THE UNIVERSITY OF ARIZONA
COLLEGE OF AGRICULTURE AND LIFE SCIENCES
COOPERATIVE EXTENSION
Yuma Agricultural Center

Diamondback Moth on Desert Cole Crops, 2016-2020

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Introduction

In the fall of 2016, widespread infestations of an invasive diamondback moth (DBM) population occurred in all vegetable growing regions in Arizona and continued throughout the remainder of the spring 2017 growing season. It was quickly determined that the source of the DBM populations originated from infested transplants grown in desert nurseries. Within weeks of transplanting, PCAs and growers found that they could not adequately control the DBM infestations. It was later discovered that the invasive DBM population was resistant to the first generation diamide insecticides (Coragen, Beseige, Belt and Vetica) commonly used to control Lepidopterous larvae. Soon after the first transplanted fields began to harvest in November, several growers reported that seriously infested fields suffered significant yield reductions, and/or incurred extremely high control costs. By late December, DBM populations began to spread from the infested transplanted fields to direct-seeded crops throughout the region, causing further losses. By February, reports of infested broccoli, cabbage, kale and cauliflower fields were routine. The DBM infestations experienced by Arizona growers in 2016-17 were not anticipated, and overall, resistant DBM caused serious losses in cole crops.

However, going into the past three growing seasons, PCAs and growers remained apprehensive about resistant DBM reappearing on their fall crops. Fortunately, DBM populations were much lighter than the 2016 fall season, and few if any complaints from PCAs or growers of uncontrollable DBM infestations, crop damage or yield losses were received since 2016-17 season. Furthermore, PCAs reported having no difficulty controlling larvae or adults with commonly used insecticides, including the diamides. Field trials and lab bioassays conducted over the past three seasons at YAC confirmed that the local DBM populations were susceptible to these insecticides. Field inspections of transplants yielded little to no larvae on plants arriving from local and coastal nurseries. Thus, we have concluded that the DBM that appeared in fall 2017-2019 were a distinctly different population than those that infested crops in the fall of 2016. To document the differences in impact of the DBM on Arizona cole crops over the past 4 years we conducted two-part surveys of growers and PCAs from Yuma and Maricopa Co., AZ and Imperial Co., CA in April of each year to estimate the severity of DBM on direct-seeded and transplanted Cole crops.

Survey Methods

A two-part survey was conducted during our annual Lettuce Insect Crop Losses Workshop held at the UA Yuma Ag Center in April in 2017-2019. In 2020, the surveys were emailed to PCAs to complete where a total of 16 PCAs and growers completed surveys down from 25 in 2019. In the first part of the survey, respondents were anonymously requested to estimate the acreage they managed by commodity, and of those acres, the percentage where DBM was present. PCA and growers were then asked to estimate the acreage where DBM was considered problematic (i.e., they had difficulty in controlling DBM). They were asked to estimate the number of sprays that were applied to each specific commodity, and the average yield loss attributed to DBM.

In the second part of the survey, the intensity of chemical management required to control DBM and the associated level of control provided by each insecticide product was estimated. Respondents were provided an inclusive list of available insecticides used for DBM control, and asked to estimate the percentage of acers treated for each product and number of sprays applied. To estimate insecticide product performance, respondents were asked to rate the level of control that each product provided in controlling DBM using the following scale: 4-Excellent; 3-Good; 2-Fair; 1-Poor; and 0-No control. Totals and percentages provided in the report were averaged across all completed surveys.

Impact of DBM on Cole Crop Commodities

The population abundance of DBM in the desert last season was similar to the 2017 and 2018 seasons, but significantly lower than what was observed under widespread outbreak conditions in 2016. This is based on PCA comments and personal observations of experimental and commercial cole crops during both growing seasons.

Results from areawide pheromone trapping that started in December 2016 show that DBM moth activity was significantly higher in spring 2017 compared to the past three years **(Fig 1)**. Although seasonal moth captures varied at lower levels from 2018 to 2020, larval populations in fields were low in each spring and fall season. This is consistent with the significantly reduced DBM larval populations observed in fields within the Yuma copping system. Interestingly, trap catches during the summer months of all three years show that DBM were non-existent in July and August due to the unavailability of suitable *brassica* host plants. In essence, the populations become extinct during this two month window. This supports our hypothesis that DBM disappear in the summer, only to reappear in the fall via transplant introductions or on wind currents during monsoon weather events.

Following these summers of inactivity in DBM trap catches, pheromone trapping data indicates that moths start to appear in traps placed adjacent to recently transplanted and direct-seeded broccoli, cabbage, and cauliflower crops in early-mid September (**Fig 2**). Early light activity appears to be associated with transplants, but the sharp increases in moth populations in September occurred soon after the remnants of tropical storm Lidia (Sep 4) and a severe monsoon storm (Sep 12) occurred in Yuma in 2017. In 2018, traps spiked following the remnants of Hurricane Rosa (Sep 30) in Yuma, and in 2020 following remnants of former Hurricane Lorena up from Baja California on Sept 24. This strongly supports our assertion that these DBM populations migrated into the area on these storms. This is further supported by similarities in moth counts in traps placed in both transplanted and direct-seeded crops **(Fig 2).** Shortly thereafter, PCAs began reporting DBM larvae appearing on seedling stands and newly transplanted crops. We also began to pick up larvae at this time on direct-seeded broccoli crops at YAC. However, the DBM populations never reached outbreak status in 2017, 2018 or 2019, and unlike 2016, we received no complaints from PCAs or growers of DBM infested transplants originating from local nurseries. Finally, DBM larvae were effectively controlled with both soil (Coragen, Verimark) and foliar (Radiant, Proclaim, Coragen and others) insecticides throughout the growing season.

Results from the first part of the survey clearly show that DBM had a minimal impact on both transplanted and direct-seeded commodities in 2019-20 (**Table 1**). A total of 16 completed surveys represented an estimated total of 11,286 acres of Cole crops in Yuma, Maricopa and Imperial counties. Transplanted cauliflower and cabbage, and direct-seeded broccoli were the most reported commodities and had the highest numbers of acres where DBM were present. Overall, the estimated average number of acres where DBM were considered problematic, the number of sprays applied to control DBM, and the average yield loss for all the *brassica* commodities in 2019-2020 was similar to the previous two season and extremely low relative to the 2016 outbreak season. For a direct comparison with estimates:

From 2016-2017 see https://acis.cals.arizona.edu/agricultural-ipm/vegetables/vipm-archive/vipm-insect-view/impact-of-diamondback-moth-on-arizona-cole-crops-2017-survey-results ;
From 2017-18 see https://acis.cals.arizona.edu/agricultural-ipm/vegetables/vipm-archive/vipm-insect-view/diamondback-moth-on-arizona-cole-crops-2018-survey-results
From 2018-19 see https://acis.cals.arizona.edu/agricultural-ipm/vegetables/vipm-archive/vipm-insect-view/diamondback-moth-on-arizona-cole-crops-2018-19-survey-results .

When averaged across all commodities, the percentage of total acres where DBM were considered problematic was about 5% in 2019-2020 compared with almost 60% in 2016-17 (**Fig 3**). The reduction in problematic acres were similar when considering the major transplanted and direct-seeded commodities grown during the past three seasons (**Fig 4 and 5**). Yield losses attributed to DBM in transplanted and direct-seeded commodities were similarly negligible in 2019-2020 as well (**Fig 6 and 7**) compared with unusually high losses in 2016. Consequently, in 2017, 2018 and 2019 seasons, PCAs reported that significantly fewer spray applications were required to control DBM in these crops compared with 2016 (**Fig 8-9**). On average, PCAs required no more than a single foliar spray to control DBM in broccoli and cauliflower, and cabbage in 2019-20. These data clearly show how differently the DBM infestations impacted desert Cole crops during the past four growing seasons.

Insecticide Usage, Efficacy, and Resistance

Estimated insecticide usage for DBM control on Cole crop commodities for all four seasons is shown in **Table 2.** Overall, significantly fewer acres were treated, and fewer sprays were applied during the past three seasons compared with 2016-201. Based on treated acres, Radiant, pyrethroids, and Proclaim were the most applied insecticides used for DBM control last season. Radiant was used by the largest percentage of PCAs and was treated on a large percentage of acres. Verimark applied as a soil treatment was applied as a transplant tray drench on a large percentage of the transplanted cauliflower crops (**Fig 10, Table 4**). Verimark usage broccoli and cabbage were down significantly in 2019-2020. Overall, the diamides (Belt, Vetica and Besiege) were used on fewer acres, but performed well compared to 2016. Surprisingly, Exirel, an effective 2nd generation diamide, usage remains light.

The PCA ratings on the insecticide field performance of insecticides used against DBM in 2019-2020 are very consistent with research conducted at the Yuma Ag Center this past season. Based on the survey responses, most of the products used by PCAs performed *Good* to *Excellent* (rating of 3-4) in 2019, including the diamide products that were found to be resistant in 2016-17 (**Table 3; Fig 10**). In contrast, survey results from 2016 showed that the highest any one product rated was a 3.0 (Verimark tray drench) and among foliar products in 2016, most products rated Fair-Good (rating of 2-3) with the exception of the diamides, Assail, Intrepid, and the older organophosphates. Field experiments conducted at YAC in 2019 showed that most products provided *good-excellent* activity consistent with PCA ratings (**Table 5**). Furthermore, Lab bioassays showed that DBM populations collected from the Yuma Ag Center in fall 2019 and spring 2020 were highly susceptible to Coragen, Radiant, Proclaim, and Exirel (**Table 4**).

Conclusions

We previously concluded that the 2016 DBM outbreaks were attributed to the establishment of a resistant population on developing transplants within local greenhouses that then dispersed into commercial cole crop fields at transplanting. This was unusual because in previous years PCAs easily controlled DBM with 1-2 well timed insecticide sprays, as has been the case since the 2016 outbreak where DBM were much lighter and comparable to what PCAs normally expect. Furthermore, the survey clearly indicates that control of the DBM populations in the past three growing seasons generally required a single spray on to prevent outbreaks or yield losses. Growers spent considerably less money controlling the pest and yield losses to DBM were negligible. We are still not completely certain where the DBM populations originated from in fall 2017-2019 but it is likely the DBM adults (moths) immigrated in from Mexico, California or elsewhere last summer via storms. Regardless of origin, it is important to note that DBM populations we saw last season were not resistant to the key insecticides used in the desert for management of Lepidopterous larvae. However, it is uncertain what will appear in desert Cole crops in fall 2020.

Acknowledgement

Special thanks go out to all the PCAs and growers who took time away from their busy schedules to participate in the surveys. Without your efforts, much of the data in this report would not exist. Data for seasonal pheromone trapping and insecticide resistance monitoring presented in this report was supported by two Arizona Department of Agriculture, Specialty Crops Block Grants provided by the USDA Agricultural Marketing Service under the award numbers SCBGP-FB17-42 and SCBGP-FB19-21. Additional funding to support resistance monitoring and field insecticide efficacy was provided by various Syngenta, FMC, Corteva, and UPL.

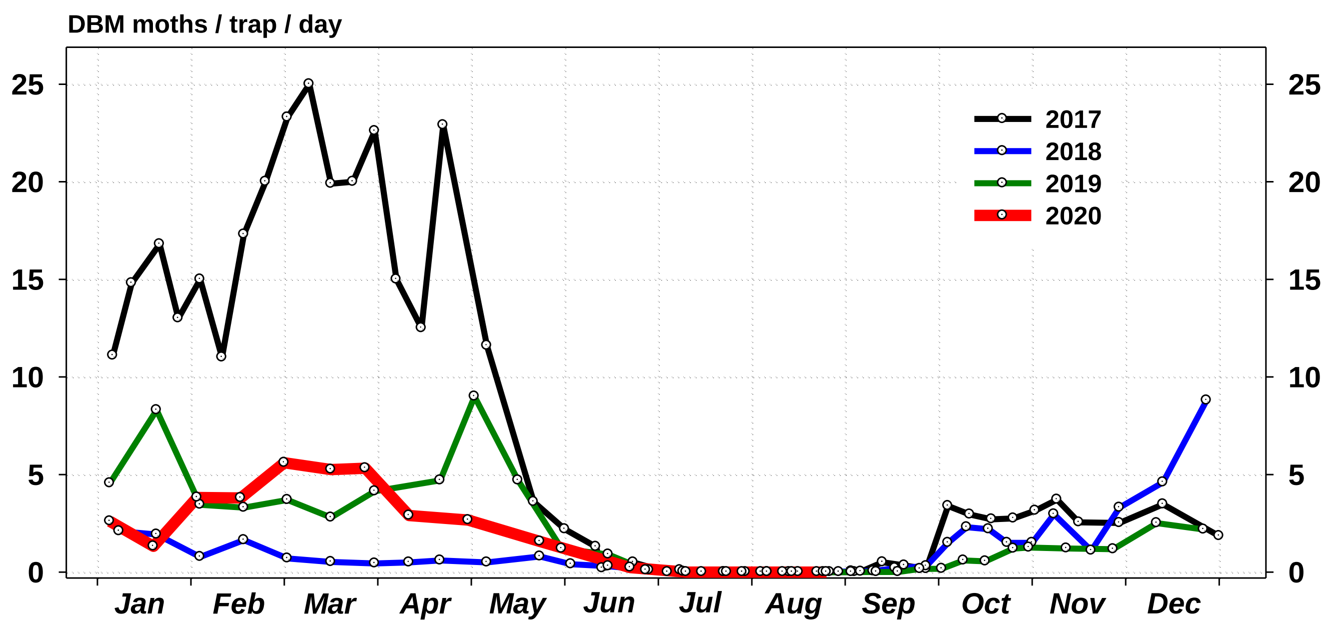

Figure 1. Relative DBM adult activity in Yuma based on pheromone trap catches of moths over the past 4 years. Initial trapping network was established on December 22, 2016.

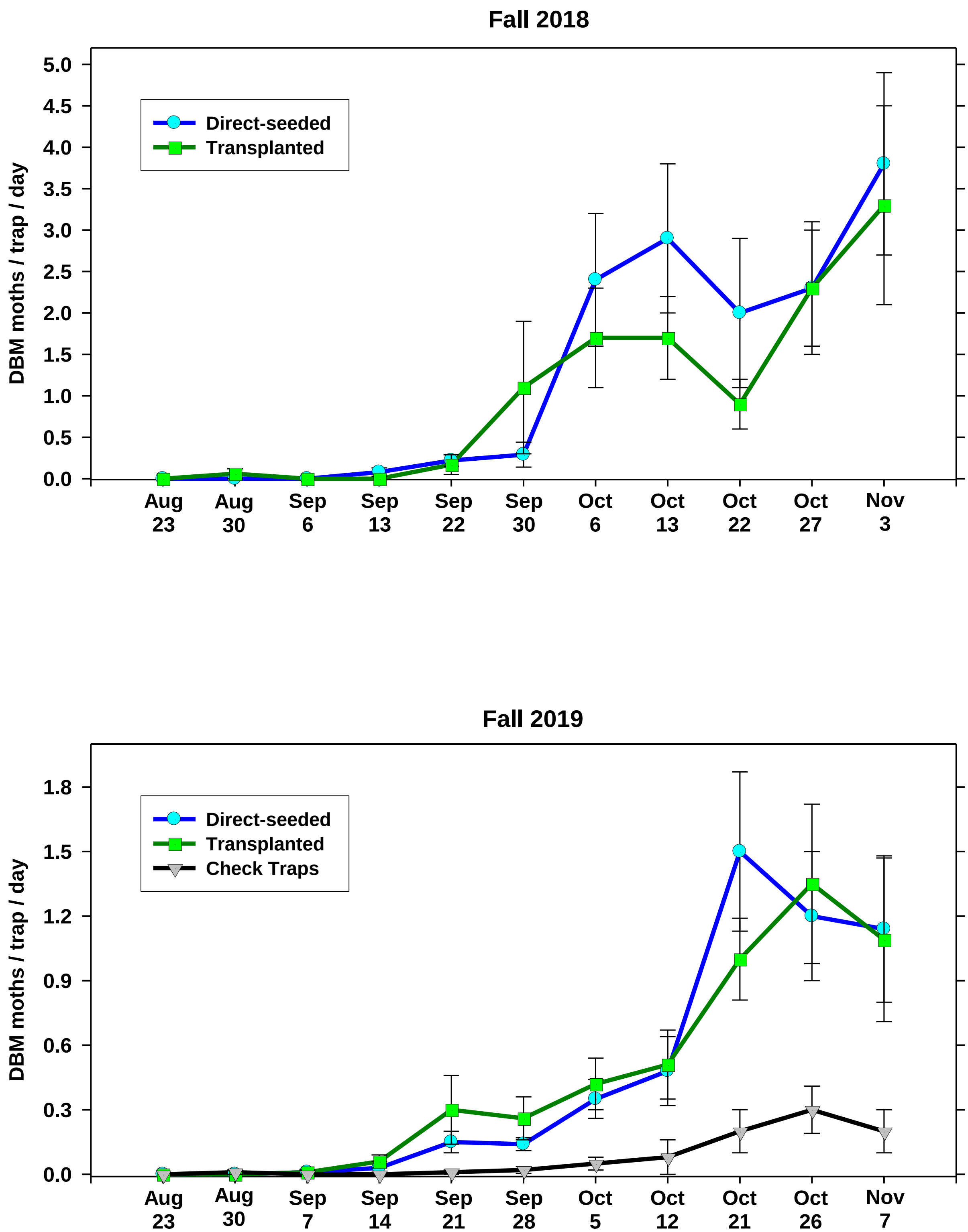

Figure 2. Relative DBM activity in Yuma County based on pheromone trap catches of moths during the fall of 2018 and 2019 in traps located in transplanted cauliflower and direct-seeded broccoli crops.

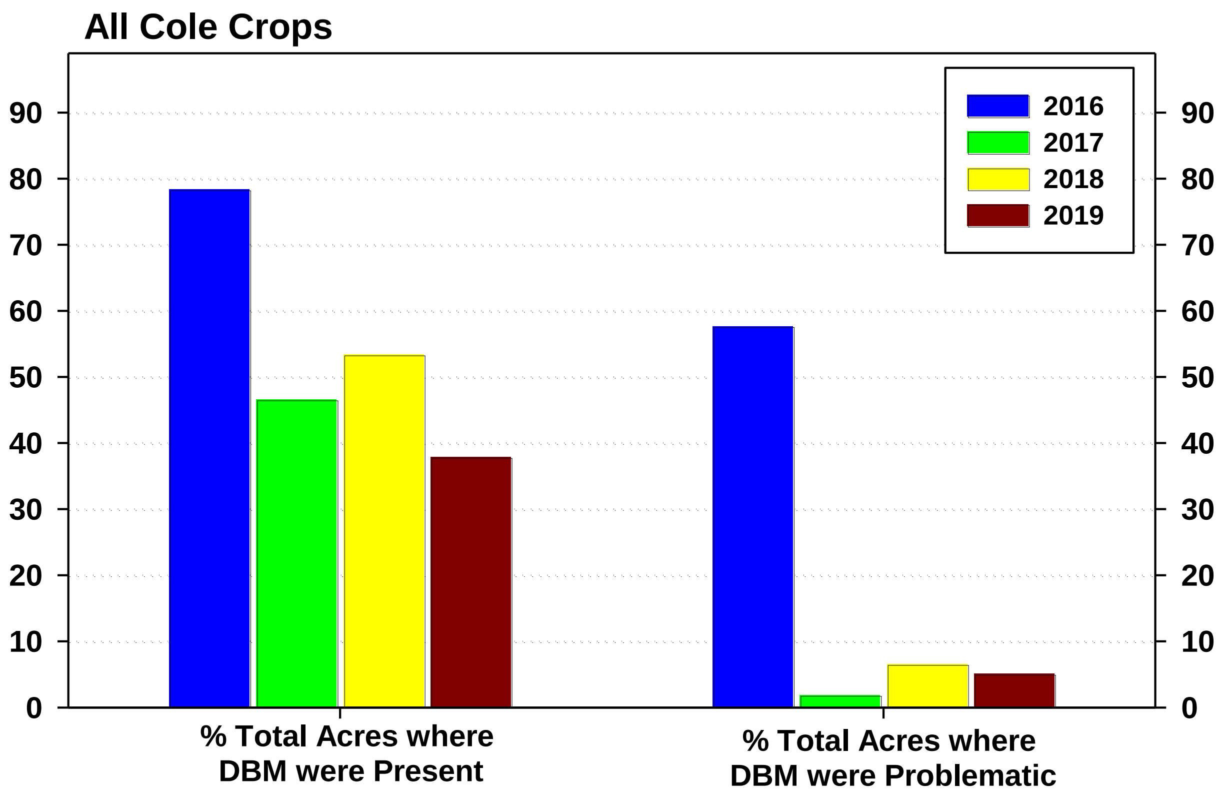

Figure 3. Comparison in the percentage of acres where DBM were present and problematic averaged across all Cole crops in 2016 -2020.

Table 1. Estimated impact of DBM on Cole crop commodities grown in Imperial county, CA and Yuma and Maricopa counties, AZ in 2019-20**.**

Crop	No. PCAs reporting	Total acres	Acres DBM Present [a]	Acres DBM Problematic [b]	Avg. No. Sprays	Max No. Sprays	Yield Loss (%)	Max. Yield Loss (%)
Broccoli-direct seeded	12	4070	1827	35	0.7	3	0.5	5
Broccoli-transplanted	4	1323	76	0	0.5	2	0	0
Cauliflower-direct seeded	1	120	120	0	0	0	0	0
Cauliflower -transplanted	13	2786	716	20	1	3	0	0
Cabbage - direct seeded	1	50	30	3	1	1	0	0
Cabbage - transplanted	3	1930	750	0	0.5	1	0	0
Baby Kale	4	410	301	114	3.3	7	1.3	3.8
Kale-transplanted	3	150	45	40	3	7	0	0
Brussel sprouts	1	400	360	360	12	12	0	0
Brassica seed crops	2	47	47	0	0.5	1	0	0
Napa/Bok Choy	0	0	0	0	0	0	0	0
Mizuna/Arugula	0	0	0	0	0	0	0	0
		11286	**4272**	**572**	**1.7**	**2.8**	**0.14**	**5%**

[a] Number of acres where DBM was present on plants in the field.
[b] Number of acres where DBM was considered a problem; PCAs had difficulty controlling larvae and adults.
[c] Average % yield loss in those acres where DBM was considered a problem (difficult to control).

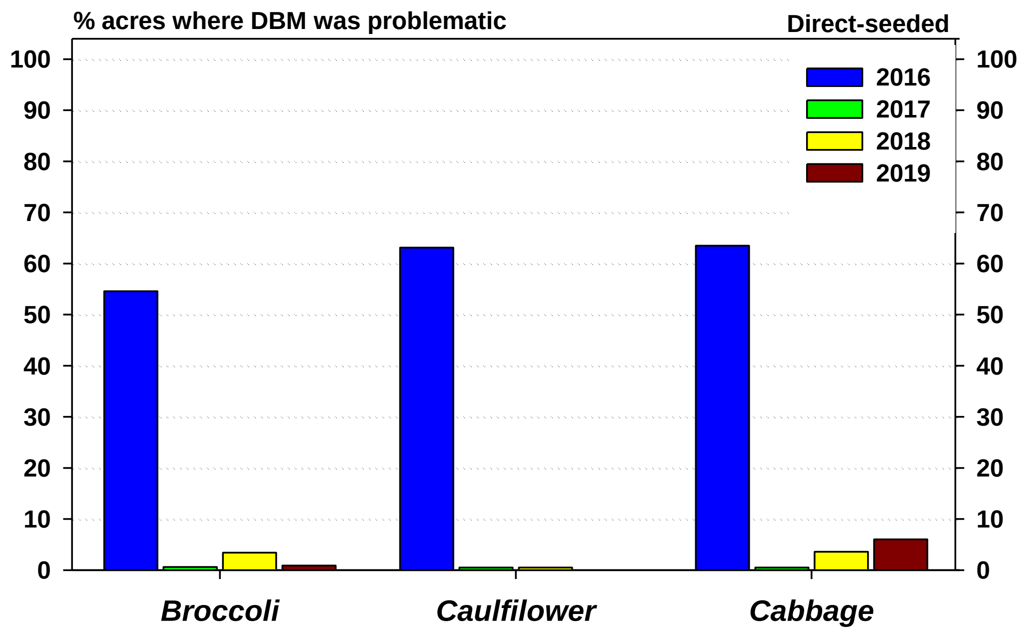

Figure 4. Comparison in the percentage of acres where DBM were considered problematic on direct-seeded Cole crops in 2016-2019.

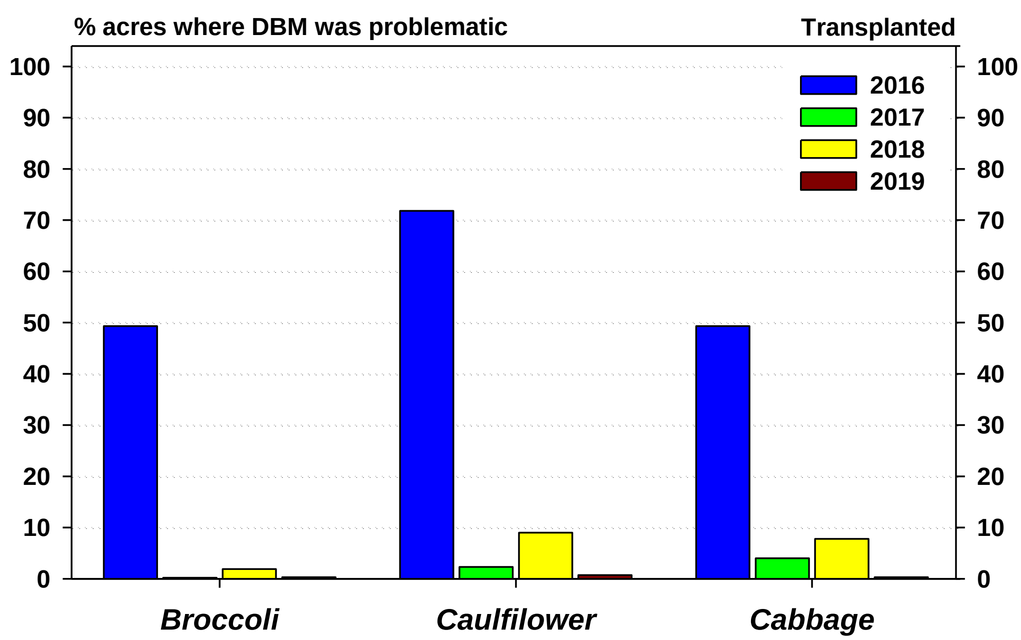

Figure 5. Comparison in the percentage acres where DBM were considered problematic on transplanted Cole crops in 2016-2019.

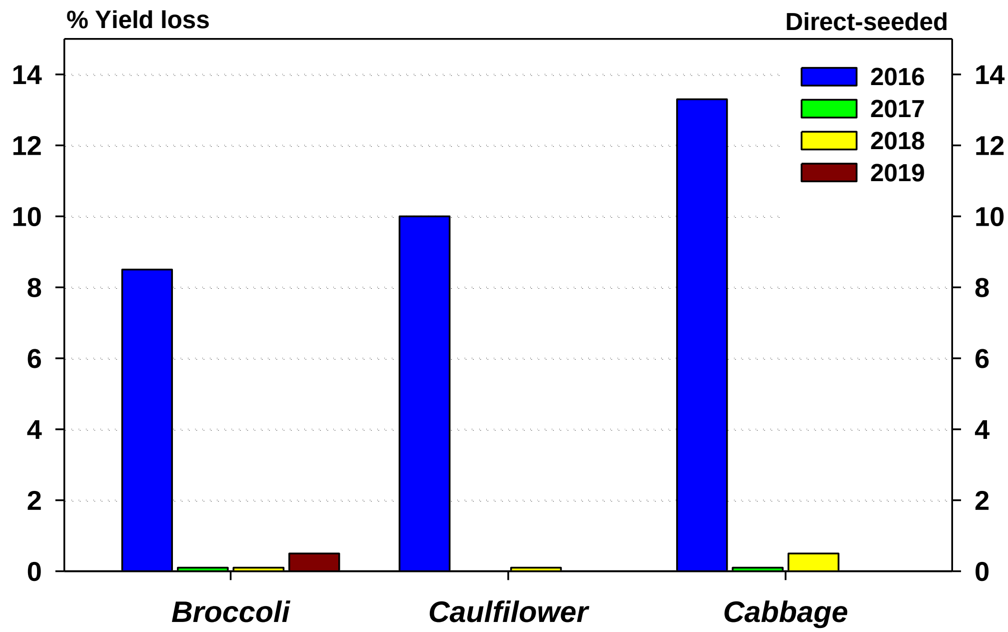

Figure 6. Comparison in the percent yield loss attributed to DBM on direct-seeded Cole crops in 2016-2019.

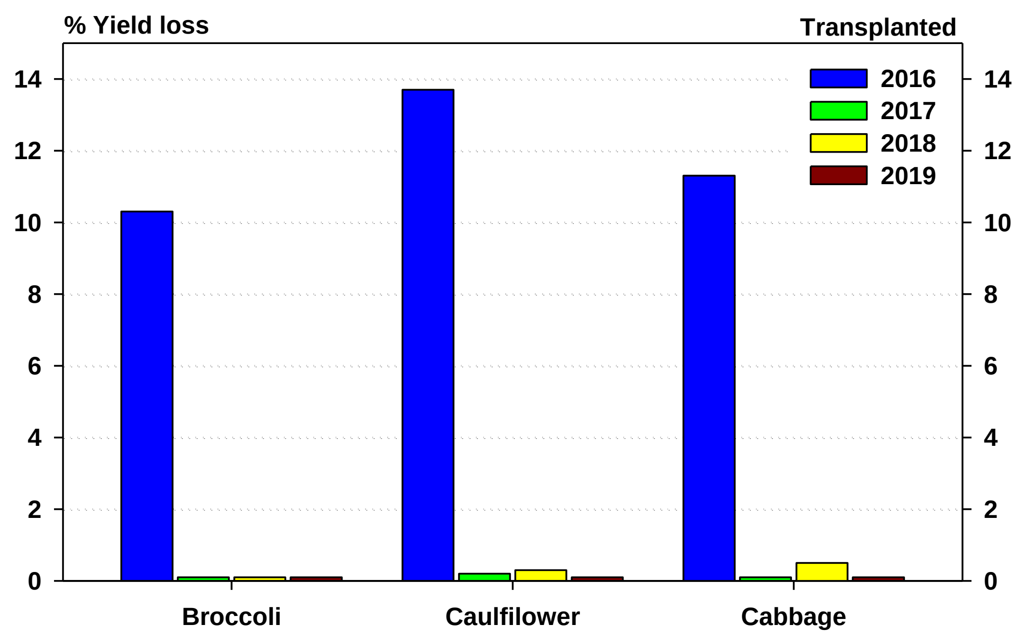

Figure 7. Comparison in the percent yield loss attributed to DBM on transplanted Cole crops in 2016-2019.

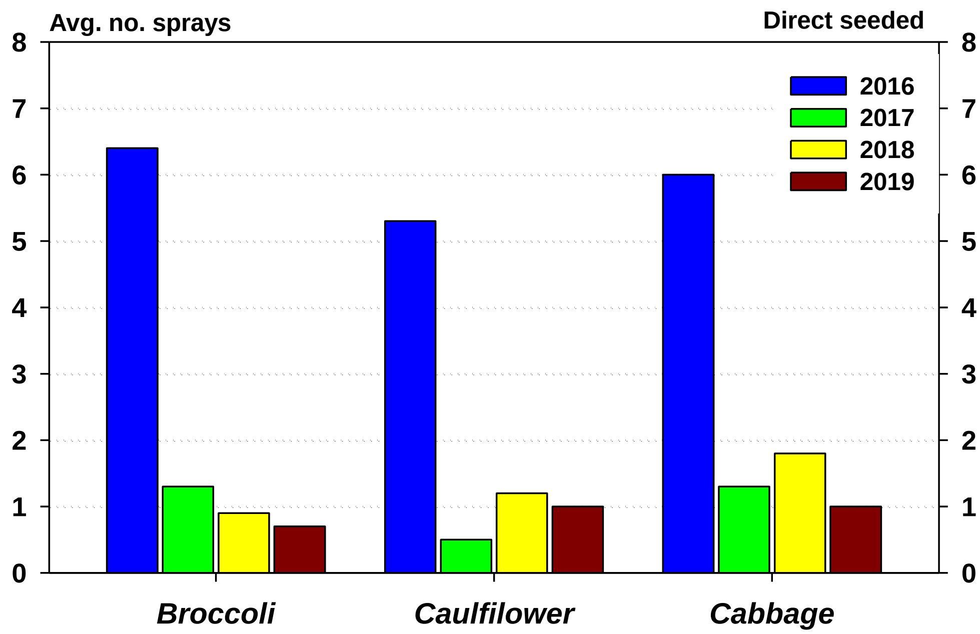

Figure 8. Comparison in the average number of sprays for DBM on direct-seeded Cole crops in 2016-2019.

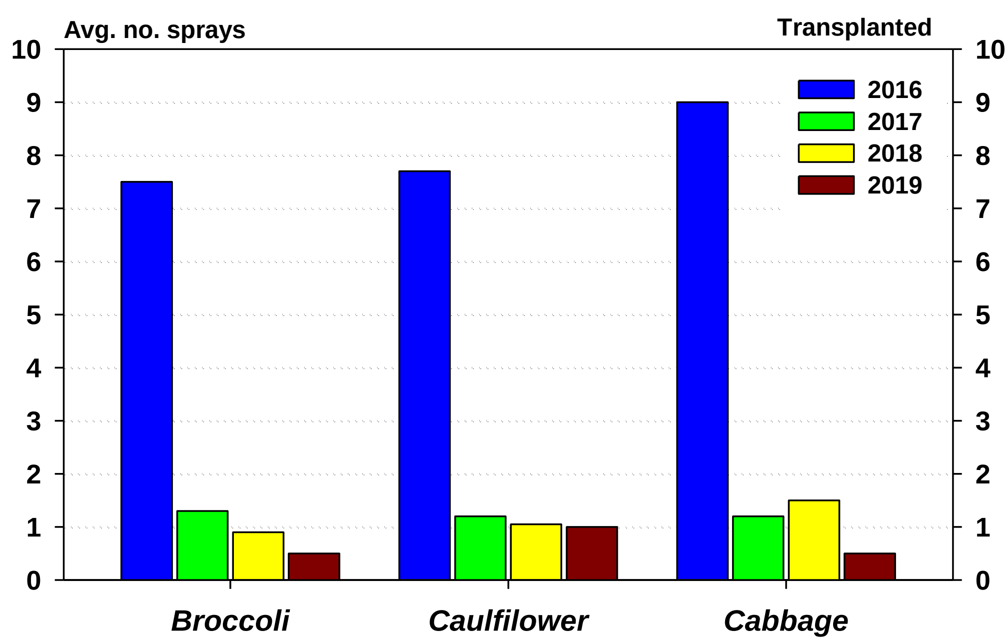

Figure 9. Comparison in the average number of sprays for DBM on transplanted Cole crops in 2016-19

Table 2. Insecticide Usage for DBM Control on Desert Cole Crops in the 2016-2020 growing seasons.

	2019-2020			2018-2019			2017-18			2016-17		
Insecticide	**% Acres treated**	**Avg. no. sprays**	**Treated acres [a]**	**% Acres treated**	**Avg. no. sprays**	**Treated acres [a]**	**% Acres treated**	**Avg. no. sprays**	**Treated acres [a]**	**% Acres treated**	**Avg. no. sprays**	**Treated acres [a]**
Pyrethroid	37.8	2.5	9,875	28.5	2.4	13,332	50.2	2	19,519	98.2	3.3	70,117
Radiant	42.1	1.6	8,115	37.5	1.5	11,576	57.9	1.4	20,894	85.4	5.5	101,629
Lannate	5.8	1.5	905	6.2	3	5,865	19.7	1.3	6,676	49.8	2.5	26,938
Proclaim	28.2	1.1	3,227	21.9	1.1	4,957	29.4	1.2	10,412	83.9	2.9	52,645
Verimark	13.9	1	1,446	22.6	1	4,655	34.6	1	7,680	-	-	-
Intrepid	4.8	1	503	9.9	1.5	3,056	20.9	1	5,051	9.3	1	2,012
Entrust	7.8	1.7	1,379	8.5	1.7	2,973	17	1.8	6,854	32.5	2.2	15,470
Belt	0	0	0	5.1	1.5	2,019	9.3	1	2,072	65.1	2.8	39,440
Coragen (soil)	13.8	1	1,436	8.3	1	1,712	13.7	1	3,052	14.1	1.4	4,271
Coragen (foliar)	11.9	1	1,238	6.1	1	1,248	12.5	1	2,778	42.6	1.4	12,904
Besiege	0.7	1	73	4.7	1	960	5	1	1,117	41.9	2.4	21,758
Exirel	2.7	1	281	3.9	1	800	1.7	1	370	18.1	1.2	4,700
Vetica	17.7	1	1,841	1.6	1	332	0.7	1	150	6.4	1	1,385
Avaunt	2.1	1	218	1.4	1	286	10.1	1	2,240	14.7	1.2	3,817
Cormoran	-	-	-	1.3	1	266	2.9	1	648	39.4	1.7	14,492
Xentari/Agree	6.2	1.7	1,096	7.5	1.1	1,658	32.4	1.8	14,150	6.3	1	1,363
Dipel/Javelin	3.1	3	967	-	-	-	12.7	1.8	5,605	5	1	1,082
Assail	1.1	1	114	0.7	1	155	0	0	0	-	-	-
Phreromone	12.7	1	1,321	8.4	1.5	1743	-	-	-	-	-	-
Malathion	-	-	-	-	-	-	5.2	1	1,150	22.9	1.8	8,919
Dibrom	-	-	-	-	-	-	3.3	1	740	15.1	1.2	3,921
Acephate	-	-	-	-	-	-	1.9	1	420	5	1.2	1,298
Chlorpyrifos	-	-	-	-	-	-	0.4	1	81	25.7	1.2	6,673

[a] Total treated acres estimated by multiplying: Avg. % acres treated * Avg. no. of applications * Acreage estimated by participating PCAs in the survey.

Table 3. Performance Rating [a] for insecticides used for DBM Control on Desert Cole Crops in the 2016-20 growing seasons.

	2019-2020		2018-2019		2017-18		2016-17	
	No. PCAs using product[a]	Rating[b]	No. PCAs using product[a]	Rating[b]	No. PCAs using product[a]	Rating[b]	No. PCAs using product[a]	Rating[b]
Verimark	6	4	9	3.9	10	4	2	3
Assail	1	4	1	3	0	-	9	1
Entrust	5	3.8	3	4	5	3.8	11	2.7
Exirel	4	3.8	5	3.8	2	4	7	2.6
Radiant	13	3.6	21	3.5	17	3.7	20	2.5
Lannate	2	3.5	3	3.7	6	3.2	15	2.4
Proclaim	8	3.4	13	3.3	12	3.7	19	2.3
Coragen (soil)	4	3	1	3.5	3	3.7	3	2.3
Pheromone	1	3	1	3	-	-	-	-
Pyrethroid	7	2.9	10	2.5	11	2.9	19	1.3
Avaunt	4	2.8	4	2.8	4	2.8	11	1
Coragen (Foliar)	3	2.7	6	3.3	6	3.5	16	1.1
Intrepid	3	2.7	2	3	5	2.6	6	1.7
Xentari/Agree	3	2.7	5	2.8	8	3	17	2.6
Vetica	2	2.5	1	4	2	4	6	2.6
Besiege	2	2.5	2	2	2	3.5	7	1
Dipel/Javelin	1	2	-	-	4	2.8	-	-
Cormoran	-	-	1	4	1	4	-	-
Belt	-	-	2	3.5	4	3.3	9	1.7
Dibrom	-	-	-	-	1	4	16	2.3
Acephate	-	-	-	-	1	4	3	1.7
Malathion	-	-	-	-	2	3.5	4	1.5
Chlorpyrifos	-	-	-	-	1	2	5	1.6

[a] A total of 16 PCAs in 2019-20 survey; 25 PCA surveys in 2018-19; 25 PCA surveys in 2017-18; 20 surveys 2016-17.

[b] Performance rating is based on the level of control achieved under field conditions for each product using the following scale: 4-Excellent control; 3-Good control; 2-Fair control; 1-Poor control; and 0-No control.

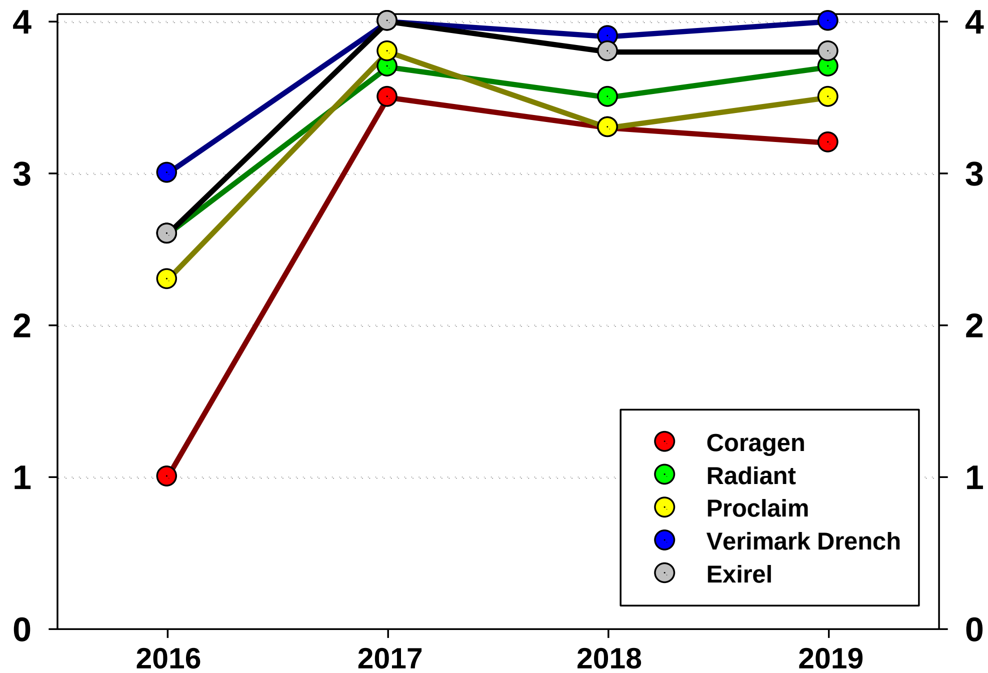

Figure 10. Avg. Performance Rating for the major insecticides used for DBM Control on Desert Cole Crops. Rating is based on the level of control achieved under field conditions for each product using the following scale: 4-Excellent control; 3-Good control; 2-Fair control; 1-Poor control; and 0-No control.

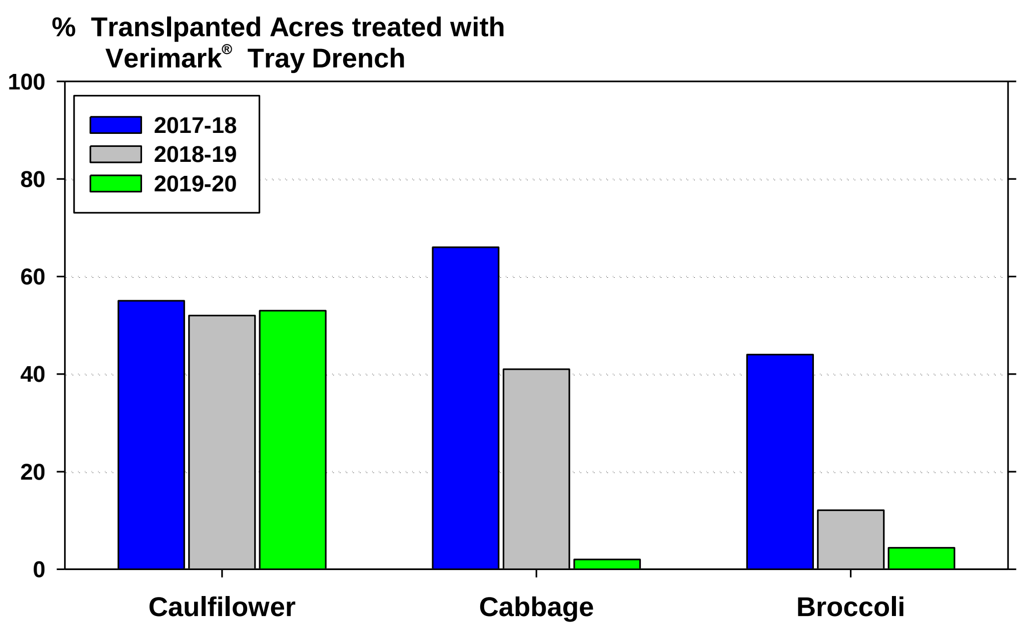

Figure 11. Percentage transplanted acres treated with Verimark Tray Drench in 2017-20.

Table 4. Relative toxicity of key insecticides against Arizona field collected populations of diamondback moth, *P. xylostella*.

Field Population	Date collected	Proclaim		Radiant		Coragen		Exirel	
		LC_{50} [1]	RR [2]	LC_{50}	RR	LC_{50}	RR	LC_{50}	RR
UA-YAC_ Susceptible	**Fall 2017**	**0.11**	**-**	**0.70**	**-**	**1.33**	**-**	**0.97**	**-**
Scottsdale, AZ	Fall 2016	1.23	11.2	12.15	17.4	590.1	443.7	-	-
Roll, AZ	Fall 2016	0.87	7.9	9.15	13.0	392.5	295.1	-	-
Yuma, AZ- Co. 9	Fall 2016	0.71	6.5	16.51	23.6	588.0	442.1	-	-
Yuma, AZ- Co. 11	Fall 2016	0.26	2.4	15.99	22.8	731.7	550.2	4.22	4.4
Yuma, AZ - Co. 13	Fall 2016	0.83	7.5	2.50	3.6	411.4	309.3	-	-
Yuma, AZ - Co. 14	Fall 2016	5.84	53.0	7.11	10.2	190.2	143.6	-	-
UA-Yuma Ag Center, AZ	Spring 2017	1.35	12.3	-	-	246.8	185.6	-	-
Roll, AZ	Fall 2018	2.55	23.2	27.74	39.6	161.3	121.3	20.19	20.8
Yuma Valley, AZ	Fall 2018	3.93	35.7	25.17	36.0	485.9	365.3	15.24	15.71
UA-Yuma Ag Center, AZ	Fall 2018	0.47	4.3	5.17	7.4	176.8	132.9	7.64	7.8
UA-Yuma Ag Center, AZ	Spring 2019	3.12	28.3	66.0	94.3	114.4	86.0	11.74	12.1
UA-Yuma Ag Center, AZ	Fall 2019	0.15	1.4	1.12	1.6	1.8	1.4	1.98	2.0
UA-Yuma Ag Center, AZ	Spring 2020	0.29	2.6	1.84	2.6	7.62	5.7	0.81	0.8

[1] mg [AI]/ml; LC_{50} calculated from laboratory bioassays using standard IRAC methods https://irac-online.org/
[2] Resistance ratio = LC_{50} of the field collected population / LC_{50} of the susceptible population (YAC -Susceptible 2017; collected from the Yuma Agricultural Center in fall 2017)

Table 5. Activity of insecticides against DBM larval populations based on PCA field performance, and local research that evaluated field efficacy and laboratory bioassays in Yuma Arizona, 2019-2020.

	Insecticide Activity Against DBM Larvae		
	PCA Surveys	Field Efficacy	Lab Bioassay
Radiant	Excellent-Good	Excellent-Good	Excellent-Good
Proclaim	Excellent-Good	Excellent-Good	Excellent-Good
Xentari	Excellent-Good	Good-Fair	Excellent-Good
Entrust	Excellent-Good	Excellent-Good	Excellent-Good
Exirel	Excellent-Good	Excellent-Good	Excellent-Good
Avaunt	Excellent-Good	Good-Fair	Excellent-Good
Verimark	Excellent-Good	Excellent-Good	Excellent-Good
Dipel	Good-Fair	Good-Fair	
Lannate	Excellent-Good	Excellent-Good	
Coragen (soil)	Excellent-Good	Excellent-Good	Excellent-Good
Coragen (Foliar)	Good-Fair	Excellent-Good	Excellent-Good
Besiege	Good-Fair	Excellent-Good	Excellent-Good
Pyrethroids	Excellent-Good	Excellent-Good	
Assail	Excellent-Good	Good-Fair	
Pheromone	Excellent-Good	Good-Fair	
Vetica	Good-Fair		
Intrepid	Good-Fair	Good-Fair	

Excellent-Good
Good-Fair
Poor