

## POPULATION DYNAMICS OF *HARMONIA AXYRIDIS* AND *APHIS GLYCINES* IN NIAGARA PENINSULA SOYBEAN FIELDS AND VINEYARDS

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### Abstract

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Multicoloured Asian lady beetle (*Harmonia axyridis*) is an occasional pest of wine and juice grapes in vineyards throughout northeastern North America. In late season, beetles aggregate on grape clusters immediately before harvest, and are difficult and expensive to remove before processing. Outbreaks of *H. axyridis* are thought to be related to soybean aphid (*Aphis glycines*) populations. Heavy infestations of aphids occur late in the season on soybeans and can sustain large numbers of *H. axyridis*. Each summer from 2004 to 2006, 23-29 soybean fields along the escarpment of the Niagara Peninsula were monitored each week for soybean aphid infestation, and all life stages of *H. axyridis* were recorded. Where substantial populations of *A. glycines* were found, larvae and adults of *H. axyridis* soon followed. Severity of *H. axyridis* infestation in vineyards was still high even when *A. glycines* populations were reduced by insecticides in soybean fields in 2005. Outbreaks of *H. axyridis* in vineyards are correlated with substantial populations of soybean aphid that occur early in the season. Outbreak populations of *H. axyridis* in vineyards were observed in years where *A. glycines* eggs were not abundant on overwintering hosts, thus *H. axyridis* density appears to be negatively correlated with numbers of overwintering *A. glycines* eggs on its primary host, *Rhamnus cathartica*. A model of interaction between the two species is proposed.

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### Introduction

Multicoloured Asian lady beetle (*Harmonia axyridis* (Pallas), Coleoptera: Coccinellidae) is an alien invasive predator important in southern Ontario agro-ecosystems. *Harmonia axyridis* is an occasional pest of wine and juice grapes in vineyards throughout northeastern North America (Ker and Carter 2004). Like most coccinellids, adults and larvae of *H. axyridis* are predacious, with a diet consisting primarily of aphids and other

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soft-bodied insects, supplemented by small amounts of plant material (Hodek 1973). In the Niagara Peninsula region of southern Ontario, late season aggregations of adults have been observed on ripening grape clusters immediately before harvest (Ker and Carter 2004). During processing, beetles may be crushed into the slurry of skins and stems (Pickering 2004). Beetles are difficult and expensive to remove from grape clusters before processing, and if they are not removed before processing the grapes, alkaloids secreted by beetles as defensive chemicals affect the flavour of wines and juices (Koch 2003, Pickering 2004).

Insects inevitably are present at grape harvest, but usually in low enough numbers that their presence does not affect quality or flavour of wine. *Harmonia axyridis* presents a problem because the beetle itself has a very unpleasant taste and odour, due to a bitter defensive chemical, 2-isopropyl-3-methoxypyrazine (IPMP), present in its haemolymph (Pickering 2004). The limit of detection by humans of IPMP in water is in the range of two parts per trillion (Pickering 2004).

The Niagara Peninsula region of Ontario is an intensely cultivated area home to 94% of Ontario's grape industry, with an annual farm gate value of \$60 million (Gardner et al. 2006). Approximately 40 million litres of wine are produced in Ontario each year, generating \$438 million in retail sales (Grape Growers of Ontario 2007). This region also has large areas devoted to field crops located above the escarpment and south of grape growing areas. Most vineyards have fields of soybeans planted within 1-2 km of their location (Fig. 1).

Outbreaks of *H. axyridis* in grapes may be related to infestations of soybean aphid (*Aphis glycines* Matsumura). Though *H. axyridis* has been present since 1994 in southern Ontario, large populations of *H. axyridis* were not observed in Ontario vineyards until 2001, coinciding with the arrival of *A. glycines* (Ker and Carter 2004). *Harmonia axyridis* is an important natural predator of *A. glycines* in its native range (Koch 2003, Wu et al. 2004). First identified in North America in 2000 in Wisconsin, *A. glycines* is now a severe pest of cultivated soybean (*Glycine max* Merrill) in 21 American states and three Canadian provinces (Ragsdale et al. 2004). *Aphis glycines* undergoes a heteroecious, holocyclic life cycle, alternating between parthenogenic reproduction on its secondary summer host, *G. max*, and sexual reproduction and overwintering on a primary woody winter host, buckthorn (*Rhamnus* spp.) (Ragsdale et al. 2004, Voegtlin et al. 2004). Typically, *A. glycines* occurs as a sexual morph on foliage of *Rhamnus* spp. in autumn, as an egg on buds of *Rhamnus* spp. in winter, as an asexually reproducing female on *Rhamnus* spp. in spring, and as an asexually reproducing female in cultivated soybean in summer (Ragsdale et al. 2004, Voegtlin et al. 2004).

Ample populations of aphids can support large numbers of *H. axyridis* (Fox et al. 2004), and there is anecdotal evidence that in years favouring heavy infestation of *A. glycines*, heavy infestations of *H. axyridis* occur in vineyards. A biennial cyclical pattern of outbreak years seems to be emerging for both *H. axyridis* in grapes and *A. glycines* in soybeans, in which economically damaging infestations of both species occurred in 2001, 2003, 2005, and 2007, but only spot infestations were observed in 2002, 2004, 2006, and 2008 (Bahlai 2007, Glemser, E. et al., unpub. data)

It is possible that soybean fields near to Niagara vineyards serve as a reservoir for *H. axyridis*. Starting near the middle of the growing season, *H. axyridis* might reproduce in

soybean fields, and feed as adults and larvae on aphids. When aphids move to overwintering sites, beetles seeking alternate food sources in the absence of aphids, might move directly to nearby vineyards filled with ripening grapes. If this relationship holds true, numbers of *H. axyridis* observed in vineyards should correspond to numbers of beetles observed in soybean fields just before soybean leaf senescence occurs.

From June to September in 2004, 2005 and 2006, we monitored 23-29 soybean fields weekly for *A. glycines* infestation and for all life stages of *H. axyridis* in the Regional Municipality of Niagara, ON. The purpose of this study was threefold:

- 1) to provide scouting information for Niagara area soybean growers regarding *A. glycines* infestation levels, and to estimate numbers of *H. axyridis* for Ontario grape growers and vintners,

- 2) to examine whether population assessments of *H. axyridis* in soybean fields correspond with infestations of the beetle in nearby vineyards,

- 3) to test the hypothesis that soybean fields act as reservoirs for *H. axyridis* before beetles infest vineyards.

## Methods and Materials

During the growing seasons of 2004-2006, soybean fields were selected along the edge of the Niagara Escarpment in proximity to vineyards from Grimsby (43.2°N, 79.7°W) to Niagara-on-the-Lake (43.2°N, 79.1°W) (Fig. 1). Nearby vineyards generally were located on the “bench” below the escarpment, in the northern portion of the peninsula, 2-8 km from the shore of Lake Ontario. Soybean fields selected were generally located to the immediate southwest of vineyards, and within a 5 km radius. In 2004, 23 soybean fields were monitored each week; in 2005 and 2006, 29 and 28 fields were monitored each week, respectively.

Monitoring consisted of sampling 10 sites randomly selected within a soybean field. At each site, three soybean plants were assessed for soybean aphid populations using the following rating scale (after Difonzo and Hines 2002). Aphid populations were assessed on stems and on the middle leaflets of the lowest, middle and top trifoliate leaves. The following rating system was applied to each part of the plant: 0 = No aphids present (not infested), 1 = 1-10 aphids present (low infestation), 2 = 11-25 aphids present (moderate infestation), 3 = 26-100 aphids present (high infestation), and 4 = 100+ aphids present (extreme infestation). Ratings for all plant parts were averaged, providing a total infestation rating out of four for each plant. These ratings were averaged by field and provided an average infestation score for the fields in a particular area.

For each of the plants assessed, the number of larval, pupal and adult *H. axyridis* present on the plant were counted. These numbers were averaged by field and geographical region, and reported in units of average number of individuals per soybean plant.

Each site was monitored once weekly, commencing on July 13 in 2004, June 22 in 2005, and June 23 in 2006. Monitoring continued until soybean leaf drop occurred in all observation fields in September. Population data for fields in particular areas were compared with *H. axyridis* infestation levels in nearby corresponding vineyards and with counts of overwintering eggs of *A. glycines* as described in Welsman et al. (2007).

Data for the regression analyses were organized by observations in a given week. Regression analyses were performed on population data using PROC GLM (SAS Institute, Cary, NC) to determine whether counts of larvae, pupae and adults of *H. axyridis* would correlate over time with infestations of *A. glycines*, or if a one or two week delay in interval would provide a better statistical relationship. A significance level of  $\alpha=0.05$  was used for all analyses.

## Results

In 2004, *A. glycines* populations reached moderate infestation levels in soybean fields across Niagara in late August (Fig. 2). None of the observation fields had insecticides applied at this time, because at the time this study was performed treatment was not recommended for soybean aphid control after the R5 ('beginning seed') plant stage is reached (Baute 2007). Infestation rankings reached an average of 0.25 in the week of August 12, 2004 (Table 1). Sharp increases in aphid infestation occurred in the two weeks following August 24, with populations peaking by September 7 in all observation fields. Numbers of *H. axyridis* larvae followed a similar growth and peak pattern, with jumps in their population growth correlating with increases in aphid infestation ( $R^2 = 0.88$ ,  $p < 0.0001$ ) (Table 2, Fig. 2). Abundance of pupae correlated significantly with aphid infestation after one week ( $R^2 = 0.53$ ,  $p = 0.006$ ), with adult beetles following at two weeks after aphid infestation increase ( $R^2 = 0.70$ ,  $p = 0.002$ ) (Table 2, Fig. 2).

In 2005, an average rating of 0.25 was first recorded on July 19, over three weeks earlier than was observed in 2004 (Table 1). Earlier infestation of soybean fields by *A. glycines* and rapid increasing severity of infestation in early summer (Fig. 2) resulted in 28 of 29 observation fields being sprayed with cyhalothrin-lambda (Matador 120E®, Syngenta Crop Protection Canada) or dimethoate (Cygon 480® and Lagon 480EC®, Cheminova Canada) (OMAFRA 2005) to control populations in the weeks of August 9 and 16, 2005. Aphid infestation across the peninsula peaked in these weeks, and subsequently decreased for the rest of the season in most of the observation fields (Fig. 2). Populations of *H. axyridis* began to increase in observation fields early in the season, correlating with aphid infestation levels (Table 2), but sharply declined after the application of insecticides (Fig. 2). The relationship between aphid infestation and larvae or pupae counts after a delay of one week in 2005 was weaker than in 2004 ( $R^2 = 0.42$ ,  $p = 0.020$  for larvae,  $R^2 = 0.44$ ,  $p = 0.012$  for pupae) (Table 2).

In 2006, very low aphid infestation and very few *H. axyridis* were observed in Niagara Peninsula soybean fields (Fig. 2). Aphid infestation density did not reach a rating of 0.25 until August 22, 2006 (Table 1). Counts of larvae of *H. axyridis* were observed to correlate well with aphid infestations in soybean fields, but occurred one week and two weeks after the corresponding aphid population estimate (Table 2). The relationship between beetle and aphid densities was significant for all three temporal relationships examined (Table 2).

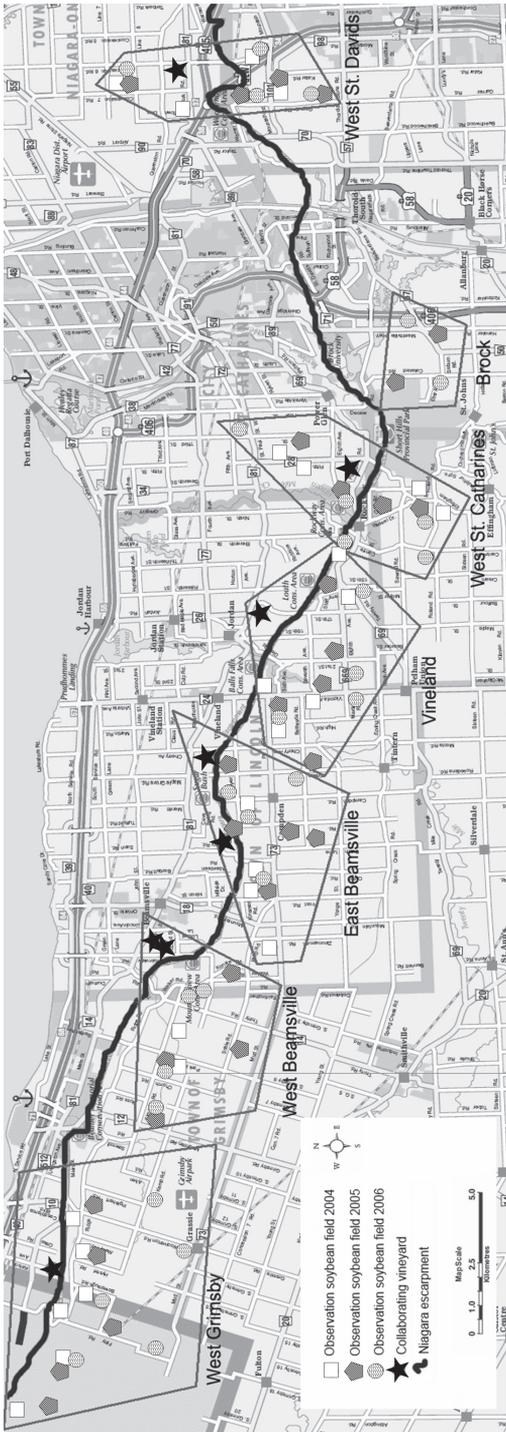


FIGURE 1: Locations of observation soybean fields and collaborating vineyards in 2004, 2005 and 2006, in the vicinity of Vineland, ON. Each observation field was monitored once weekly during the soybean growing season, to determine soybean aphid infestation level and multicoloured Asian ladybeetle counts. Observation fields were typically located at the top of the Niagara escarpment, to the southwest of collaborating vineyards. Map adapted from the Regional Municipality of Niagara Public Works Department, Operational Services Division.

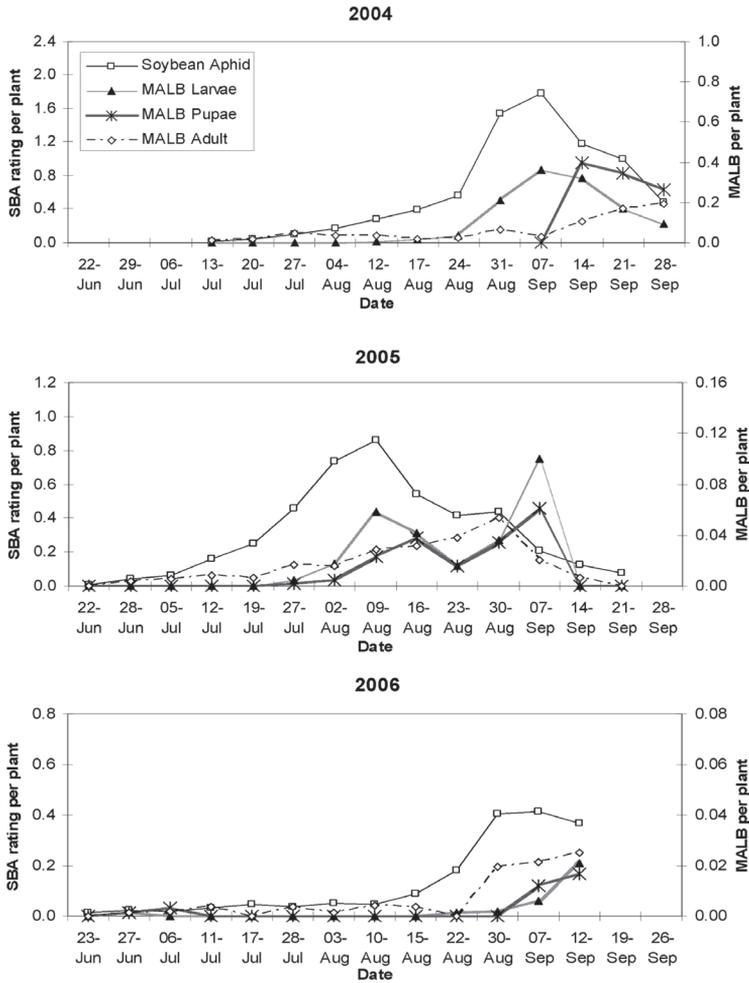


FIGURE 2: Soybean aphid (SBA) infestation rating and multicoloured Asian ladybeetle (MALB) counts for soybean fields in the Niagara Peninsula region of southern Ontario in 2004, 2005 and 2006. Area-wide averages are shown. A sample of thirty soybean plants in observations field were monitored weekly. SBA ratings were performed by examining the stem and upper, middle and lower trifoliates of each plant and rating each portion of the plant on a scale of 0 to 4, where 0=No aphids present, 1=1-10 aphids present, 2=11-25 aphids present, 3=26-100 aphids present, 4=100+ aphids present. Raw counts of MALB adults, pupae and larvae were performed for each plant. Note: scales of graphs differ to preserve detail when average aphid infestation levels and ladybeetle counts are lower in 2005 and 2006.

TABLE 1: Soybean aphid (SBA) populations in soybean fields in the Niagara Peninsula region of southern Ontario, 2004-2006. Dates when an average of one aphid colony per plant was first observed and when soybean leaf drop occurred, a description of the peak aphid population, is provided. Counts of aphid eggs subsequently observed in overwintering sites and infestation levels of multicoloured Asian ladybeetle (MALB) in vineyards for each year are included.

Year	Date rating of 0.25 reached	SBA peak	Date of soybean leaf drop	Total SBA eggs observed on <i>R. cathartica</i> <sup>1</sup>	MALB infestation in vineyards <sup>2</sup>
2004	12-Aug-04	Moderate, after pod set, no chemical control required	28-Sep-04	5585	Low: spot infestations (raw data not available)
2005	19-Jul-05	Moderate, before pod set, chemical control widely applied	21-Sep-05	4	High: widespread infestation (896 adult MALB observed in sampling period)
2006	22-Aug-06	Low, after pod set, no chemical control required	12-Sep-06	250	Low: spot infestations (105 adult MALB observed in sampling period)

<sup>1</sup> Welsman et al. (2007): soybean aphid eggs collected from 10 cm buckthorn twig segments (N=1200) in autumn near Guelph, ON.

<sup>2</sup> Kevin Ker, Ker Crop Management Services, personal communication. Assessments completed by counting number of MALB observed per meter of grape vine in commercial vineyards.

TABLE 2: Linear regression of observed populations of various life stages of multicoloured Asian ladybeetle (MALB) on soybean aphid infestation scores in soybean fields in the Niagara peninsula region of southern Ontario, 2004-2006. Counts of each life stage of MALB were correlated to soybean aphid infestation observed concurrently, one, and two weeks before.

Year	Week	MALB life stages								
		Larvae			Pupae			Adults		
		R <sup>2</sup>	P		R <sup>2</sup>	P	R <sup>2</sup>	P		
2004	0	0.88	< 0.0001	*	0.09	0.340		0.06	0.420	
	1	0.83	< 0.0001	*	0.53	0.006	*	0.30	0.080	
	2	0.33	0.080		0.91	< 0.0001	*	0.70	0.002	*
2005	0	0.18	0.130		0.12	0.230		0.40	0.020	
	1	0.42	0.020	*	0.44	0.012	*	0.50	0.007	*
	2	0.19	0.150		0.33	0.050		0.56	0.005	*
2006	0	0.41	0.200		0.45	0.012	*	0.84	< 0.0001	*
	1	0.70	0.001	*	0.82	< 0.0001	*	0.86	< 0.0001	
	2	0.98	< 0.0001	*	0.85	< 0.0001	*	0.71	0.001	*

\* Significant at  $\alpha=0.05$

## Discussion

To date, a biennial cycle of outbreak years of both *H. axyridis* and *A. glycines* has consistently occurred in the Niagara (Glemser, E. et al, unpub. data). As was observed in 2001 and 2003, in the present study, high numbers of aphids appeared early in the 2005 growing season, and high lady beetle numbers appeared in vineyards later in the season (Table 1). In 2004 and 2006, as in 2002, low or moderate late-season soybean aphid infestations occurred, and only low infestations of *H. axyridis* were observed in vineyards (Table 1). Infestation by *H. axyridis* in vineyards in a given year did not necessarily correlate with observed numbers of ladybeetles in soybean fields immediately before leaf senescence. More *H. axyridis* individuals in total were observed in soybeans in 2004, when only spot infestations of the beetle were observed in vineyards, than in 2005, when vineyard infestation by *H. axyridis* was reported to be much higher. This provides evidence against the hypothesis that abundance of ladybeetles in vineyards results entirely from abundance of *A. glycines* and that beetles move directly from soybeans to ripening grapes.

The application of insecticides to most of our observation soybean fields in 2005 confounded our results considerably. The insecticides cyhalothrin-lambda (Matador 120E<sup>®</sup>, Syngenta Crop Protection Canada), a pyrethroid, and two formulations of dimethoate (Cygon 480<sup>®</sup> and Lagon 480EC<sup>®</sup>, Cheminova Canada), an organophosphate, are registered for use in controlling soybean aphid in Ontario soybeans (OMAFRA 2005). Pyrethroids are extremely toxic to larvae of *H. axyridis* (Youn et al. 2003) and unpublished field trials suggest they have a repellent effect on adults (K. Ker, personal communication). In leaf-dip trials, organophosphorous pesticides applied at normal rates resulted in low survivorship of all life stages of *H. axyridis* (Youn et al. 2003)

This decline in abundance of *H. axyridis* in soybean fields observed after insecticide application may occur for several reasons: 1) the insecticide is toxic to *H. axyridis*, 2) the insecticide may act as a repellent to adults of *H. axyridis*, so that they disperse from the field and new migrants avoid the field, or 3) the sudden drop in aphid abundance results in insufficient aphid populations for the induction of oviposition by *H. axyridis*, so that beetles disperse to locate other populations of insects on which to feed. A combination of these explanations likely leads to the observed population decline of *H. axyridis*. By early August, when insecticides are applied if needed to soybeans for control of *A. glycines* in the Niagara region, we have observed other aphid species supporting feeding populations of *H. axyridis* on common weeds such as lamb's quarters (*Chenopodium album* L.) or milk vetch (*Vicia cracca* L.). If insecticides repel surviving adults of *H. axyridis*, and there are not sufficient aphid populations in soybean fields, beetles will move out of soybean and forage on abundant populations of other aphid species occurring in weedy areas, woodlots or orchards. This dispersal of *H. axyridis* from soybean fields confounds monitoring of ladybeetle population numbers because large numbers of *H. axyridis* are likely present outside soybean fields in late summer, and at that time of year, populations of *A. glycines* may no longer have as much influence on the population growth of *H. axyridis*.

The exact relationship between outbreaks of *H. axyridis* in vineyards and outbreaks of *A. glycines* in soybeans can only be speculated upon at this time, but the two may be related. Grape harvest in Ontario usually begins in the last week of September, and continues until the middle of October, except for vineyards where grapes are destined for

use in late-harvest or ice wines. In most years, there is a two to three week difference in time between soybean leaf senescence and the beginning of grape harvest. It is unknown where *H. axyridis* populations which were previously residing in soybean are located during this two to three week period. It is possible that *H. axyridis* simply uses grapes as a food source immediately prior to overwintering, as sugars in grapes may be more efficiently converted to stored energy in the fat body of the insect than proteins from aphids (Hodek 1973, Denlinger 2005). In this scenario, grapes may be a preferred food of *H. axyridis*. However, if ripe grapes are preferred over aphids by *H. axyridis*, beetles would be observed in vineyards in every year, and not just when aphids are scarce.

A possible explanation may be found in the overwintering habits of *A. glycines*. As day length decreases and soybean leaves senesce, *A. glycines* migrates to the overwintering host, buckthorn (*Rhamnus* spp.) (Voegtlin et al. 2004). Mating occurs on this host and eggs are laid on buckthorn buds (Ragsdale et al. 2004). In Ontario, oviposition by *A. glycines* typically occurs by late October (Welsman et al. 2007). In this study, during years when *A. glycines* infestation remained below economic threshold (i.e. 2004 and 2006), moderate populations of aphids were observed in soybean fields immediately prior to soybean plant senescence. In a companion study in the same years Welsman et al. (2007), found that high numbers of overwintering eggs of *A. glycines* were found in *Rhamnus cathartica* stands in Ontario (Table 1). Conversely, in 2005, when soybean fields monitored in this study had heavy, early infestations of *A. glycines*, very few overwintering eggs were observed using the same protocols as in 2004 and 2006 (Table 1).

We propose that interactions between *A. glycines* and *H. axyridis* on the primary host of *A. glycines* in spring and again after soybean senescence on the overwintering host of *A. glycines*, play a larger role in dictating the abundance of *H. axyridis* in vineyards than do late summer interactions in soybean, as previously speculated. Large populations of *A. glycines* on its overwintering host may “kick-start” or “distract” *H. axyridis*, depending on the time of year at which it occurs. Abundance of *A. glycines* early in the season initiates (kick-starts) population growth of *H. axyridis*. Abundances of *A. glycines* on *R. cathartica* in autumn function to draw *H. axyridis* away (distract) from vineyards in the fall (Fig. 3).

In spring, *H. axyridis* are usually found on *Rhamnus cathartica* almost immediately after bud swell in mid to late April, feeding on aphids, and mating (Bahlai et al. 2007, Bahlai et al. 2008). *Rhamnus cathartica* leaves begins to grow earlier than most other woody plants in southern Ontario agroecosystems and egg hatch of *A. glycines* coincides with this event (Bahlai et al. 2007), so it is likely that *A. glycines* on *R. cathartica* represent one of the earliest abundant food sources for *H. axyridis* (Fig. 3A iii). Predation by coccinellids, predatory bugs, and syrphid larvae and parasitism by braconid and aphelinid wasps have been shown to affect the population dynamics of soybean aphid in soybean fields (eg: Fox et al. 2004, Heimpel et al. 2004, Fox et al. 2005, Desneux et al. 2006, Brosius et al. 2007). Welsman et al. (2007) found that predation, rather than parasitism, slows the growth of these early-season populations of *A. glycines* occurring on buckthorn, and attributed most of the mortality to coccinellids. Oviposition among coccinellids typically occurs in the presence of food (Hodek 1973) so it is reasonable to speculate that abundance of *A. glycines* in April may allow *H. axyridis* to oviposit earlier in the season than would have occurred otherwise, effectively ‘kick-starting’ the population growth of *H. axyridis*.

In early summer, *A. glycines* migrates to its summer host, soybean. When large

numbers of aphids are observed in soybean, increasing numbers of larvae and adults of *H. axyridis* are observed soon after. Predation can cause a crash in aphid populations by the end of the season (Fig. 3A ii, shaded curve) (Fox et al. 2004) . Alternatively, insecticides may be applied to soybean fields for aphid control, causing aphid numbers to decline in soybean fields (Fig. 3A ii, solid curve).

In mid-September, *A. glycines* migrates back to its overwintering host, *R. cathartica*, where it remains feeding on foliage until oviposition occurs, usually around the time the shrub drops its leaves in late October (Welsman et al. 2007). *Rhamnus cathartica* retains its leaves later than many other plants in southern Ontario agroecosystems, so this

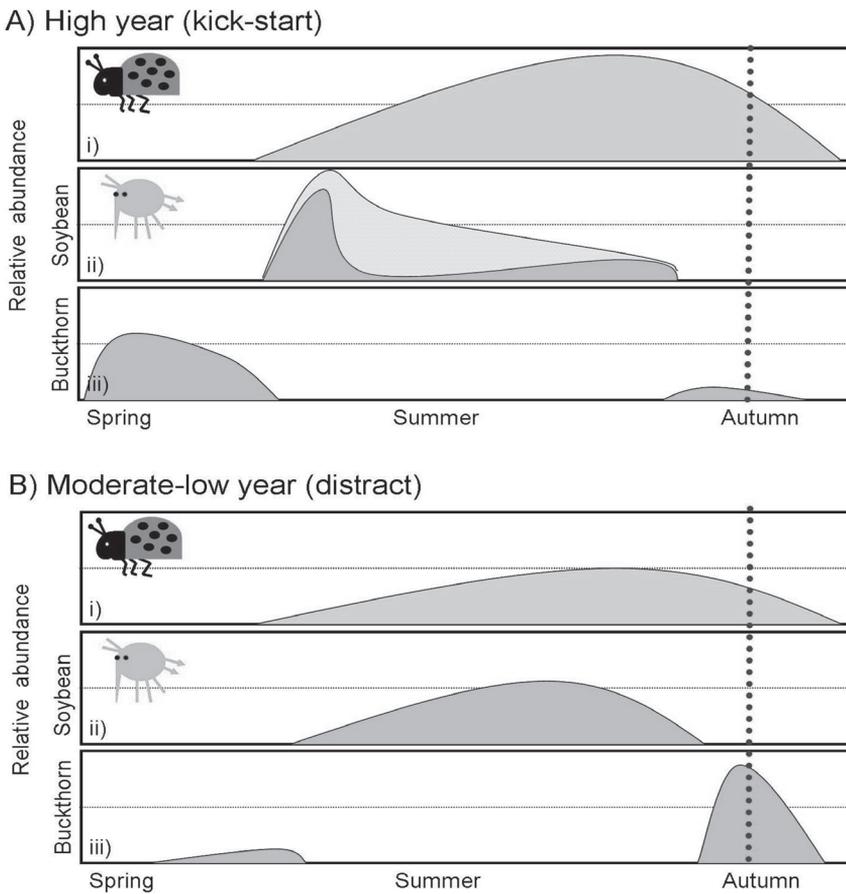


FIGURE 3: Hypothetical “kick-start- distract” model of interaction between *Harmonia axyridis* and *Aphis glycines*. In this scenario, early season abundances of *A. glycines* on buckthorn ‘kick-start’ population growth of *H. axyridis*, and late season abundances of *A. glycines* ‘distract’ *H. axyridis* from grapes until after harvest. A) Kick-start year, B) Distract year. Illustrated for each year are hypothetical abundances of i) *H. axyridis*, ii) *A. glycines* on soybean and iii) *A. glycines* on buckthorn. Dotted vertical lines represent grape harvest.

host may represent the last reservoir of aphid populations before winter within the Niagara region agroecosystem. In years when *A. glycines* is abundant on its overwintering host, *H. axyridis* typically is observed with the aphid (Bahlai et al. 2008), and is 'distracted' from ripening grapes in vineyards (Fig. 3 B iii).

In years when *A. glycines* is not abundant on buckthorn, *H. axyridis* aggregates in large numbers in Niagara Peninsula area vineyards (Fig. 3A i, iii) (Welsman et al. 2007). When aphids are scarce, beetles may move to ripening grapes because volatiles released by fermentation of fruit may be similar to volatiles associated with aphid honeydew (Bahlai et al. 2008). If this is the case, ripe grape odour could 'trick' *H. axyridis* into foraging in vineyards for aphids, or simply act as a cue for the location of a 'next best' food source.

In years when a high number of aphid eggs had been observed in the previous winter, both *A. glycines* and *H. axyridis* were observed at higher numbers in soybean in July. Higher counts of *H. axyridis* were observed in late July in 2005 than in 2004 and 2006. However, when insecticides were applied to these fields in August 2005, numbers of *H. axyridis*, like aphid infestations, decreased immediately, and persisted at low levels for the remainder of the season (Fig. 2). Yet we observed substantial numbers of *H. axyridis* feeding on aphids living on weeds in naturalized and semi-naturalized areas adjacent to our observation fields in mid to late August of 2005 and large numbers of *H. axyridis* were observed in vineyards that year. In years where only spot infestations of *H. axyridis* were observed in vineyards (i.e. 2004 and 2006), abundance of *A. glycines* on the overwintering host was observed. In these years, lower numbers of *H. axyridis* could have been satiated by large populations of aphids preparing to mate and oviposit on buckthorn.

This kick-start/distract model for the interaction of *H. axyridis* with *A. glycines*, combined with insecticide application practices, may help to explain the biennial cycle of infestation for both *A. glycines* and *H. axyridis*. To develop an effective integrated pest management strategy to control vineyard infestations of *H. axyridis*, several specific areas of inquiry should be pursued. Population monitoring of these beetles and their prey should be continued to gain data regarding numbers and distribution; monitoring of *A. glycines* and *H. axyridis* should continue in Niagara Peninsula area soybean fields, and should be expanded to include populations of aphids in other crops and weeds in late summer. This monitoring could provide information about agroecosystems in which *H. axyridis* occurs in late summer. This may provide an early warning for potential vineyard infestations. Because the interactions between *A. glycines* and *H. axyridis* appear to be consistently following a biennial cycle, additional population data can be used to refine predictions of when and where outbreaks of these two species will occur, and under what conditions.

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