Do aphid-resistant soybeans need insecticides for maximum yields?

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Introduction

Soybean aphid, ***Aphis glycines*** Matsumura (Hemiptera: Aphididae), was first identified in the U.S. in the state of Wisconsin in 2000 and rapidly spread through the north central region of the US. The pest can reduce soybean yield by diminishing photosynthesis rates and/or by inducing premature senescence. Both effects reduce seed yield and seed quality. Since its introduction in North America, insecticides have been the primary management tool used by growers when outbreaks occur, which are frequent despite the impact of predators commonly found in North American soybean fields. Although predatory insects can limit soybean aphid population growth, their impact is nevertheless limited in landscapes dominated by field crops. In China, parasitoids are important for aphid control in soybean fields, however, they are largely missing in the natural enemy community of North America. Efforts to release exotic parasitoids into North America have begun.

Development of resistant cultivars is another option to reduce aphid effects. There have been some advances in the identification of sources of resistance that may be introgressed in commercial cultivars. The Germplasm Resources Information Network (USDA-Agricultural Research Service, 2009) lists 16 soybean aphid resistant plant introductions (PIs) and six PIs showing moderate resistance. The genetic base of the resistance for some entries has been determined. Resistance in Dowling (PI 548663) (Hill et al., 2006a) is conferred by a single dominant gene (***Rag1***), and a different single dominant gene was also found to be responsible for resistance in Jackson (PI 548657) (Hill et al., 2006b). Mensah et al. (2008) found resistance in PI 567541B and PI 567598B to be determined by two recessive genes. On the other hand, resistance in PI 243540 was conferred by a single dominant gene different from ***Rag1***, named ***Rag2*** (Mian et al., 2008; Kang et al., 2008).

The majority of the studies aimed to identify soybean aphid resistant sources were conducted under controlled laboratory conditions or in field conditions with few locations. The degree of resistance to soybean aphid depends on plant genotype, the environment where the crop develops and on the interaction between the two, which suggest that resistance patterns may differ among genotypes and environments. An additional factor that may contribute to the potential interaction is the occurrence of new soybean aphid biotypes that can reproduce on soybeans carrying the Rag1 gene (Kim et al., 2008) or in any of the other genetic plant material already identified. Field-based evaluations are necessary to determine how effectively soybean resistant genotypes subjected to different field conditions respond to varying levels of aphid pressure. Furthermore, interaction between genotype and environment can provide insight into the pervasiveness of biotypes that reduce the utility of soybean aphid resistant varieties.

Methods

To evaluate the performance of ***Rag1*** gene across environments, and its effect on yield, LD16060 and SD76R were planted from May to June in 2007 in four Midwestern states, Illinois (Whiteside Co.), Iowa (Story Co.), Minnesota (Redwood Co.) and Michigan (two locations: Ingham Co. and Saginaw Co.). We refer to LD16060 as "resistant" because it contains the ***Rag1*** gene. The lineage of LD16060 [(Dowling x Loda) x SD76R), Backcross 2, F2 derived line] includes SD76R which we refer as "susceptible". The susceptible line was produce from lineage (Stride2 x ResnikRR) that does not contain the ***Rag1*** gene. In 2008 plantings of the lines were conducted in five states, Illinois (Whiteside Co.), Iowa (Story Co.), Minnesota (Redwood Co.), South Dakota (Brookings Co.) and Michigan (two locations: Ingham Co. and Saginaw Co.). Considering both years, 11 environments were used to test the consistency of the Rag1 gene.

At each location and year, a split-plot design with four blocks was used, with soybean lines as whole plots and aphid exposure (manipulated with insecticide) as subplots. Whole plots were planted at 30 seeds m2 with 12 rows spaced at 0.76 m and 16 m long. Subplot (6 rows wide and 16 m long) were randomly assigned within each whole plot and were either not treated with insecticide (referred to as 'natural aphid infestation') or treated with lambda-cyhalothrin at the labeled rate when more than 50 aphids per plant were observed. These plots were referred to as 'aphid free' to simulate an environment in which aphids would not reduce the yield of the plant (e.g. well below the economic threshold; Ragsdale et al., 2007). Depending upon location, the aphid free subplots received 1 to 3 applications of the insecticide during the growing season. The aphid infestation on all sub-plots was estimated as described previously and reported in terms of logCAD. Aphid infestation levels in the resistant and susceptible lines was analyzed using PROC ANOVA (SAS Institute, 2002-2004) with locations and lines as fixed factors and replications as random effects.

To determine yield loss in the resistant and susceptible lines in response to different levels of aphid infestation, regression analyses between relative yield and aphid infestation were used. Relative yield (%) was calculated as the ratio between the yield in the subplot treatments (natural aphid infestation: aphid free). Yield (expressed on 13% moisture basis) was measured in the four central rows of each subplot. A bilinear model was used to fit the susceptible line using Table curve 2D v5.01 software (Jandel Scientific, 1991). No yield estimates were obtained from the Ingham Co. location in Michigan State during 2007 (MI07/1).

To determine if the presence of the ***Rag1*** gene is associated with a reduction in yield (e.g. yield drag), we compared the yield between resistant and susceptible lines in the subplots that were sprayed with insecticide. Yield was evaluated in all locations where we estimate relative yield except in Michigan 2008 Ingham Co. These data were analyzed using PROC ANOVA (SAS Institute, 2002-2004) with locations and lines as factors and replications as random effects.

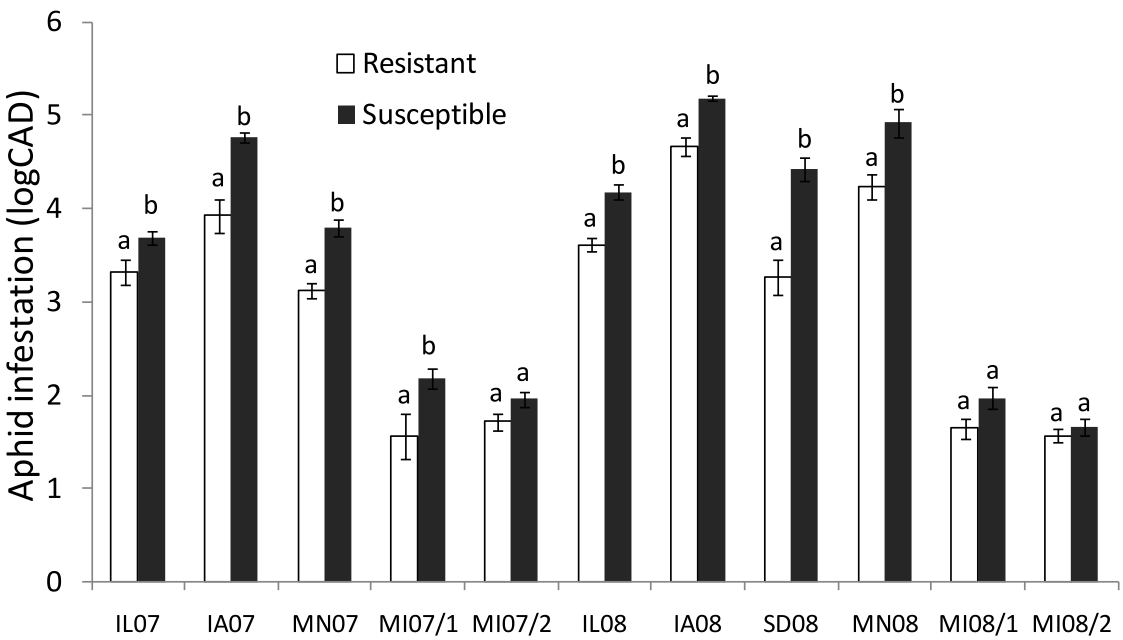

Figure 1. Average aphid infestation in the resistant (LD16060) and the susceptible (SD76R) lines across locations-years. Different letters represent significant differences between lines at each location. Bar indicates average ± standard error. IL= Illinois (Whiteside Co.), IA= Iowa (Story Co.), MN=Minnesota (Redwood Co.), SD (Brookings Co.), MI/1= Michigan (Ingham Co.) and MI/2= Michigan (Saginaw Co.).

Results

Aphid infestation levels on the resistant (LD16060) line were significantly lower (lower logCAD) than on the susceptible (SD76R) line at all location-year combinations except in Michigan during 2007 (Saginaw Co. [MI07/2]) and 2008 (Ingham Co. [MI08/1]; Saginaw Co. [MI08/2]) (location/year by line interaction P=0.004). Although aphid populations were higher on the susceptible line at these Michigan locations (Fig. 1), the aphid populations were not significantly different from the resistant line.

As aphid infestations increase, the relative yield dropped significantly for the susceptible line (Fig. 2, linear phase). We observed a 42% decrease in yield when the CAD value reached 151,355 aphids/plant (logCAD= 5.18). We did not observe such a significant drop in the resistant line (location by line interaction, P=0.0009). The resistant line showed no changes in relative yield at increasing levels of aphid infestation, the slope in the linear regression was not significantly different from zero (P= 0.09). Relative yield of the susceptible line, however, was similar to that of the resistant line when the CAD value was below 4073 aphids/plant (logCAD= 3.61). We did not include data from the 2008 Ingham Co. in Michigan (MI08/1) in the models due to a sever infestation with Japanese beetle (Popillia japonica Newman) (D.I Chandrasena, personal communication). The infestation by the Japanese beetle may have confounded the relationship between soybean aphid infestation and yield in our model.

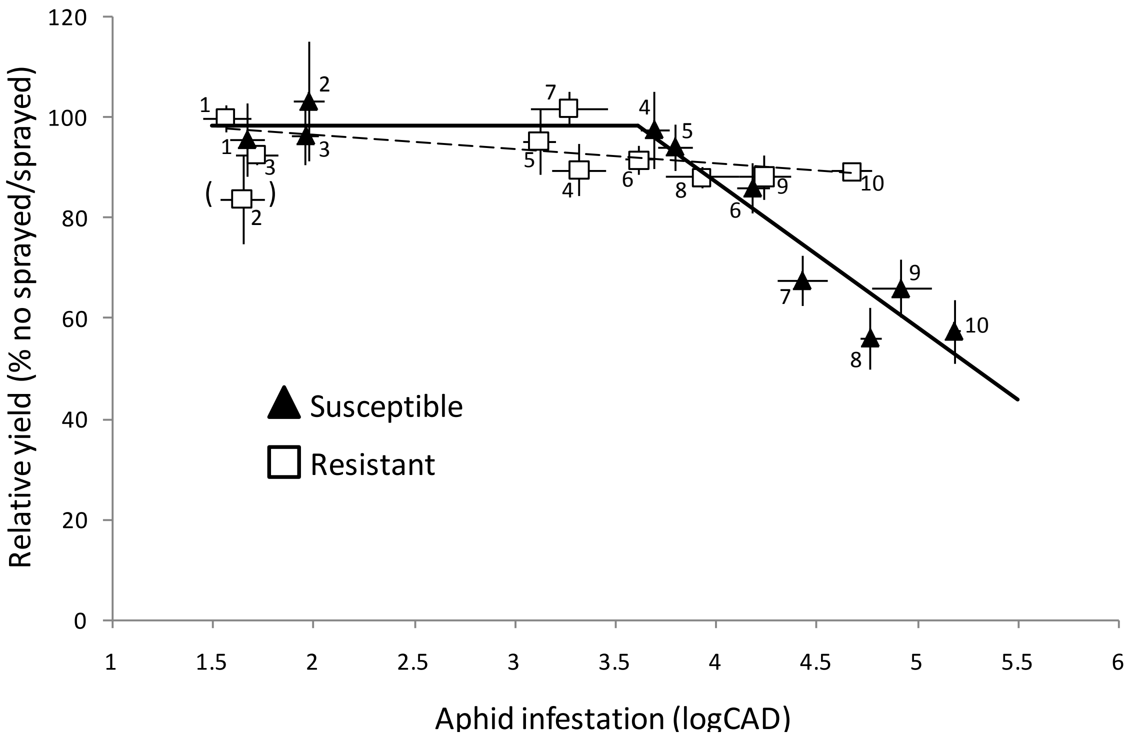

Figure 2. Linear regression between relative yield and aphid infestation in the resistant (LD16060) (dashed line) and the susceptible (SD76R) (solid line) lines across locations-years. Data are mean ± standard error. For the resistant line y=-2.86x + 102.41, r2=0.35. For the susceptible line in the constant phase y= a + b*c and in the linear phase y= a + b*x. a=202.48, b=-28.8 and c=3.61, r2=0.92. 1= MI 2008 second location (Saginaw Co.), 2= MI 2008 first locations (Ingham Co.), 3= MI 2007 second location (Saginaw Co.), 4= IL 2007 (Whiteside Co.), 5= MN 2007 (Redwood Co.), 6= IL 2008 (Whiteside Co.), 7= SD 2008 (Brookings Co.), 8= IA 2007 (Story Co.), 9= MN 2008 (Redwood Co.) and 10= IA 2008 (Story Co.).

To determine if yield drag was potentially associated with the presence of ***Rag1***, we compared yield in the resistant and susceptible lines in the subplots that were sprayed with insecticide. We observe a difference in yield between these two lines at one location (South Dakota, 2008; data not shown) resulting in a marginally significant location by line interaction (P=0.0532). There were no differences in yield differences between susceptible and resistant lines in the aphid-free subplots at any of the other locations-years.

Discussion

To answer the question from our title, performance of the aphid-resistance from our studies suggests that this management tool may not need an insecticide for maximum yield. Our results suggest that the performance of aphid-resistant soybeans that contain the ***Rag1*** gene will initially be consistent across multiple environments. We observed fewer aphids on a related susceptible line compared to the LD16060 that the ***Rag1*** gene at every location that we tested this aphid-resistance. The ***Rag1*** gene not only showed no evidence for yield drag, but also tolerance to soybean aphid. Thus the economic threshold (ET), which was determined for soybean aphids on susceptible lines, will be increased in aphid resistant lines. Farmers should be aware that at no location was the ***Rag1***-containing line free of aphids. As described by Kim et al. (2008), biotypes of the soybean aphid can survive on ***Rag1*** containing soybeans. As the use of this resistance becomes more common the presence of such biotypes will likely increase. Unlike genetically modified sources of resistance (i.e. Bt corn) that are required by EPA to have a resistance management plan to prevent such a development, no such plan is in place for ***Rag1***. Growers are therefore recommended to continue scouting aphid-resistance to avoid experiencing yield loss from outbreaks that may occur when biotypes become common.

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