maxx Potato
late generations	abamectin	6	F	Agri-Mek, generics
	chlorantraniliprole	28	F	Coragen, Voliam Xpress†
	cyantraniliprole	28	F	Exirel*
	imidacloprid	4A	F	Admire Pro, Leverage 360‡, generics
	indoxacarb	22A	F	Avaunt
	spinetoram	5	F	Radiant
	spinosad	5	F	Blackhawk, Entrust
	thiamethoxam	4A	F	Actara, Endigo ZC†
trap crop	indoxacarb	22A	F	Avaunt
	phosmet	1B	F	Imidan

[a] Foliar (F), In-furrow (IF), and Seed treatment (ST)
† Contains lambda-cyhalothrin, use when PLH and CPB at threshold
‡ Contains cyfluthrin, use when PLH and CPB at threshold
*Anticipated New York registration 2015 season

Figure 3. Product rotation suggestions to manage Colorado potato beetle larvae. Programs A-E alternate IRAC Mode of Action (MoA) across several early and late generation treatment windows in each season. Short maturity cultivars (e.g. Reds, heirlooms) may not require application of another MoA for later generation CPB. Foliar neonicotinoid or other insecticides can be used in seasons when populations reach threshold after initial applications. Check label restrictions for preharvest intervals (PHI). In-furrow, at-plant insecticides are designated with IF. Active ingredients pre-packed with lambda-cyhalothrin are designated with a dagger (†). Cyantraniliprole diamides (*) will not have a federal registration until the 2015 growing season and may not have NY registration until 2016. Insecticides included represent formulations that are commonly available, other active ingredient formulations may be labeled see the Cornell Pest Management Guidelines[21] for a comprehensive list of NY registrations.

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