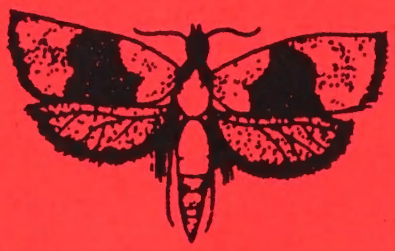

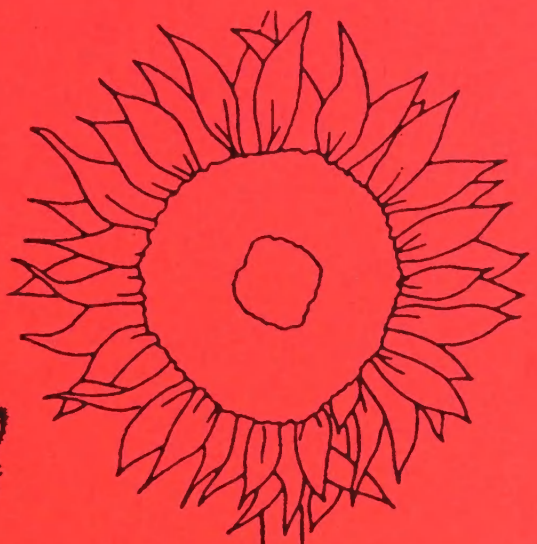

Proceedings 11th Great Plains Sunflower Insect Workshop

April 13-14, 2000 - Fargo, North Dakota

PROCEEDINGS

ELEVENTH GREAT PLAINS SUNFLOWER INSECT WORKSHOP

April 13-14, 2000

U. S. Department of Agriculture
Agricultural Research Service
Northern Crop Science Laboratory
Fargo, North Dakota

Workshop Chair & Proceedings Editor:

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The Great Plains Sunflower Insect Workshop was developed to foster communication, exchange information, and develop solutions to insect problems of common interest. This volume contains the program, a list of participants and the presentations from the 2000 Workshop.

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Copies of the proceedings are available from the Workshop Chair

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11th Great Plains
Sunflower Insect Workshop
April 13-14, 2000

U. S. Department of Agriculture, Agricultural Research Service
Northern Crop Science Laboratory
Fargo, North Dakota

Workshop
Program & Schedule

*Thursday, April 13*th

8:00 - 8:30 **Registration**

8:30 - 8:45 ***Introduction & Welcome*** - *Larry Charlet*, USDA, ARS, Northern Crop Science Laboratory, Fargo, ND *& Larry Chandler*, Center Director, USDA, ARS, Red River Valley Agricultural Research Center, Fargo, ND

8:45 - 10:00 ***Overwintering strategies of four insect pests of sunflower*** - *Roger Leopold*, USDA, ARS, Biosciences Research Laboratory, Fargo, ND

Molecular biosystematics of sunflower insect pests - *Rich Roehrdanz*, USDA, ARS, Biosciences Research Laboratory, Fargo, ND

Discussion

10:00 - 10:30 **Break & Refreshments**

10:30 - 10:45 ***Adage, a new seed treatment insecticide for sunflower*** - *Dain Bruns*, Novartis Crop Protection, Fargo, ND

10:45 - 12:00 ***Sunflower midge - history, biology & damage*** - *Larry Charlet*, USDA, ARS, Northern Crop Science Laboratory, Fargo, ND

Sunflower midge - morphology & identification of adults & larvae - *Gary Brewer*, Department of Entomology, North Dakota State University, Fargo, ND

Discussion

12:00 - 1:30 **Lunch**

1:30 - 2:30 ***Sunflower midge - field distribution patterns & sampling*** - *Erin Hodgson*, Department of Entomology, North Dakota State University, Fargo, ND

Sunflower midge - monitoring, emergence patterns, edge-effect, degree-day models & economic threshold determination - *Vasanth Tatta*, Department of Entomology, North Dakota State University, Fargo, ND

Discussion

2:30 - 3:00 **Break and Refreshments**

3:00 - 4:30 ***Sunflower midge - integrated pest management strategies:***

Chemical & biological control - *Larry Charlet,* USDA, ARS, Northern Crop Science Laboratory, Fargo, ND

Attractants - *Brady Vick,* USDA, ARS, Northern Crop Science Laboratory, Fargo, ND

Host-plant resistance - *Gary Brewer*, Department of Entomology, North Dakota State University, Fargo, ND

Discussion

*Friday, April 14*th

8:30 - 9:30 ***Preliminary work on making laboratory diets for resistance to sunflower moth using lyophilized sunflower heads*** - *Dick Wilson, USDA, ARS, Plant Introduction Station, Ames, IA*

Integration of pollination with sunflower insect pest management - *Gary Brewer,* Department of Entomology, North Dakota State University, Fargo, ND

Discussion

9:30 - 10:00 **Break & Refreshments**

10:00 - 10:45 ***Precision pest management - how does it work?*** - *Ian MacRae*, Department of Entomology, University of Minnesota, Northwest Experiment Station, Crookston, MN

Discussion

10:45 - 11:45 ***The wild west: sunflower insect pest update 1999*** - *Jan Knodel,* North Central Research Extension Center, North Dakota State University, Minot, ND

Review of the 1999 sunflower insect pest situation in the central & northern plains - *Phil Glogoza,* Department of Entomology, North Dakota State University, Fargo, ND

Discussion

11:45 - 12:00 **Workshop Wrap-up**

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MOLECULAR BIOSYSTEMATICS OF SUNFLOWER INSECT PESTS

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INTRODUCTION

Development of a biosystematic and population data base for key species groups of pest insects is a necessary step in efficiently employing a variety of control methods. Effective implementation of many control programs requires accurate identification of the insect species involved, an understanding of systematic relationships between insect populations, along with some idea of their geographic distribution. Where do these species fit in the evolutionary scheme? Where do they come from and where do they go?

Sunflowers have an array of pests that attack various parts of the plants (Charlet 1992, Charlet and Seiler 1995). Sunflowers are endemic to North America and the variety of pests has co-evolved with the plants. The predominance of any one pest species waxes and wanes over a few years time period with no discernible pattern of species order. This makes it very difficult to predict what next year's most significant pest will be. Different parts of the growing regions may have different major pests in any given year. This fact also makes it difficult for researchers to focus on a thorough study of any one pest. This work describes a molecular biosystematic examination of a group of lepidopterous pests and a group of coleopterous pests of sunflowers. Numerous molecular markers are reported that have potential as species or population identifiers.

METHODS

The insect species and their abbreviations are listed below. CH, CA, RSW, GSW, and STW were collected in North Dakota. HE is a laboratory colony originally started with insects from Texas. BW are from the southern USA. Total DNA was prepared from individual insects that had been frozen at -80 C. Long PCR was performed on the moth DNA templates as described (Roehrdanz, 1995). Two pairs of mitochondrial universal primers were employed. 16S2 and N4 primers amplify about 4 kb of DNA. 16SR and C2 amplify about 6.8 kb (Roehrdanz & Degrugillier 1998). For the weevils the 16S2-N4 regions were amplified along with the smaller regions, 12S-16SR (1.8 kb) and C1-C2 (1.5 kb). Standard PCR was carried out as previously described (Roehrdanz 1997). The RFLP (restriction fragment length polymorphism) patterns were determined by cleaving the PCR amplicons with an assortment of restriction endonucleases and the restriction fragments were separated by electrophoresis. Phylogenetic comparisons used the software Restsite (Miller 1991). The fraction of shared restriction fragments (F) and the per cent sequence divergence (d) were determined and the latter was used to create UPGMA (unweighted pair group method with arithmetic mean) trees.

Table 1. Insects used for phylogenetic comparisons

Abbreviation	Species	Name
Moths		
CH	*Cochylis hospes*	Banded moth
CA	*Cochylis arthuri*	"Arthuri" moth
HE	*Homeosoma electellum*	Sunflower moth
Weevils		
RSW	*Smicronyx fulvus*	Red sunflower seed weevil
GSW	*Smicronyx sordidus*	Gray sunflower seed weevil
STW	*Cylindrocopturus adspersus*	Sunflower stem weevil
BW	*Anthonomus grandis*	Boll weevil

RESULTS

The Moths

Long-PCR RFLP of mtDNA provided the data for analysis. Conserved insect-derived primers amplified two sections of the mitochondrial genome. Together the two amplicons cover about 11 kb or 2/3 of the mtDNA. The 16S-N4 amplicon is flanked by primers in the 16S rRNA gene and the ND4 gene. 11 restriction enzymes were used. The size of the restriction fragments obtained with each enzyme is shown in Table 2. The fragment sizes are given in base pairs (bp) and fragments that appear to be the same size in different species for a particular restriction enzyme are assumed to be the same fragment. The 16SR-C2 amplicon is flanked by primers in the 16S rRNA and Cytochrome oxidase I genes. 12 restriction enzymes were used with this PCR product and the fragment sizes are in Table 3. The choice of restriction enzymes combined with the long PCR products has resulted in a large number of RFLPs for comparison. When the various sizes of the enzyme recognition sequences are factored in, the equivalent of about 675-700 bp of DNA sequence has been sampled. At most, only two of the restriction digests produced the same pattern for all three species, 16S2-N4 *Sau*96 I and 16SR-C2 *Scr*F I. The larvae of the three moth species all feed on the developing flower and seed head. The adults are readily identifiable but the CH and CA larvae are similar. Although most of the patterns differentiate the species, only a few are simple enough and distinctive enough to be considered for species identification of immature insects, e.g. the *Swa* I and *Hin*F I digestions of the 16S2-N4 product (Table 2).

Table 2. RFLPs from the 16S2-N4 amplicon of sunflower infesting moths

16S2-N4	SUNFLOWER MOTHS		
Rest. Enz.	CH	CA	HE
Alu I	1650	1500	1500
	870	740	850
	600	700	740
	280	420	220
	170	350	170
	150	200	
		150	
Ase I	500	700	750
	425	500	350
	dbl 400	475	255
	290	400	245
	270	255	215
	235	230	185
	200	200	180
	185	185	150
	140	140	135
	100	110	100
	75	90	90
	65	85	?
DpnII/MboI	1600	1600	1600
	750	800	820
	520	520	540
	150	150	520
	140	140	240
	100	100	170
	80	80	140
	60	60	80
			60
Dra I	770	850	1000
	680	770	680
	640	350	480
	415	290	350
	290	280	220
	220	220	130
	135	170	120
	130	135	80
	120	130	
	90	100	
	80	95	
	50?	80	
		75	
EcoR I	2400	2400	2600
	1600	1550	1600
	200	200	
Hinf I	2000	1700	2000
	1900	1300	1280
		670	690
		400	
Mbo II	1500	2700	900
	1000	850	700
	700	300	650
	300	140	dbl 620
	200		450
	140		
Sau96 I	2100	2100	2100
	1600	1600	1600
	340	340	340
Ssp I	930	830	650
	650	620	630
	320	270	270
	260	260	260
	210	210	240
	170	170	210
	160	155	140
	140	140	100
	125	130	90
	100	100	75
	75	65	
	60	60	
Swa I	no cut	1700	2800
		1280	1300
		1050	
Xba I	2700	1900	2700
	1300	1300	1400
		850	

dbl = probably 2 bands of that size

Table 3. RFLPs from the 16SR-C2 amplicon of sunflower infesting moths.

16SR-C2	SUNFLOWER MOTHS		
Rest. Enz.	CH	CA	HE
Ase I	500	500	950
	410	410	730
	360	360	410
	340	340	360
	235	(330)B	295
	195	240	265
	175	235	250
	140	195	235
	120	175	195
	100	(145)B	175
		140	155
		120	120
		100	105
Cla I	5.5-6	4800	Not done
	440	700	
		440	
Dpn II	1600	1500	1600
	1450	1200	1100
	1100	600	850
	740	540	600
	540	220	400
	400	140	340
	250	70	220
	140	45	140
	105		105
	70		70
	45		45
Dra I	930	930	1450
	650	830	860
	580	650	590
	500	500	580
	440	400	320
	250	350	285
	245	285	240
	220	260	225
	180	250	210
	150	(220)B	185
	140	180	150
	120	150	140
	90	140	130
	80	120	115
	70	80	
		70	
Hind III	3100	3100	3200
	1700	1600	2700
	800	800	820
	400	400	360
Hinf I	2200	2200	2200
	1700	1700	1700
	1500*	1400	590
	590	590	250
	250	250	
Hpa I	NC	>5	NC
		800	
Mbo II	3000?	2700?	4000?
	700	dbl 900	770
	650	700	650
	580	600	580
	440	340	330
	350		280
	340		
	280		
*Scr*F I	~4200	~4200	>5000
	1450	1450	1450
	640	640	640
Swa I	1600	2000	2400
	1100	1600	1600
	1050	900	1000
	700	500	750
	(620)A	350	670
	(580)B	250	325
	450	(243)A	250
	350	(220)B	
	240		
Ssp I	950	850	950
	650	550	650
	550	490	600
	320	400	540
	300	320	450
	290	300	380
	260	260	325
	180	220	270
	155	155	250
	140	140	240
	85	110	230
	75	95	200
		80	155
		75	145
Xba I	3500	4500	6000
	1600*	1400	1400
	1400		

()A or B = polymorphic bands

A small amount of intraspecific polymorphism was observed in CA 16SR-C2 *Ase* I, *Dra* I, and *Swa* I. CH 16SR-C2 also has a polymorphism in *Swa* I. Since only 2 individuals of each species were used for most of the RFLPs, these particular polymorphisms do not reveal anything meaningful about the extent of intraspecific variability of the species across their range.

The numbers of shared and unique RFLP bands were used to calculate "F" or the fraction of shared fragments between each species pair. These values are shown in Table 4 below the diagonal. The two PCR products used here do not overlap. Therefore the data were combined for the entire 11 kb amplified region. The two congenerics, CH and CA have the most fragments in common at 56%. Nearly 300 bands were scored. The fraction of shared fragments between HE and each of the other two species is less, 39% and 34%.

Table 4. Fraction of shared RFLP fragments (F) and genetic distance (d) of sunflower moth pest species

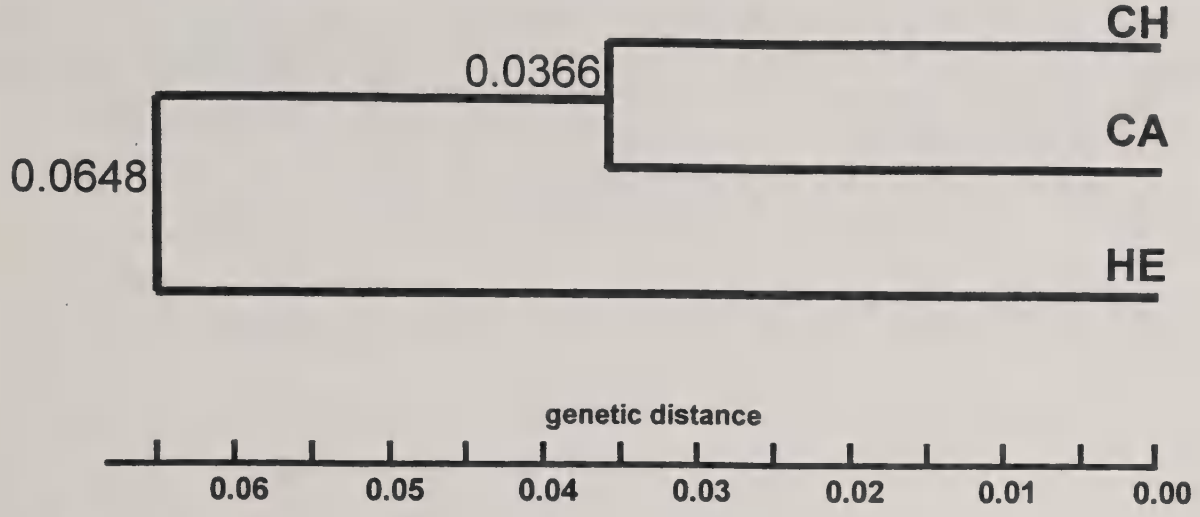
	CH	CA	HE
CH	-	3.66%	6.15%
CA	0.560 ±0.039 (296)	-	6.80%
HE	0.390 ±0.048 (253)	0.344 ±0.044 (259)	-

Combined results from 16SBR-C2 and 16S2-N4 amplicons
F - Fraction of shared fragments below diagonal
d - Genetic distance (per cent sequence divergence) above diagonal
in parentheses is total number of fragments for the species pair.

The genetic distance "d", also referred to as the sequence divergence, is determined from F and incorporates the size of the restriction enzyme recognition sites. It is an estimate of the number of nucleotide substitutions per site between a pair. These numbers are presented above the diagonal. The sequence divergence between CH and CA is the lowest, 3.66%, which means that those two species are the most closely related. Divergence between HE and the other two is >6%. Typically the divergence between recognized species is greater than 2-2.5%, whereas intraspecific divergence is often less than 2.5%. These are not hard and fast dividing lines. The two categories overlap and therefore the numbers cannot be used to say with certainty that two groups are or are not species.

The genetic distance can be used to construct phylogenetic trees. These usually help visualize the relationships between the taxa being sampled. UPGMA trees have defined branch points. The branch points represent the means of the pairwise divergence values. The branch point for the CH/CA pair is at 0.0366 the same as in the table. The branch point for HE versus the CH/CA pair becomes 0.0648 as shown in Fig 1.

Fig.1 Sunflower moth UPGMA tree from restriction fragment distance



The Weevils

Comparative data for the three sunflower weevils less extensive. Although the 16S2-N4 region was used, two smaller PCR products were used instead of the large 16SR-C2 amplicon. The combined total of amplified regions was 7.3 kb. Fewer restriction fragments were examined for the weevils compared to the moths, about 125-140 per species pair. DNA from the cotton boll weevil was included as an example of a distantly related weevil to serve as an out group.

Table 5. Fraction of shared RFLP fragments (F) and genetic distance (d) of sunflower weevil pest species

	RSW	GSW	STW	BW
RSW	-	2.5%	12.3%	13.7%
GSW	0.659	-	13.3%	15.8%
STW	0.186	0.149	-	20.8%
BW	0.166	0.131	0.069	-

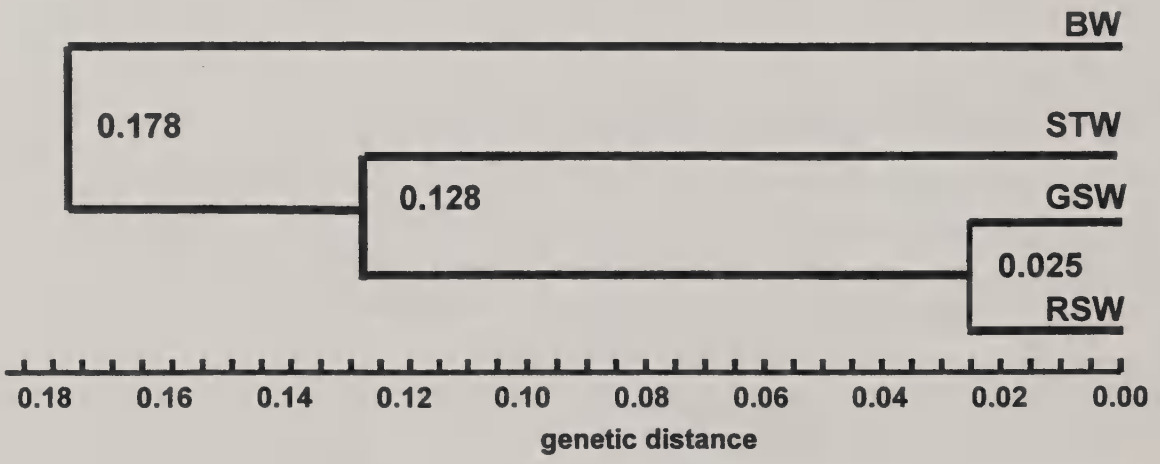
F - Fraction of shared fragments below diagonal
d - Genetic distance (per cent sequence divergence) above diagonal

The shared fragments and sequence divergence data are in Table 5. There is a much greater range of shared fragments in the weevils than the moths with nearly a tenfold difference between the highest and the lowest. The genetic distance between the two seed weevils is only 2.5% indicating a very close relationship between these species. The seed weevil pair is about equally distant from STW and BWI. As a result the boll weevil is not a very good out group for this comparison. STW/BW genetic distance of 20% is at level where forward and reverse mutation are both significant. Random convergence starts

to impact evolutionary divergence and the mathematical value becomes meaningless.

The UPGMA tree (Fig 2) gives the potentially misleading impression that the STW is a substantially closer to the seed weevils than it is to the BW. The seed weevil/STW distances (0.128) and the seed weevil/BW distances (0.147) are rather similar. The very large BW/STW distance (0.208) forces the tree into this conformation. It might be more reasonable to consider the groups as three relatively equidistant branches. Additional weevil species along with a more distant out group would help refine the tree.

Fig 2. UPGMA tree based on restriction fragments in sunflower weevils



DISCUSSION & SUMMARY

The genetic distance of the two congeneric moths, CA and CH, indicates that they are about 1.2% more divergent than the two congeneric weevils, RSW and GSW. The 2.5% value for the weevils puts it in the range where intra- and interspecific divergences overlap. Geographic divergence among populations of the same species can reach this level. RSW and GSW are very closely related, perhaps even sibling species. Perhaps their past divergence revolved around favoring different species of native sunflowers. Although they are quite distinct as adults, the larvae are morphologically indistinguishable and they have similar habits. The moth, HE (Family Pyralidae), from a different family is more closely related to CH and CA (Family Cochylidae) than the three divergent weevil groups (Family Curculionidae) are to each other. However the Curculionidae is one of the largest families of insects and extensive diversity in such a large group is possible.

The PCR-RFLP fragments can be used to differentiate any of the species. This would be suitable for smaller scale studies of competition and distribution of the congeneric species. Larger scale studies would benefit from species-specific primers. Such primers can often be designed by comparing the nucleotide sequence of a small region of mtDNA protein coding genes.

The existence of polymorphism in the very narrow geographical collections of all of these species suggests that these DNA polymorphisms would be suitable for population and phylogeographic studies. An examination of additional genes and a survey of both species over a wider geographic area is needed to give a more definitive description of intraspecific variation.

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Adage – A New Seed Treatment Insecticide For Sunflower

Dain Bruns

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Introduction

Novartis Crop Protection is developing thiamethoxam (proposed) (4H-1,3,5-Oxadiazin-4-imine,3-[(2-chloro-5-thiazolyl)methyl]tetrahydro-5-methyl-N-nitro) as a seed treatment (tradename Adage) for control of chewing insects in sunflower and other crops. Thiamethoxam, first synthesized in 1991, is in the neonicotinoid chemical class, subclass thianicotinyl, which differentiates thiamethoxam from imidacloprid, also a member of the neonicotinoid class, but chloronicotinyl subclass. Thiamethoxam will be formulated as a 5 FS seed treatment in sunflower and will be applied at rates from 5.1 to 10.2 fl. oz./100 pounds of seed. Registration is expected in sunflower in 2001 to 2002.

Uptake and Translocation

Thiamethoxam is rapidly absorbed by roots as seeds germinate in the soil and is transported systemically upward in the xylem into young shoots, cotyledons, and leaves. Rapid absorption and transport of thiamethoxam within the plant is due in part to its water solubility of 4,100 ppm compared to 510 ppm for imidacloprid, the industry standard. While Adage is relatively water soluble, it binds well to the soil particles around the seed and is released for plant uptake as the plant absorbs moisture from the soil or seed coat.

Mode of Action

Thiamethoxam controls insects through contact and stomach activity. The nicotinic acetylcholine receptor is the target site within the insect's nervous system. A behavioral response can be seen within 15 minutes to one hour after exposure, depending on the insect species. Insect mortality usually occurs within 24 to 48 hours of exposure. The binding site of thiamethoxam is different from organophosphates, carbamates, and pyrethroids, making cross-resistance unlikely.

Insect Spectrum

Thiamethoxam controls a wide range of chewing and sucking insect pests, such as aphids, seed maggots, wireworm, and flea beetle when tested on other crops. In sunflower, thiamethoxam effectively controls sunflower beetle, but has essentially no activity on sunflower stem weevil, when applied as a seed treatment. Thiamethoxam will be evaluated for activity against wireworm, cutworm, and sunflower midge in sunflower.

Sunflower Midge: History, Biology, and Damage

Larry D. Charlet

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Introduction

The sunflower midge, *Contarinia schulzi* Gagné, is included in the insect order Diptera, which comprises the flies. It is classified as a member of the Family Cecidomyiidae which contains the gall midges or gall gnats, minute delicate flies that have long antennae and legs and reduced wing venation. The Hessian fly, an important pest of wheat, also occurs in this group. Some of the many other *Contarinia* species that also are pests include the pea midge, *C. pisi,* Douglas-fir cone gall midge, *C. oregonensis*, Ponderosa pine gall midge, *C. coloradensis,* Guar midge, *C. texana,* Bromegrass seed midge, *C. bromicola*, and the Douglas-fir needle midges, *C. pseudotsugae, C. constricta and C. coniculata*. The sunflower midge was described from specimens collected in 1971 from Cass and Traill County, North Dakota, Norman County, Minnesota and Knox County, Texas. The sunflower midge was named for J. T. Schulz, who was at that time, chair of the Entomology Department at North Dakota State University and the first to conduct research on this insect (Gagné 1972). In addition to cultivated sunflower, the sunflower midge also has been collected from the native *Helianthus* species, *H. annuus, H. petiolaris,* and *H. maximiliani* (Schulz 1973).

Sunflower Midge History

The incidence, degree of infestation, and amount of damage caused by the sunflower midge has been quite sporadic since it was first reported as a pest by Schulz (1973) in 1971. Heavy infestations were noted in 1971 in southeastern Traill and northeastern Cass Counties (eastern portion of the state) of North Dakota and northwestern Clay and southwestern Norman Counties (western part of state) in Minnesota. Approximately 25,000 to 40,000 acres were affected, which represented about 10% of the sunflower acreage that year. In some fields, losses were described to be up to 50%. During the years 1972 to 1976 only light infestations occurred in eastern North Dakota and northwestern Minnesota with damage, where present, only in 1-5% of the border rows of the field (Schulz 1976,1977).

Serious damage from sunflower midge attack was evident in 1979 in both northeastern North Dakota and northwestern Minnesota with some heavily infested fields plowed under because of severe damage (Lilleboe 1979). The infestations were described as sporadic, depending on the amount of rainfall that had been received; the greater the moisture the higher the damage that was noted. The early part of the season as described as cool and damp, the same conditions that were evident in 1971 when there was also a problem with sunflower midge. However, only light infestations were present in the southeastern portion of North Dakota. The conditions in 1980 were warm and dry in the early spring and the weather continued to be dry throughout the season. These factors were considered to be less than optimum for the sunflower midge and damage was reported to be much lower than in 1979 (North Dakota State University 1980).

In 1981 a survey of 150 fields was conducted to assess the damage to fields by the sunflower midge (Lilleboe 1981). The damage followed the border of North Dakota and Minnesota, extending 20-40 miles on either side of the Red River Valley. There were three epicenters of severe damage: the Georgetown-Ada-Borup, Minnesota, area; the Warren-Argyle, Minnesota, area; and the Casselton-Mapleton, North Dakota, area. Even the portions of these states that had the worst infestations also had fields with little or no damage. The fields with the most severe damage tended to be those that were planted the earliest. However, even though some fields had heavy damage, overall the losses in the valley region due to the sunflower midge were still reported to be only 5-10%.

The damage from the sunflower midge in 1982 extended north into Manitoba, Canada (Kopp and Busacca 1983). Based on a survey of about 600 fields, the range of the midge was determined to be similar to 1981. Most of the severely affected fields were in the northern portion of the Red River Valley, with later planted fields again showing reduced damage. Approximately 15-20% of the total acreage was infested with losses estimated to be between 3 to 5%. Results of a survey conducted in 1983 showed reduced damage by the sunflower midge compared to the previous two years (Busacca and Kopp 1984). There were two problem areas which included Mayville, North Dakota, to Felton, Minnesota, and northwestern Minnesota, extending into Manitoba, Canada. Losses were reported to be more severe in Canada than in either North Dakota or Minnesota, but total losses were less than 1%. The range of the midge was noted to have expanded west in North Dakota compared to the previous year's survey. In 1984 the sunflower midge survey included 427 fields and detected only a few moderate infestations south of Winnipeg, Manitoba, Grand Forks County, North Dakota, and Norman County, Minnesota (Busacca and Kopp 1985). There was a slight western expansion in the southeastern portion of North Dakota with bract damage evident in LaMoure, Dickey, and Ransom Counties. Busacca and Kopp (1985) remarked that the "trend [from 1984] suggests the sunflower midge should not cause significant damage to the 1985 crop. This conclusion does not mean the midge will never be an economic problem again. The midge evolved with wild sunflower and ... will continue to be a potential problem." This comment was very accurate because for the years 1985 to 1994 there were few, if any, reports of damage caused by the sunflower midge.

Significant infestations of the sunflower midge were reported in 1995 from the southern end of the Red River Valley extending from Detroit Lakes, Minnesota, west to Valley City, North Dakota (Glogoza 1995). Some fields had levels that compared with those in the early 1980s when damaging infestations were common in sunflower fields. Although some fields had damage only in their margins, others had damage that extended throughout the field. The midge was reported to be present in 1996 as well, but little damage was noted (Glogoza 1996). In 1997 a severe outbreak of the sunflower midge occurred with the extensive damage noted farther west in North Dakota than was evident in previous infestations. The previous 2 to 3 years had been extremely wet, especially during late June and early July, which probably aided in the buildup of midge populations (Lilleboe 1998). Two counties in North Dakota (Barnes and Stutsman) had about 50,000 acres damaged with some fields abandoned due to severe head distortion. In addition, a survey conducted in early fall also showed infestations in northwestern Minnesota and into northeastern South Dakota (Charlet and Brewer 1998). The 1998 sunflower midge survey showed reduced damage compared to 1997, with a similar range (Fig. 1). During the

following year, 1999, only two locations were noted to have had moderate infestations and these were in southeastern Manitoba, Canada, near Morden, and an area just north of Devils Lake, North Dakota (Fig. 2).

Sunflower Midge Biology

The sunflower midge overwinters as a mature larva in a cocoon 2-6 inches below the soil surface, pupating in June. Adults of the overwintering generation of midge emerge from the soil in early to mid-July, mate, and live for about 2-3 days. Emergence of this generation is 90% complete by 25-30 July. Females oviposit in sunflower buds, inserting eggs between the bracts or in the center of the head. If emergence occurs before heads are present, eggs may be deposited in the leaf axils of the sunflower plant. Eggs are laid singly or in masses of up to 50 eggs. When eggs are deposited they are yellow, turning orange when mature. Eggs hatch in 3 to 5 days. The larvae are white and develop through three instars. After hatching, the newly emerged larvae move to the base of the bracts and feed, producing necrotic feeding depressions (Samuelson 1976, Schulz 1978, Charlet et al. 1997, Glogoza et al. 1997).

The mouthparts of the larva are weakly sclerotized and early studies showed that there was no physical abrasion of the cells. There also was no particulate matter in the larval gut. The belief was that the cell membranes were disrupted and the contents emptied allowing the larvae to feed on the cellular fluid. It is possible that enzymes produced by the larvae dissolve the plasma membranes allowing the release of the cell contents. The feeding by the larvae within the head results in head distortion or growth deformity likely from elevated levels of phytohormones (North Dakota State University 1983).

The second and third instars move to the center of the sunflower head. Feeding by these larvae occurs at the base of the developing seeds. The larval stage lasts from 10-14 days. The mature larvae drop to the soil and complete development or remain as larvae and overwinter until the following year. Approximately 90% of the overwintering generation of larvae have completed development and move into the soil by 4-10 August. The life cycle of the midge that emerge the same season as first generation adults takes 31-35 days. By 25-31 August 90% of these first generation adults have emerged from the soil. After larval development is complete they drop to the soil to overwinter with the majority exiting the sunflower heads by mid-September (Charlet et al. 1997, Glogoza et al. 1997).

Sunflower Midge Damage

The first evidence of damage by the sunflower midge in the sunflower head is necrotic feeding depressions between the bracts. The damage, if severe, is later evident in the blackened areas on the exterior surface of the bracts of the heads. Heavily infested heads are also visible in the sunflower field because of the absence of ray flowers due to the destruction of the underlying tissues. Although heads may be infested with only a few larvae, over 5000 larvae have been noted in some infested sunflower heads (Anderson and Brewer 1991). The greater the infestation, the more pronounced is the distortion or deformity of the sunflower head as it develops and matures. The altered head growth is due to an overgrowth of the margins of the sunflower head. Heads that have been attacked early may be completely closed into a ball. The

range of damage is a result of both the time of attack and the number of larvae present within the sunflower head. The feeding by the sunflower midge larvae causes heads to be gnarled and cupped or have a "clamshell" appearance with few fertile seeds produced, especially in the center of the head. A large variation in the severity of head damage can occur in each field that is attacked by the midge. In light infestations, damaged heads occur mainly on the border rows extending further into the field as the degree of infestation increases (Anderson and Brewer 1991, Charlet et al. 1997, Glogoza et al. 1997).

The first generation midge, which attacks sunflower in the middle of the season, does not cause the same type of damage as the overwintering generation because heads have already developed and seeds are filling and maturing. However, I have noted distortion of seeds within heavily infested heads which could result in either lowered yield or poorer quality seed. Additional research is needed to document the impact of the first generation midge on both oilseed and confection sunflower.

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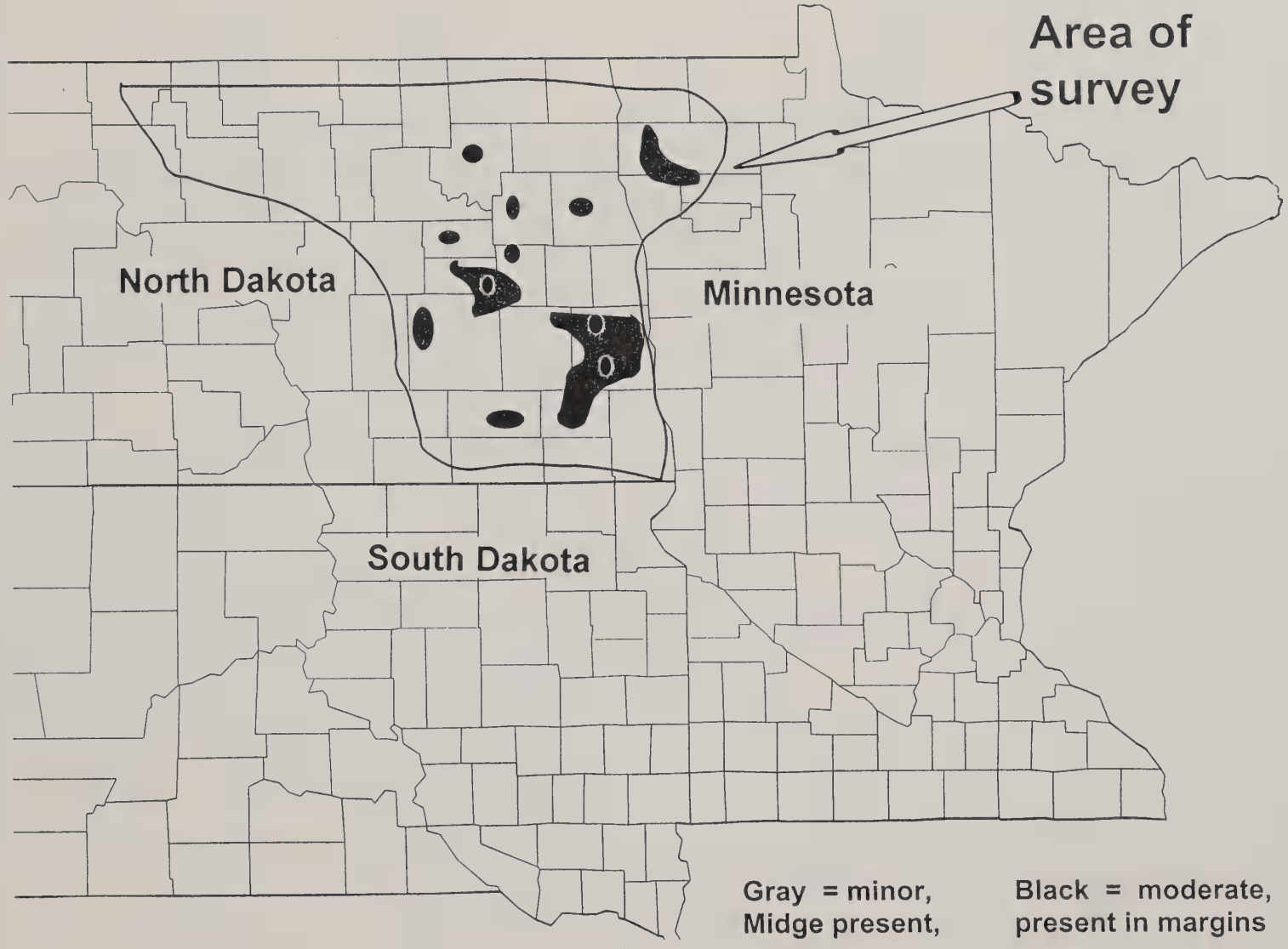

Fig. 1. Survey of sunflower fields for sunflower midge damage in 1998.

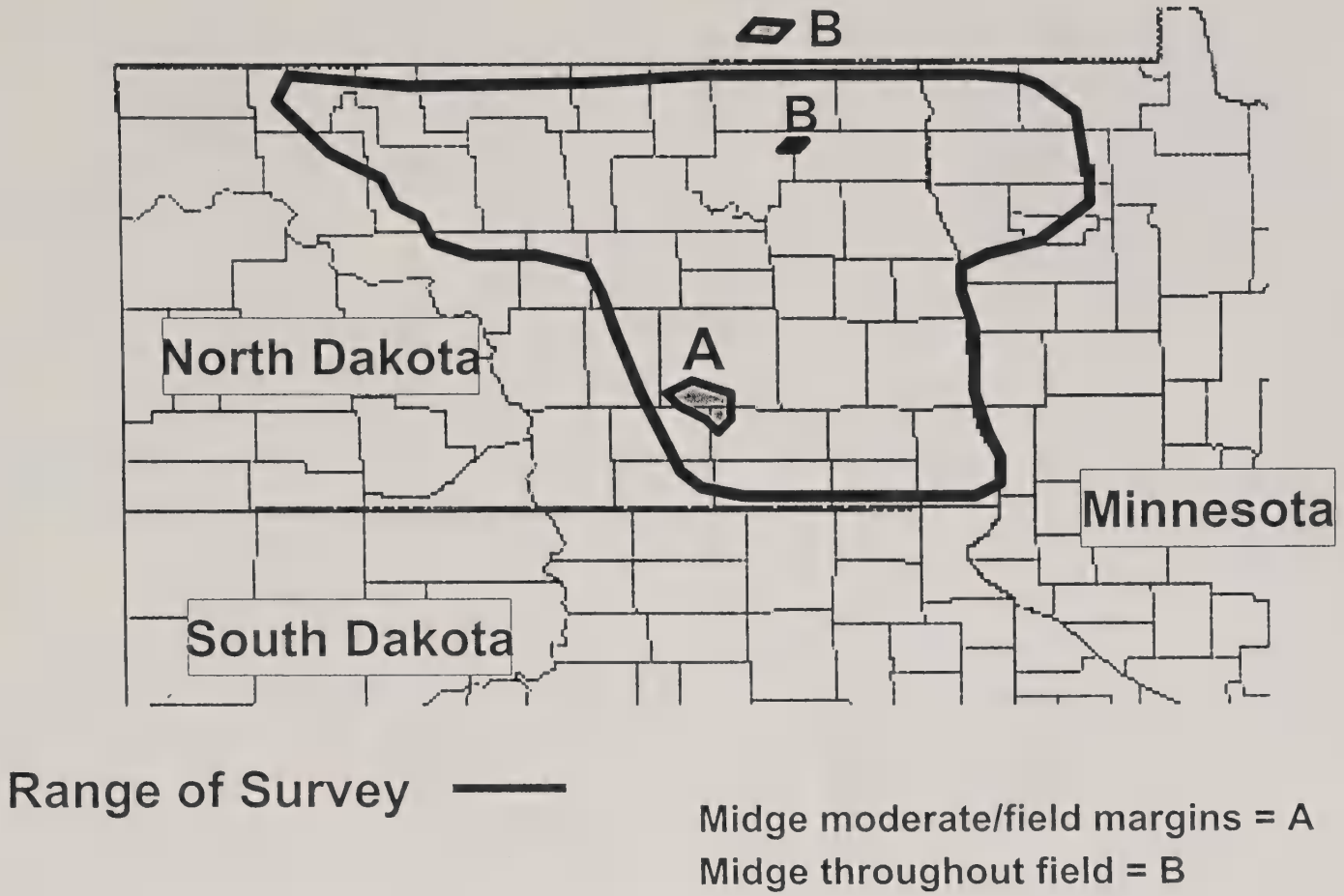

Fig. 2. Survey of sunflower fields for sunflower midge damage in 1999.

Sunflower Midge - Morphology & Identification of Adults

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Emergence cages are used to trap the emerging overwintering population of the sunflower midge, *Contarinia schulzi* Gagné (Diptera: Cecidomyidae). Along with sunflower midge, the cages also collect a number of species of small flies, including other species of midge, that can be confused with the sunflower midge. However, by looking for key characters and with a little practice, adult sunflower midge can be accurately identified and males and females separated.

When populations of midge are high, females will sometimes be found on sunflower buds where they go to oviposit. Any midge of the appropriate size found on sunflower buds are likely to be sunflower midge. For more definitive identification, collect specimens for viewing in the laboratory.

The following characteristics can be used to identify sunflower midge from collections of mixed species of midges. All the characters can be seen through a dissecting microscope at 35 power.

General characters

- appropriate wing venation, Fig. 1A.
- lack of a postvertical peak (located on top of head), Fig. 2A.
- second tarsal segment much longer the first, Fig. 1B.
- tarsal claws simple, Fig. 1B.

Female characters

- body approximately 2 mm in length (not including extended ovipositor), Fig. 3A.
- 12 apparently fused, somewhat dumbbell-shaped antennal segments (flagellomeres), Fig. 1C.
- long telescoping ovipositor, Fig. 3A.

Male characters

- approximately 1.5 mm in length
- 12 antennal segments (flagellomeres), Figs. 1C, 2B.
- upturned claspers at end of abdomen, Fig. 2B, 3B.

Fig. 1 *Traits Used to Identify Sunflower Midge*

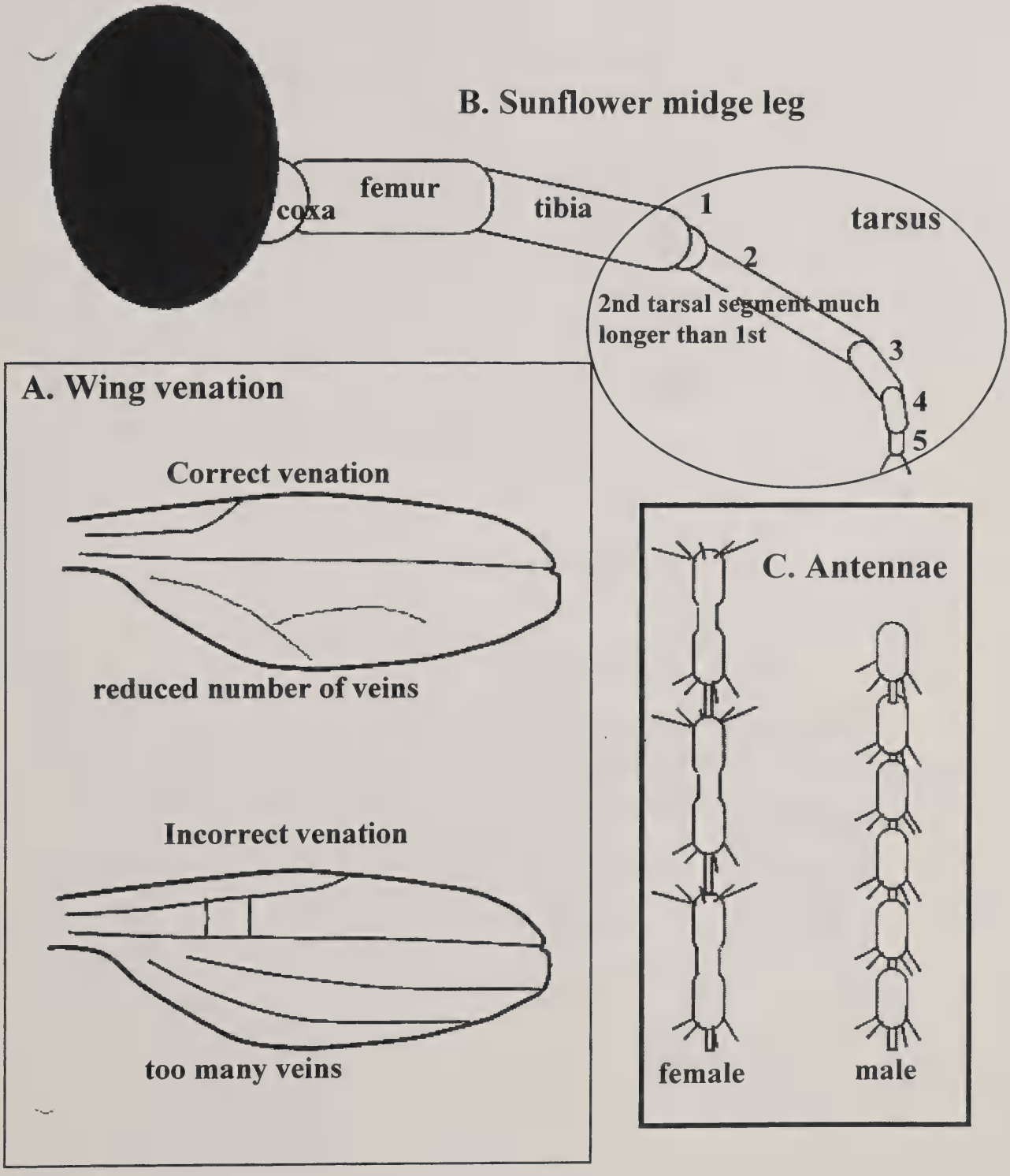
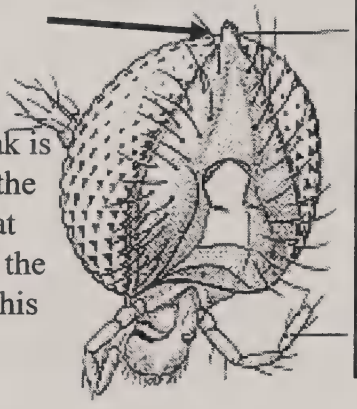


Fig. 2. Characters of an unidentified midge species and a *Contarinia* male

A. Post-vertical peak

The post vertical peak is located on the top of and at the back of the head as in this diagram viewing a midge head from the back.



A post vertical peak is found in an unidentified species of midge that is sometimes collected from sunflower midge emergence traps. It has all the identifying characters of the sunflower midge. BUT the sunflower midge does NOT have a post-vertical peak as in this example from a *Clinodiplosis lappa*, male.

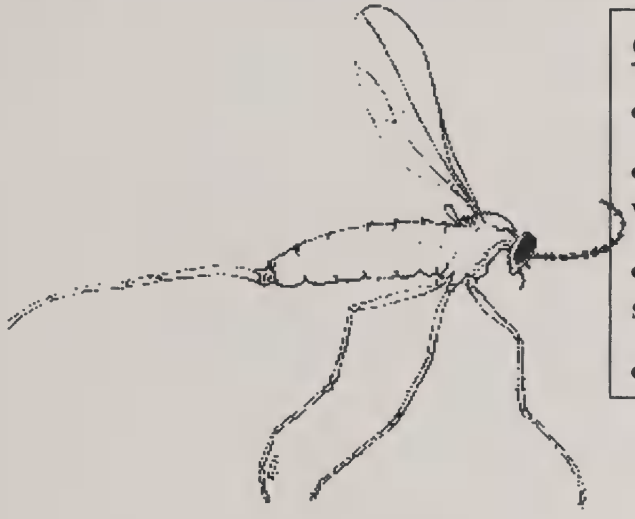
B. *Contarinia* male

Showing characteristics used to identify the sunflower midge.

- reduced wing venation
- lack of a postvertical peak (located on top of head)
- second tarsal segment much longer the first

Fig. 3. Comparison of female and male sunflower midge characteristics

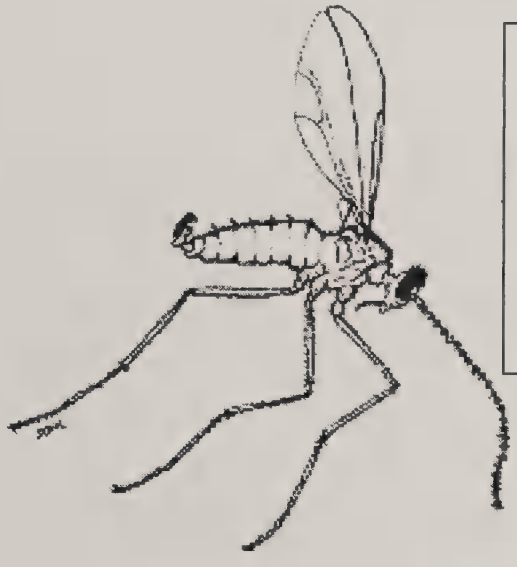
A. Female sunflower midge



Characteristics:

- 2nd tarsal segment longer than 1st
- only one vein reaching distal edge of wing
- apparently fused, cylindrical antennal segments
- long telescoping ovipositor

B. Male sunflower midge



Characteristics:

- 2nd tarsal segment longer than 1st
- only one vein reaching distal edge of wing
- antennal segments not fused
- claspers at end of the abdomen

SPATIAL DISTRIBUTION OF THE SUNFLOWER MIDGE *CONTARINIA SCHULZI* GAGNE` (DIPTERA: CECIDOMYIIDAE)

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Introduction

Sunflower midge can be a serious insect pest causing severe damage and yield loss. The sunflower midge is a threat to North Dakota because it grows over 40% of sunflower in the United States annually. Because there is no effective treatment of previous outbreaks in the Red River Valley, some farmers are not planting as many sunflower or avoiding planting sunflower. The within field distribution is also not fully understood, and is generally thought to infest the edge of sunflower fields. Our objectives were to determine sunflower midge infestation levels and to describe the spatial distribution of the sunflower midge.

Design and Methods

Computer technology greatly enhanced this project; we incorporated Global Positioning Systems (GPS) and Geographic Information Systems (GIS). We used the Garmin 12 GPS (Garmin, Birtle Manitoba) which is not differentially corrected and was accurate to within fifteen meters to collect latitude and longitudinal coordinates from satellites. ArcView with Spatial Analyst (ESRI, Redlands California) is a GIS package capable of mapping spatial distributions. ArcView can create contour maps made up of many layers by interpolating databases. Kriging is the interpolation method best suited for point pattern analysis and uses an inverse distance weighting method estimating unknown points based on known data.

Sampling to map sunflower midge distribution in a systematic design was used in 1999 in two commercial fields, of approximately 32.4 ha each. Both fields were chosen because they were near fields infested by sunflower midge in 1998. The first field was two miles south of Pillsbury, ND in Barnes county and the second field was five miles east of Shelly, MN in Norman county. In both fields, the 1998 field was located directly north of the 1999 field. A grid pattern with sixty regularly spaced cells was superimposed on each field. The center of each cell was marked with a pole for reference.

Sunflower head collection started at the R2 stage and continued until the R6 (end of anthesis) stage. Four heads were randomly sampled from near the center of each cell, two times per week for five weeks. Heads were separately labeled, bagged and brought to the laboratory. Later they were dissected and examined for all stages of sunflower midge. Sunflower damage ratings were taken at the end of the season according to the Bracken method (1990).

For each sampling date, sunflower midge population densities were calculated by taking the average count from the four sunflower heads of each cell. Egg masses were classed into two groups. A small egg mass had less than ten eggs and was considered equivalent to one larvae. A

large egg mass had more than ten eggs and was considered equivalent to four larvae.
For both fields, cumulative insect days were determined by continuously adding collection date population densities Cumulative insect days tables were imported into ArcView and interpolated to create contour maps to visualize changes in population density and location. A log scale of sunflower midge cumulative insect days was used to categorize the data. Although samples were taken from July12 to August 19, only dates when sunflower midge were collected are shown. For the maps, darker colors indicate higher densities of sunflower midge. The GPS coordinates were the base layer of the map and cumulative insect days were stacked to show sunflower midge infestation patterns through the period of midge activity.

Results

In both fields, infestations began at the R2 plant stage and in general, areas of initial infestation remained the most highly infested areas when plants were at the R6 plant stage.

At Pillsbury, ND, field, the sunflower midge infestation began in the northeast corner and along the northern edge of the field (Fig. 1A, July 23). Eventually, the sunflower midge population moved across the field, but overall populations were low to moderate throughout the season (Fig. 1A, August 5). The final damage ratings were also low, with mostly no visible damage or very little bract damage (Fig. 2A). At Shelly, MN, field, infestations began along the northern and southern edges and moved towards the center (Fig. 1B, July 19). Over time, the sunflower midge were found over the entire field (Fig. 1B, August 5). Although populations were greater than in the Pillsbury field, damage ratings were very similar to those at Pillsbury (Fig. 2B).

Summary and Conclusions

Both fields had relatively low populations of sunflower midge and levels of damage (Fig. 2A, B). In general, the infestations began on the sides of the fields that were closest to the 1998 sunflower fields. As the growing season continued, sunflower midge were eventually found throughout the field. Damage was highest near the 1998 field.

While it was possible to map populations of sunflower midge in the two fields in 1999, changes to the sampling design and another years data are needed to more accurately understand patterns of sunflower midge distribution. The spatial distribution of the sunflower midge is not fully understood, chemical control is not effective and adult emergence is unpredictable (Glogoza et al. 1997). Predicting patterns and movement of sunflower midge may benefit farmers by improving insecticide timing and application.

2000 Plans

To improve precision of sampling the entire field, modification of the cell design to unequal spacing will be used. Generally, the sunflower midge is thought to infest the edge of fields, so more samples will be taken near the edge and fewer samples will be taken in the center of the field Interpolation and kriging in ArcView will not be affected by non-regular spacing. Sampling of heads will be increased to three times a week to expand data collection, but all other techniques will remain the same.

A sunflower midge lab project will also be started to test for survival rate differences between egg mass size. Egg to larval mortality will be measured so that a better estimate of larval numbers can be made from egg counts.

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Fig. 1. Cumulative insect days calculated from population densities of sunflower midge at Pillsbury, ND and Shelly, MN. Sampling dates are shown beside each contour map for dates that sunflower midge was recorded. Cumulative insect day totals are under each sampling date. Fields infested with sunflower midge the previous season were located directly north of the 1999 field sampled.

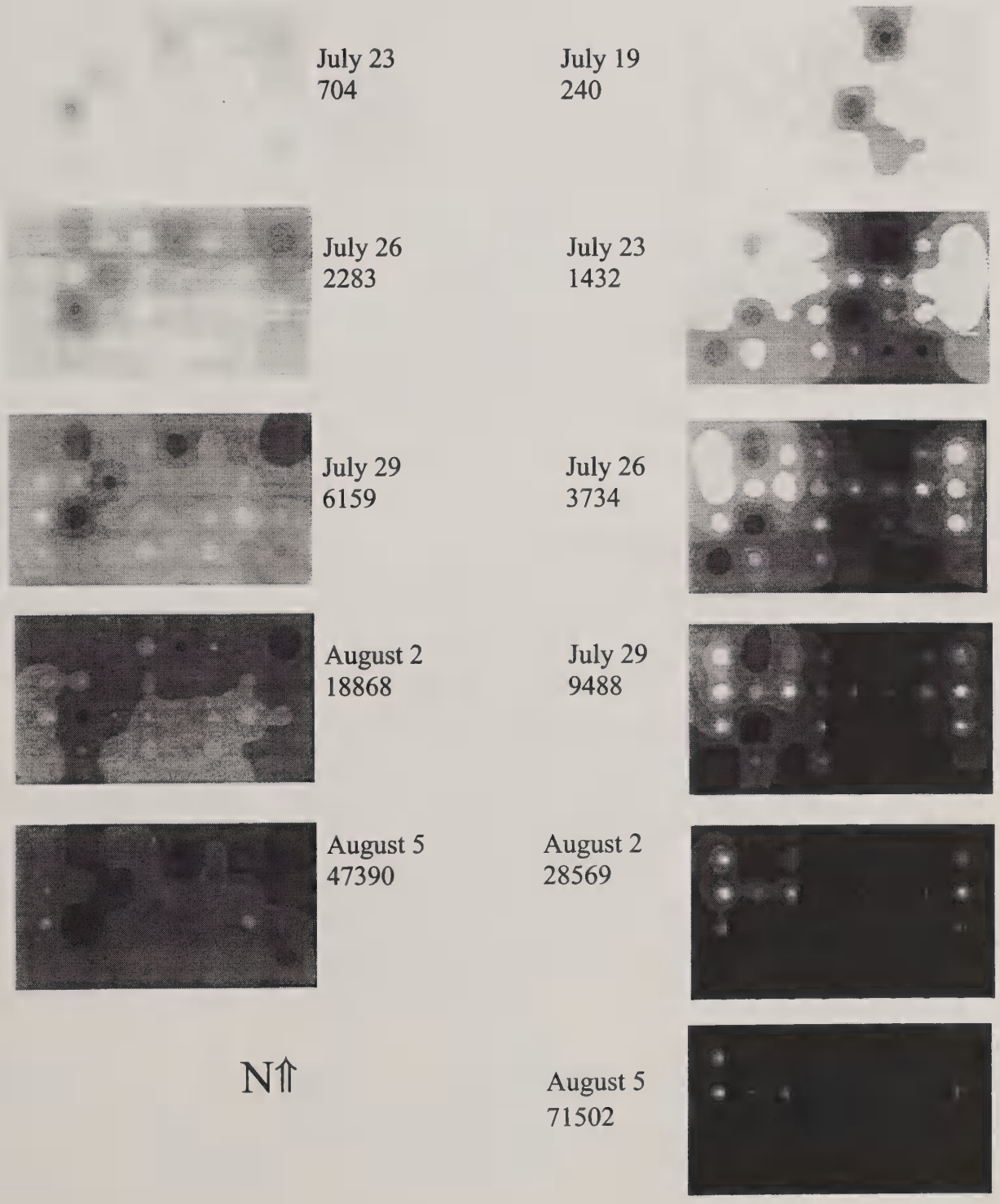
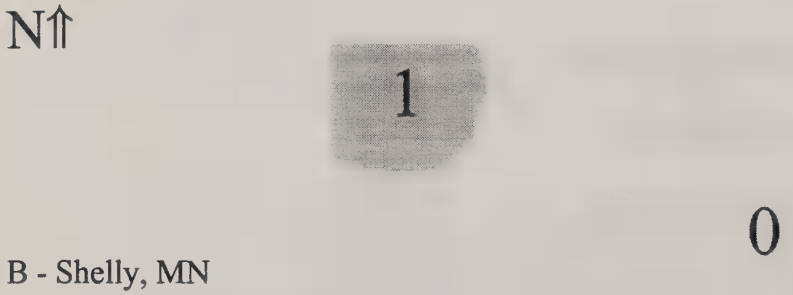


Fig. 2. Sunflower midge ratings in two commercial fields. Damage ratings were based on methods according to Bracken (1990):

0 = no visible damage
1 = light bract damage, little bract damage
2 = bract damage, light cupping and developing central hole or seedless area
3 = extreme bract damage, cupping to seedless area and receptacle thickening to ½ diameter
4 = extreme cupping to large central hole, receptacle thickening greater than ½ diameter, few seeds
5 = head closed and no seeds present

A - Pillsbury, ND



B - Shelly, MN

Sunflower Midge: Monitoring, Emergence Pattern, Degree-Day Models, Edge Effect, and Economic Injury Levels

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Introduction

The sunflower midge, *Contarinia schulzi* Gagne', infests sunflowers at the bud stage and distorts the growth of developing sunflower heads and can wholly or partially prevent seed development. The sunflower midge has two generations per year in the northern Great Plains. Emergence of the overwintering generation of the sunflower midge begins in the late June and continues through July but the exact environmental parameters for emergence are not known. The adults from the overwintering generation lay their eggs on the bracts of sunflower buds, and the resultant larval feeding causes distorted head growth and reduced yields (Samuelson 1976, Glogoza et al. 1997). Chemical control measures have not been successful probably because insecticide application has not been accurately timed with adult flight. Monitoring adult emergence and developing a predictive model of sunflower midge adult emergence based on various parameters (air and soil temperature data, and soil moisture data) would help in effectively timing control measures.

Monitoring emergence patterns and using Degree-Day models to predict emergence

Our objective was to develop an emergence model for the overwintering generation of sunflower midge using air, soil temperature, and soil moisture parameters. Data from 1993-1997 were used to develop the model. Emergence of midge adults in 1999 was used to validate the model.

Air and soil temperature and midge emergence

In order to predict the emergence of adults, insect degree-days were utilized. Soil and air temperature from NDAWN (North Dakota Agricultural Weather Network System) data from March 1st through September 31st of each year were used to calculate cumulative degree-days at various base temperatures ranging from 40^0 F to 80^0 F (4.4^0 C to 26.7^0 C). Base temperature is the minimum temperature required for the emergence of adults. Cumulative degree-days were regressed on cumulative midge emergence data from 1993 to 1997. The regression with the lowest coefficient of variation and highest r^2 was chosen as the best fit of the data.

Adult midge emerging from the soil were collected from locations near Mapleton, ND, and Shelly, MN, that had been planted to sunflower and that had been infested with midge previous season. Cone shaped emergence cages (traps) with a base cross-sectional area of 0.071m^2 were used. The cones were painted black with a clear plastic collection vial placed at the peak. The cages were set base side down on the soil. As midge emerged, they are attracted to light and are

collected in the vial. These vials were removed at 2-5 day intervals from late June to early September and brought back to the lab to determine total number of midge that emerged. Males and females were recorded separately. Midge emergence was converted to cumulative percentage emergence.

Using sunflower midge adult emergence records and air temperature data from 1993 to 1997 our analysis showed the best fit was a model with a base temperature of 57^0F (13.9^0C) (r^2=0.96, slope=0.003 ± 0.0003, CV=20.4). The best fit of the data to the model for soil temperature was at a base temperature of 58^0F (14.4^0C) (r^2=0.98, CV=4.72). At higher and lower temperatures, data fit to the model declined as indicated by smaller r^2 values.

Based on air temperature at base 57^0F, the model predicts the first emergence at 488 ± 94.63 degree-days with temperature accumulations beginning March 1st. In figure one there are three lines; the thick line is at 488 degree days, the predicted first emergence and the two dotted lines on either sides are plus and minus one standard deviation. The black solid star represents the first emergence in the year 1999. The same notation is used for figures 2-4. In 1999, based on air temperature at base 57^0F, the first emergence of the adults at Mapleton, ND, occurred at 479 degree days which is well within the estimated value of 488 ± 94.63 degree days. In 1999 at Shelly, MN, based on air temperature at base 57^0 F, the first emergence occurred at 405 degree days which is close to the estimated value of 488±94.63 degree days (Fig. 2).

Predicting emergence in 1999 using a soil temperature model was not as accurate as the air temperature model. The soil temperature model predicted emergence to begin at 339 ± 90.49 degree days. At Mapleton, ND, in 1999 emergence began at 469 degree days which is close to the extreme of the estimated value (Fig. 3). First emergence in 1999 at Shelly, MN, was observed at 438 degree days which is close to the extreme of the estimated value of 339±90.49 degree days (Fig. 4).

From the data we concluded that air temperature at base 57^0 F is a better parameter to predict the midge first emergence than is soil temperature.

Soil moisture and midge emergence

In 1999, emergence data from Mapleton, ND, and Shelly, MN, were used to compare the relationship among soil moisture and adult emergence. Five soil samples were collected from each location where midge traps were placed and the percent soil moisture content at each sampling date was calculated (weight of water/total weight of the sample x 100). Emergence data were converted to proportionate emergence for both the first and second generation of the midge in order to correlate midge emergence with % soil moisture by weight.

The emergence of adult midge was greatest at soil moisture content of 12% to18%. However, adult midge emergence at both the locations had no linear relationship with the varying soil moisture.

Edge Effect

Observations have suggested that midge density in heads is greatest at field margins and decreases with distance into the field. Our objective in this study was to calculate the possible edge effect.

Two commercial fields (Shelly, ND and Pillsbury, ND) and a large field plot (Mapleton, MN) were used in this study. Edge effect is described by an edge effect coefficient defined as $C=D_n/D_1$, where D_n is the density of larva or eggs on each head at a distance 'n' from the edge of the field and D_1, the density of larva or eggs on each head at the edge of the field. Samples in the commercial fields (80 acres [32 ha]) were taken at the edge and at 10, 20, 40, and 60 m. The large plot was 1 acre (0.4 ha) in size and was sampled at 5, 10, 15, and 20 m. At the Mapleton plot, egg or larval density on 5 heads were determined at plant stage R1, R2, R3, and R4. The same methodology was followed for the two commercial fields, but the number of heads sampled per site was 10.

At the Mapleton site eggs were not found until stage R2. The edge effect coefficient for plant growth stages R2, R3, and R4 is shown in Figures 5 through 7. At this site, changes in the coefficient were not consistent.

Figures 8 through 11 show the edge effect coefficients in the commercial fields at Pillsbury, ND, and Shelly, MN, at stages R1, R2, R3, and R4, respectively. At stage R1 at Pillsbury, the coefficient fluctuated with distance (Fig. 8). No midge were detected at Shelly, MN. However, at stages R2, R3, and R4, the edge effect coefficient decreased as distanced into the fields increased from 10 to 60 m (Figs. 9-11).

Poisson's regression was used to determine if there was a relationship between distance from the edge and the midge numbers for the data at the Shelly, MN, and Pillsbury, ND, fields. After applying the appropriate statistic we found that at Shelly during the R2 stage Pr>Chi for distance was 0.0474 which is less than $\alpha=0.15$; R3 Pr>Chi was 0.0010 & $\alpha=0.15$; and R4 Pr>Chi was 0.0001 & $\alpha=0.15$. Since the calculated value is less than the estimated $\alpha=0.15$, we conclude that there is a significant edge effect. Thus at stages (R2 to R4), distance had a significant effect on midge numbers. At Pillsbury at R2, Pr>Chi was 0.10 & $\alpha=0.15$, R3 Pr>Chi was 0.0001 & $\alpha=0.15$, R4 Pr>Chi was 0.0001 & $\alpha=0.15$. Thus, distance had a significant effect on midge numbers at both the fields as shown by Poisson's regression analysis.

Edge effect was not evident in the Mapleton plot for any of the growth stages or for stage R1 in the commercial fields at later growth stages. The edge effect coefficient, in general, decreased with distance into the field, indicating that midge population's decline with distance into the fields. These findings may have implications for pest control since in some situations, control strategies could be concentrated in the periphery of the field rather than the entire field. This would result in a reduction in the cost of control.

Plan of study for 2000

Emergence pattern & edge effect

We plan to increase the precision of the emergence model by continuing to sample adult midge as they emerge from the soil this coming season and analyzing the data using both air and soil temperature. We also will be analyzing emergence data collected near Winnipeg, Manitoba, Canada. The effect of soil moisture on midge emergence will also be evaluated. The same techniques will be utilized to calculate the edge effect of sunflower midge in sunflower fields.

Economic injury level

An artificial infestation technique will be used to determine economic injury levels for the sunflower midge. The experiment will be conducted in the greenhouse. We will utilize a susceptible seed variety and staggar the dates of planting so that we have all the four stages of sunflowers (R1 through R4) when larvae are present in the field. We will collect larvae during the growing season from fields infested with midge. First instar larvae will be recovered from sunflower heads and stored until needed. We will infest heads of all four stages of plants with low, medium, and high levels of midge larvae. The midge numbers to be used will depend on the total number of first instar larvae collected from the fields. After infesting, the plants will be maintained in the greenhouse until heads are mature. Damage rating and yield will be taken at the end of the season.

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Fig. 1 1999 emergence of midge based on air temperature at base 57^0 F, Mapleton,ND

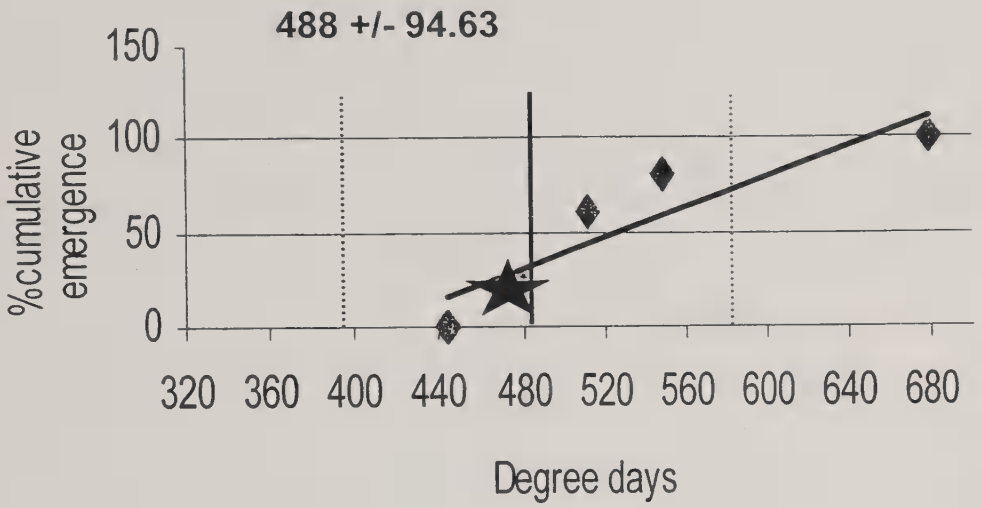


Fig. 2 1999 emergence of midge based on air temperature at base 57^0 F, Shelly,MN

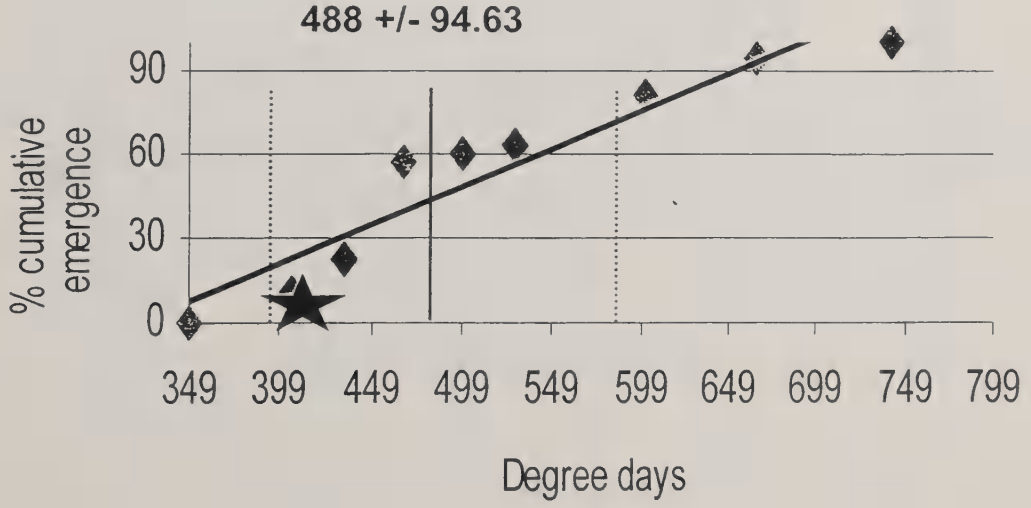


Fig. 3 1999 emergence of midge based on based on soil temperature at base 58^0 F, Mapleton,ND

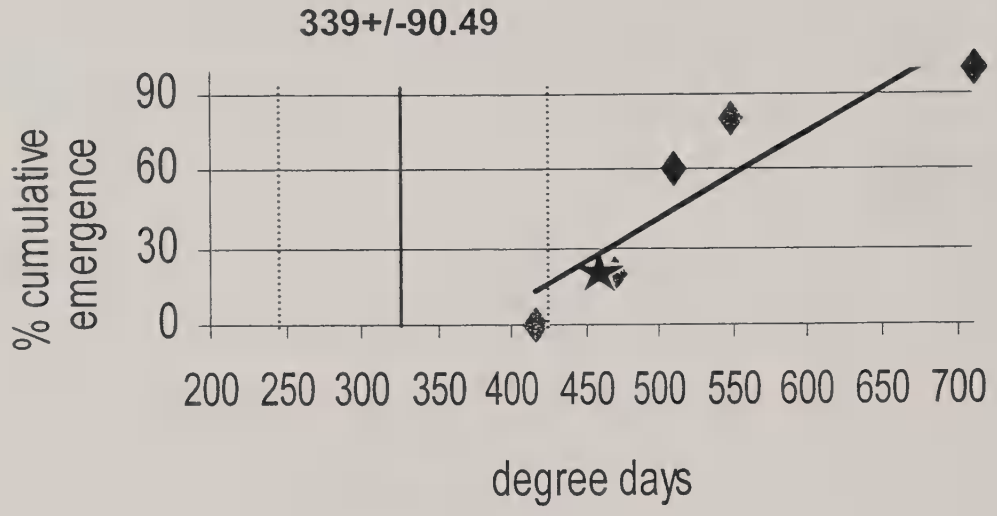


Fig. 4 1999 emergence based on soil temperature at base 58^0 F,Shelly,MN

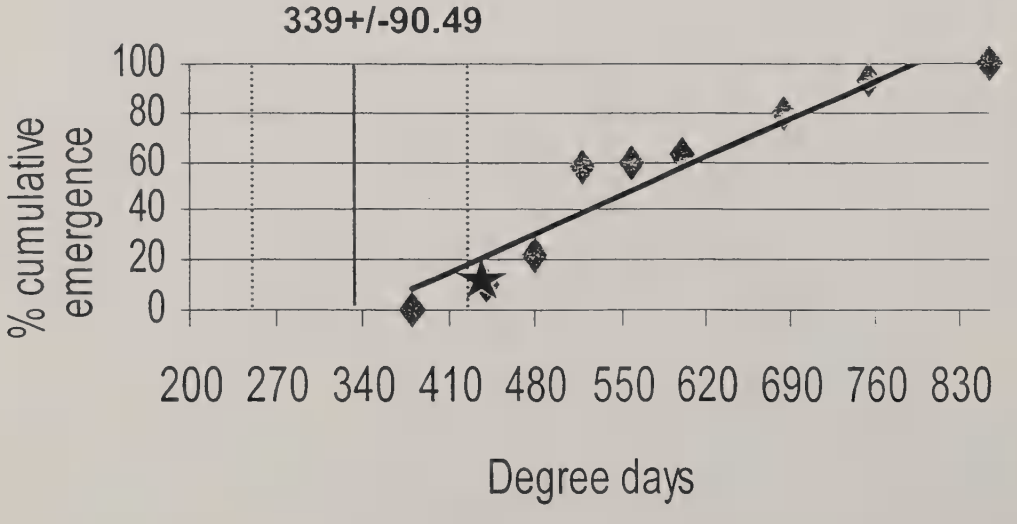


Fig. 5 Edge effect at Mapleton,ND 1999 R2 stage

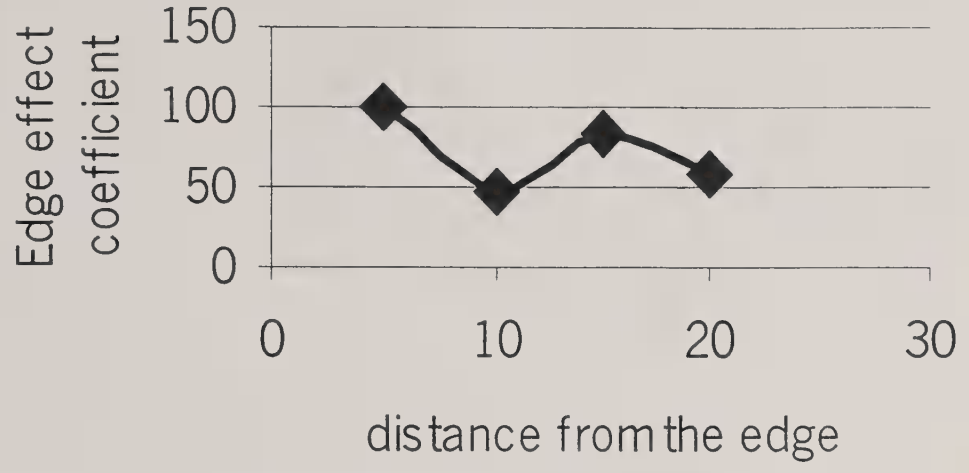


Fig. 6 Edge effect at Mapleton,ND 1999 R3 stage

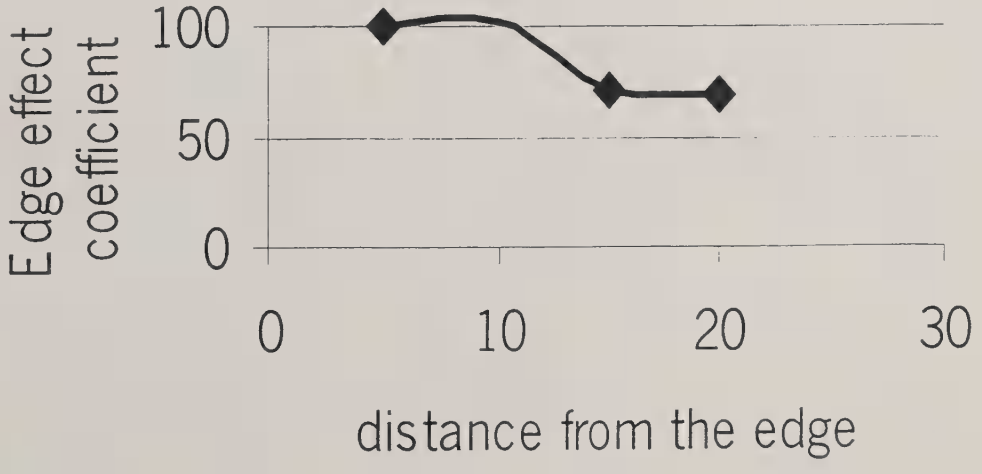


Fig. 7 Edge effect at Mapleton.ND 1999
R4 stage

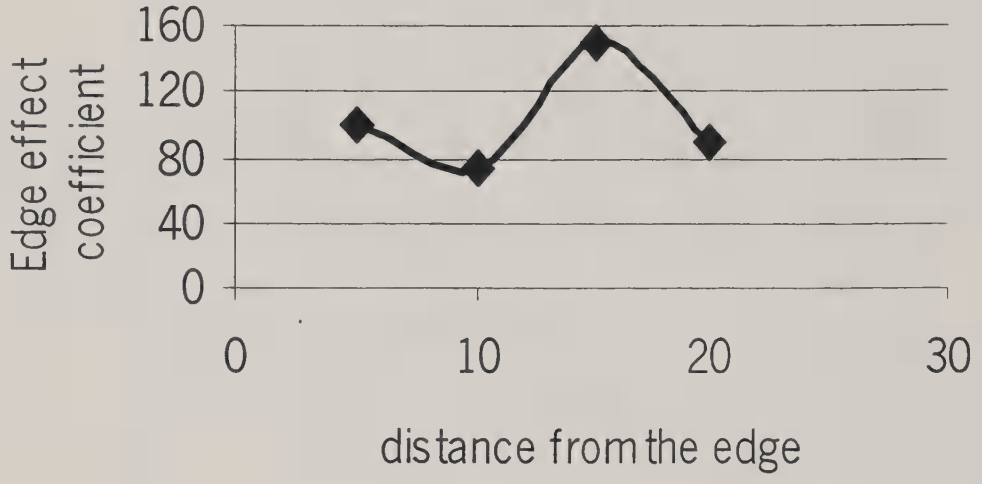


Fig. 8 Edge effect at Pillsbury,ND and Shelly,MN 1999
R1 stage

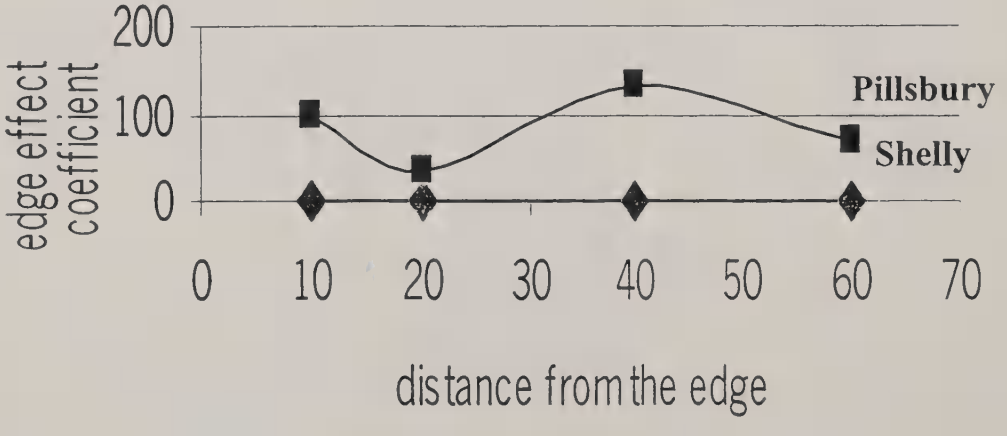


Fig. 9 Edge effect at Pillsbury,ND and Shelly,MN 1999
R2 stage

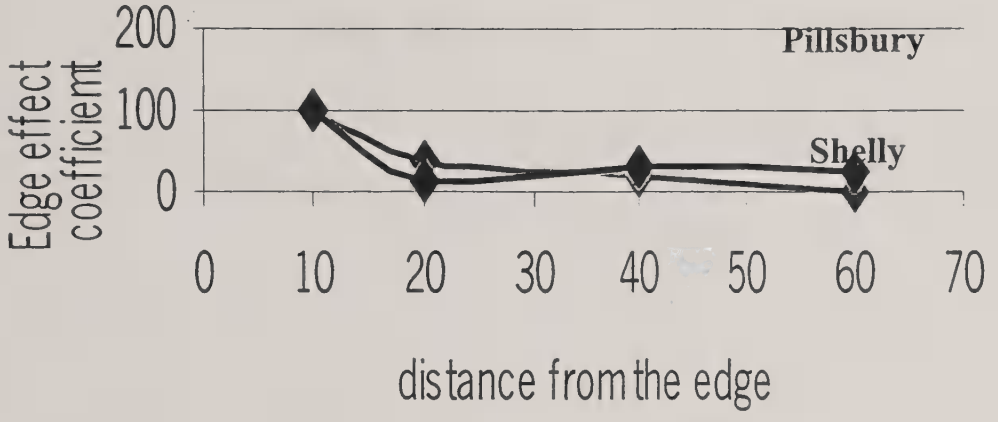


Fig. 10 Edge effect at Pillsbury,ND and Shelly,MN 1999
R3 stage

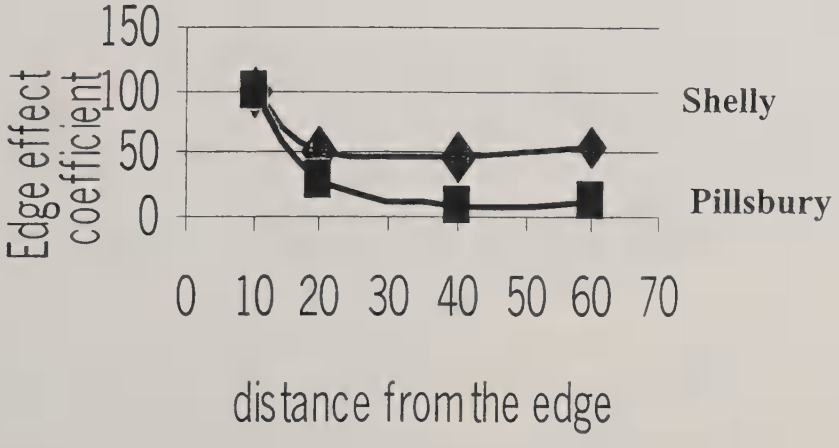
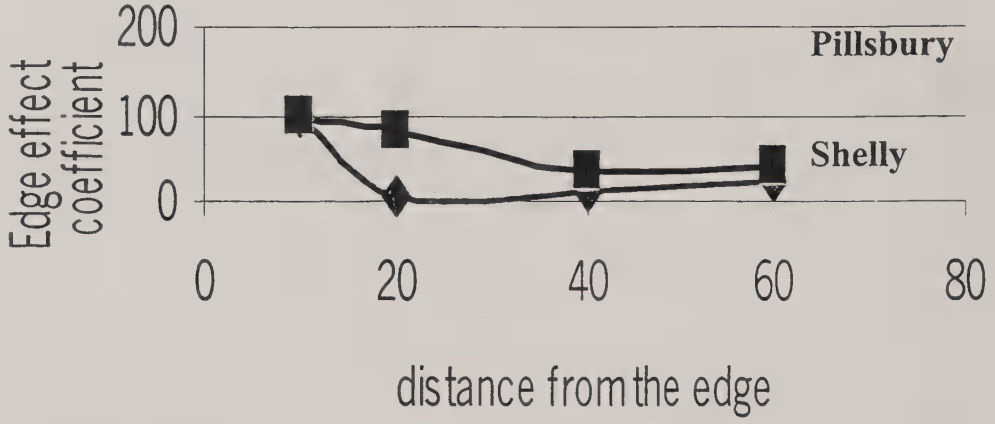


Fig. 11 Edge effect at Pillsbury,ND and Shelly,MN 1999
R4 stage



Pest Management Strategies for the Sunflower Midge: Chemical and Biological Control[1]

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Chemical Control

Research trials were conducted from 1980 to 1983 to evaluate the efficacy of insecticides for the control of the sunflower midge, *Contarinia schulzi* Gagné. This midge had surfaced as an insect pest of cultivated sunflower in 1971 and especially beginning in the 1979 production year in both northeastern North Dakota and northwestern Minnesota with some heavily infested fields plowed under because of severe damage (Lilleboe 1979). This research effort was initiated by John Busacca, Department of Entomology, North Dakota State University and the results of his efforts were recorded in the department's annual reports (North Dakota State University 1980-1983). During these years both foliar and systemic insecticides were applied at different rates, with multiple applications, and at different sunflower growth stages. The majority of the treatments were applied when the sunflower buds were 2-4 inches in diameter. The efficacy of the chemical trials was evaluated, when plants were mature, using a 0 to 5 scale. The midge damage rating utilized for these studies was: 0 = no visible damage; 1 = sepal damage only; 2 = 0-10% damage; 3 = 11-25% damage; 4 = 26-75% damage; and 5 = total loss (North Dakota State University 1980).

The insecticide trials in 1980 were conducted near Leonard, North Dakota, and included Pounce, Supracide, Furadan, Lorsban, Pydrin, and Cymbush. The midge damage rating for the controls were 2.0 and 2.1 and the best chemical was only 2.0. Thus the trial showed no real difference among the materials tested. This was probably due to the low midge activity occurring at the location of the test (North Dakota State University 1980).

The chemical studies were moved to Mapleton, North Dakota, in 1981. The trials included the systemics Furadan, Temik, and Counter. The foliar materials tested were Supracide, Sevin, Ammo, Lorsban, Orthene, Pounce, Ambush, Baythroid, Furadan, and Pydrin. The application of the foliar materials was made one day after the midge eggs were discovered on the heads. Damage from the midge was more severe than in 1980 and some differences were noted among the insecticides tested. The control plots were rated at 3.2 and 3.4 and the best chemical tested was rated at 2.4. The conclusions from the trials were that the pyrethroids were somewhat better than other classes of compounds tested, but none gave enough control to manage midge damage with only one application after eggs were present on the heads (North Dakota State University 1981).

In 1982, the trials at Mapleton, North Dakota, included systemic insecticides and two separate foliar experiments. The first was applied to coincide with adult emergence and the second was designed to test single versus multiple applications and the treatments were timed based on plant growth stage. The systemic chemicals included Temik, DiSyston, Counter, and Furadan, but the

results indicated no significant differences among any of the treatments and the control. The foliar trial was applied to coincide with peak adult emergence and consisted of Ammo, Pydrin, Baythroid, Furadan, Larvin, Lorsban, Nudrin, Orthene, Supracide, PayOff, Pounce, Sevin, Metasystox, and DiSyston. The midge damage rating in the control plots averaged 2.2, with the best insecticide at 2.0, thus showing no control by any of the materials tested. The experiment using multiple applications included two planting dates (7 and 21 May) and varied treatments (1, 2 or 3 applications) were initiated when heads were R1 (beginning of head development) and continued at 5 day intervals. There were four materials tested including Furadan, Lorsban, Pounce, and Orthene. The checks from the first planting date had a midge rating of 2.7 with the best material rated 2.2 and the controls in the second planting date were rated 2.7 with the best chemical 2.0. The results were inconsistent and showed that there was no economic benefit from any of the insecticidal treatments (North Dakota State University 1982).

The trials conducted in Mapleton, North Dakota, in 1983 again included both systemic and foliar treatments. The systemic insecticide (Temik, DiSyston, Counter, and Furadan) plots had midge damage ratings equal to the control plots (both were 2.0), revealing no significant reduction in midge damage. The foliar trials included Pydrin, Furadan, Lorsban, Pounce, and Orthene and were applied to plots planted on 19 May and 6 June. There were no significant differences among any of the treatments or controls in either planting date (North Dakota State University 1983).

The results from the insecticide trials conducted between 1980 and 1983 revealed the lack of effectiveness for reducing midge damage from a chemical control strategy. The approaches had included many different types and classes of insecticides, utilized both systemic and foliar applications, incorporated single and multiple applications, and investigated timing based on both midge biology and plant growth stage. Overall the results were inconsistent and showed that the insecticides were not able to effectively reduce sunflower midge damage. The conclusions reached by those conducting the trials indicated that insecticides were not an effective or economic control procedure for the sunflower midge (Busacca 1983, North Dakota State University 1983).

The failure of insecticides to adequately control the sunflower midge was probably a result of either inaccurate timing for the spray application to kill the adults or the expansion of the buds so that adults were exposed to untreated surfaces rather than the chemical itself. In addition, the material may not be contacting the larvae since they are located inside the bracts or at the base of the disk flowers. The systemic insecticides were undoubtedly not present in sufficient quantity within the plant when the adults were ovipositing on the buds or later when the larvae were feeding in the head (Charlet and Brewer 1998). Laboratory trials have shown that the larvae are susceptible to a variety of insecticides. Compared to the controls in which mortality after 3 days was only 5%, the insecticides Malathion, Baythroid, Warrior, Lorsban, Asana, and Scout killed between 80 and 100% of the larvae (Charlet and Brewer 1998).

Insecticides have been reported to be effective against other *Contarinia* species. Aerial applications of Asana and systemic insecticides Orthene, Furadan, Cygon were effective in reducing populations and seed damage of the Douglas-fir cone gall midge, *C. oregonensis* Foote (Sandquist et al. 1993, Stein et al. 1993). The Douglas-fir needle midges, *C. pseudotsugae*, *C.*

constricta, and *C. cuniculator*, cause serious damage to needles on trees grown in plantations for Christmas use. Chemical treatments have been effective if they are applied prior to the larvae entering the needles. As in the case with the insecticidal treatments for the sunflower midge, timing based on plant stage was not successful. Traps have been used to monitor adult emergence of the needle midges from the soil combined with knowledge of the midge biology (males emerged first and emergence period was 7-10 days). The chemical treatments were applied 3-5 days after female emergence began (Antonelli 1977, Simko 1982).

Additional insecticidal trials are planned for the sunflower midge in 2000. These will include approximately five chemicals including those applied to the foliage, but with systemic properties. The experiments will be conducted at Mapleton, North Dakota, in an area that was heavily infested with midge in 1999. Two planting dates will be utilized and the materials will be applied with high volumes of water plus a wetting agent to move the chemicals farther down into the sunflower head. The spray timing will coincide with the degree-day models for predicted emergence of the adult midge from the overwintering generation. A second application will be made on some of the plots approximately 3-4 days after the first application. The treatments will be evaluated when heads are mature using a 0-5 midge damage rating scale (Bracken 1991).

Biological Control

Little information is available on the natural enemies of the sunflower midge. There has been no research on predators that attack the midge eggs or larvae, but a number of generalist predators are present on the sunflower head and may consume either eggs or larvae when available. A parasitoid of the sunflower midge was first reported by Samuelson (1976) and described as *Inostemma* sp. (Hymenoptera: Platygastridae). Anderson and Brewer (1991) recovered 8 *Inostemma* sp. parasitoids from emergence traps in 1987 after the majority of sunflower midge adults had already emerged and noted that they were probably the same species that Samuelson had collected. Our laboratory has been rearing overwintering sunflower midge larvae since 1997 and we have recovered both males and females of *Inostemma* sp. (L. Charlet and T. Gross, unpublished data). Specimens of *Inostemma* sp. have been sent to Matt MacGown at Mississippi State University for determination of the species. He is the platygastrid specialist who initially examined the parasitoids recovered by Samuelson. Although he has not finished comparing the parasitoids with other species of *Inostemma*, he initially believed them to be *I. horni* Ashmead. Recently, he has indicated that the parasitoids should be described for now as *Inostemma* new species near *californica*. A drawing of a female *Inostemma* n. sp. is shown in Fig. 1.

The biology of the sunflower midge parasitoid is unknown, although it probably is similar to other species in the same genus. The genus *Inostemma* is contained in the family Platygastridae. This family of wasps is parasitic in cecidomyiid midge larvae as internal parasitoids. The majority deposit eggs into the host egg. The parasitoid ultimately kills the host when it is in the pupal stage. Most have only one generation per year. They all have long extendable ovipositors, with the genus *Inostemma* having a curved 'horn' that extends over the thorax into which the ovipositor can be retracted (Clausen 1972).

Based on research with other midges, there may be additional parasitoids of the sunflower midge that have not yet been recovered. The Ponderosa pine midge, *C. coloradensis* Felt, is attacked by

two species of *Platygaster* that parasitize about 50% of the larvae. In addition, the midge is parasitized by *Gastrancistrus* sp. and *Trichomalus* sp. (Pteromalidae) and *Tetrastichus semiauraticeps* (Girault), *Tetrastichus* sp., and *Euderus* sp. (Eulophidae) (Brewer and Johnson 1977). Approximately 75% of the overwintering Douglas-fir needle midges (*C. pseudotsugae, C. constricta, C. cuniculator*) were reported to be parasitized by *Platygaster* sp. Although, the most common midge, *C. pseudotsugae* was noted to encapsulate parasitoid eggs, a large portion of the midge were still destroyed. The parasitoids emerge several weeks after the emergence of the adult midge allowing for chemical treatment of the midge without harm to the natural enemies (Simko 1982). Research on the bromegrass seed midge, *C. bromicola* Marikovskiy and Agafonova, in Saskatchewan, Canada, found that a parasitoid, *Tetrastichus* sp. was present and very active in all years of the study. There were two population peaks a few days subsequent to the first and second emergence of the midge. Parasitism of the bromegrass midge was estimated at 30 to 75% (Curry et al. 1983).

Future research on the sunflower midge natural enemies will focus on a survey of both cultivated and native sunflower to search for additional parasitoids. Midge eggs and larvae will be collected 2 to 3 times per week in research plots to investigate the biology of *Inostemma* n. sp. These studies will help to elucidate the stage of the midge attacked, sex ratio, temporal and spatial patterns, and impact on both the overwintering and first generation midge populations.

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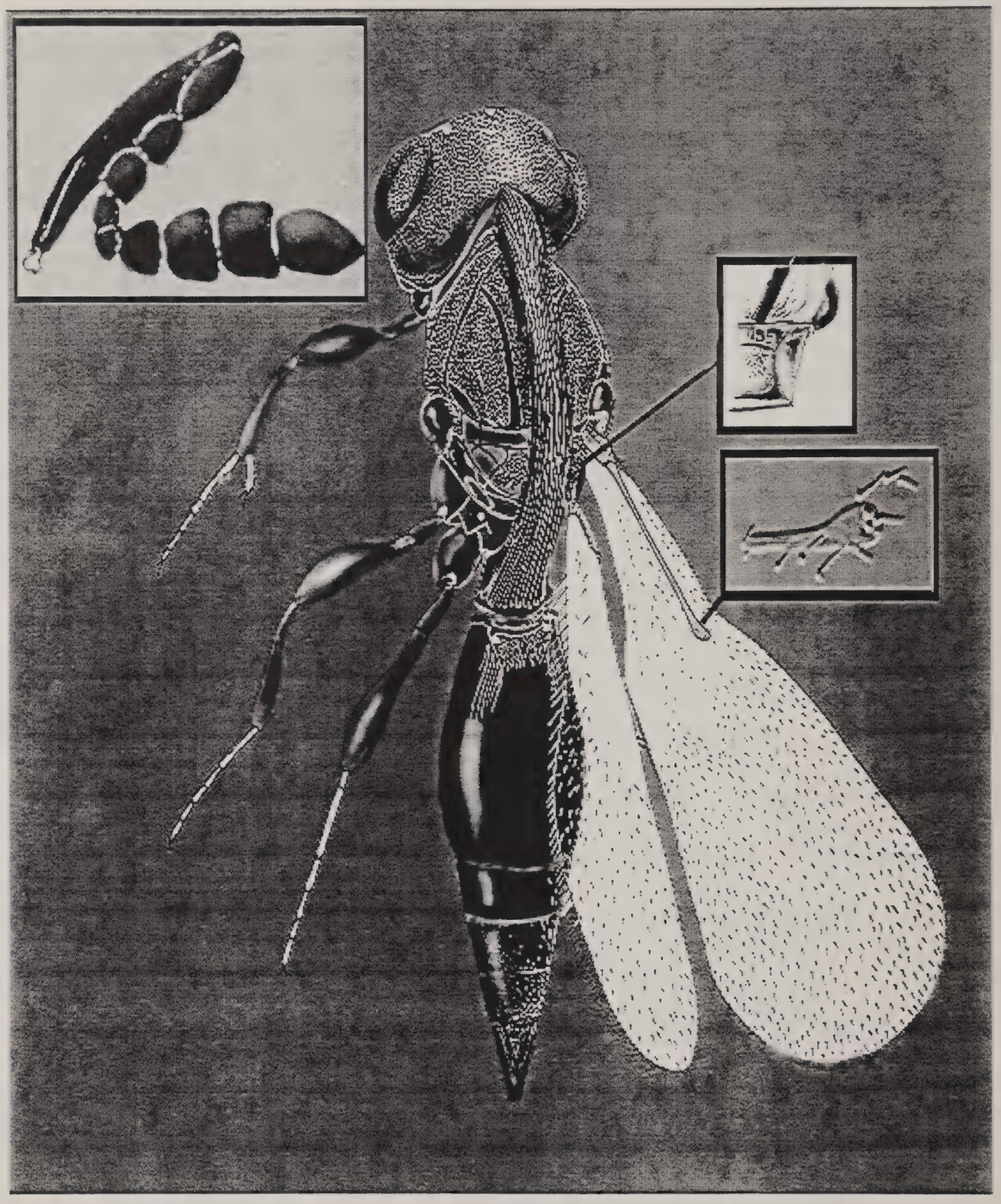

Fig. 1. Drawing of female sunflower midge parasitoid, *Inostemma* n. sp. and detail of antenna by Matt MacGowan

Preliminary Results of a Search for Sunflower Midge Attractants

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Introduction

The sunflower midge, *Contarinia schulzi* Gagné, was first discovered in 1971 by J. T. Schulz and coworkers from the Department of Entomology at North Dakota State University. The insect was identified as the cause of serious damage to the heads of cultivated sunflower in North Dakota and northwestern Minnesota. Symptoms were severe gnarling of the heads or cupping, resulting in reduced seed set and in the worst case, complete loss of seed set. Although the sunflower midge is distributed throughout the Great Plains growing region of cultivated sunflower, it has only been a serious economic pest in the northern production area of North and South Dakota and northwestern Minnesota.

The biology of the sunflower midge was studied by Mulkern (North Dakota State University, 1983), who used light and electron microscopy to study the larval morphology and feeding behavior. Attempts to rear the midge in the laboratory by placing field-collected larvae on greenhouse-grown sunflowers were unsuccessful because the larvae failed to establish themselves. However, fully developed larvae which had dropped to the ground in the field successfully pupated in the laboratory after 4 to 5 weeks and emerged as adults after an additional 4 to 5 weeks.

Other aspects of sunflower midge biology and behavior are less well known, including the factors which attract them to sunflower buds. In the summer of 1998 I conducted some preliminary field and laboratory studies in an attempt to determine whether the midge is attracted to sunflowers by chemical cues. These initial experiments are described in this report. I will begin with a brief review of the terminology which describes interspecific interactions caused by chemicals emitted by one of the species.

An *allomone* is a chemical that is produced by one species that causes a reaction in an individual of another species, and is favorable to the emitter, but detrimental to the receiver. The chemicals often serve to repel, deter, or harm the feeding insect. For example, potato plants produce allomones in the form of protease inhibitors which disrupt the digestive system of herbivores, and result in cessation of feeding.

In the reverse situation, a *kairomone* is a chemical that is favorable to the receiver, but harmful to the emitter. Plant-produced kairomones typically act as attractants, arrestants, or oviposition and feeding stimulants for herbivores. Many examples exist, such as the strong attraction of cucumber beetles and corn rootworms to phenylpropanoid volatiles emitted from cucurbit blossoms (Metcalf and Lampman, 1990).

A *synomone* is a substance released by an organism that benefits both the emitter and the receiver. An example is the production of volatile compounds by elm leaves when the elm leaf beetle oviposits. The volatiles attract the egg parasitoid *Oomyzus gallerucae*, and thus are synomones because they benefit the emitter (the elm leaf) and the receiver (*O. gallerucae*) (Meiners and Hilker, 2000).

Antimones are substances that are injurious to both the sender and the receiver. In some cases plant volatiles can repel natural enemies of herbivores, and are therefore antimones because they are detrimental to the plant and to the natural enemy, albeit advantageous to the herbivore.

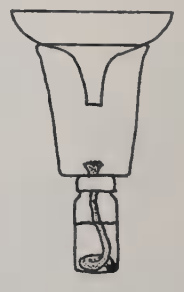
	Benefit	
	Emitter	Receiver
Allomone	+	-
Kairomone	-	+
Synomone	+	+
Antimone	-	-

My study aimed to establish whether sunflower heads emit volatile compounds that attract the sunflower midge. Such compounds would serve as kairomones: beneficial to the midge, but harmful to the sunflower.

Methods

Steam distillation of sunflower volatiles. About 200 g of sunflower buds (4 to 6 cm diameter) were collected from greenhouse-grown plants and cut into small pieces. The bud material was placed in a round-bottom distillation flask with about 1.5 L of water and the mixture distilled. The condensate was collected (1 L) and frozen in 100-mL aliquots for future use.

Design and implementation of insect traps. A trap with a wick and reservoir to hold the sunflower steam distillate was designed. It was constructed from a 7 oz. clear plastic tumbler glass, a modified plastic champagne glass, and a 20-mL scintillation vial. The vials were filled with sunflower bud steam distillate or water, and the trap taped to a bamboo pole at a height approximately the same as emerging sunflower heads. Twenty-eight traps were placed randomly in a sunflower field near Mapleton, ND, on July 6, 1998. The adjacent field had experienced high sunflower midge infestations the previous year.



Olfactometer studies. A five-arm olfactometer was used to assess whether sunflower midge could be attracted to sunflowers by volatile substances emitted from the buds. An unopened bud from RHA 274 was placed in chamber #1, young leaves of RHA 274 were introduced into chamber #3, and a young bud of a known midge-susceptible inbred line was put in chamber #4. Chambers #2 and #5 remained empty. Forty-eight adult, field-collected sunflower midge were added to the central introduction chamber over a 20-hour period. After 4 days the number of midge in each chamber were counted.

Results and Discussion

Field traps. Several insect species, including a few sunflower midge, were attracted to the traps and were collected in the glass tumblers. However, control traps with water were as effective as traps containing sunflower bud steam distillate. The experimental design did not allow one to distinguish whether the insects were attracted to water vapor emitted from the wicks or whether they were attracted to the reflectiveness of the plastic glass. In this experiment no conclusions could be drawn about sunflower midge attraction to volatiles extracted from young sunflower buds.

Olfactometer studies. Four days after placement of 48 sunflower midge in a five-arm olfactometer, ten midge had navigated from the central chamber to sources in the five arms. The results are shown in Table 1.

Table 1. Attraction of sunflower midge to sunflower bud volatiles in a five-arm olfactometer.

Chamber	Source	No. of midge†
1	RHA 274 bud	5
2	empty	0
3	RHA 274 young leaves	1
4	midge-susceptible bud	4
5	empty	0

† 48 sunflower midge were initially introduced into the olfactometer. Insect count was taken after 4 days.

The preliminary results presented in Table 1 indicated that sunflower midge are attracted to volatiles emitted from sunflower buds. Because the olfactometer was designed so that the insects could not "see" the sunflower buds, the results suggested that volatile chemicals produced by the buds were responsible for attracting sunflower midge. However, this represented the results of a single experiment. In a second experiment with only 17 midge placed in the olfactometer, three midge navigated to chambers with no source and none traveled to the two chambers with sunflower buds. This emphasizes the need for many more replications of the experiment in order to draw a firm conclusion.

A major hindrance to conducting sunflower midge attraction studies is the availability of adult sunflower midge. It is apparent that many more adults than used here are necessary to give meaningful results. The adults used for this study were collected from emergence traps in the field. Adult sunflower midge live for only about 48 hours, so rapid mortality quickly reduces the numbers able to travel through the olfactometer arms. Future experiments will require more adult sunflower midge emergence traps to supply adequate numbers of adults. With

more adults available, it should be possible to use the olfactometer to test more accurately the attractiveness of sunflower buds, sunflower bud steam distillates, and commercially available volatile constituents of sunflower buds which have been reported in the literature (Etievant et al., 1984; Flath et al., 1985).

Acknowledgment

The technical assistance of Tuan Nguyen is gratefully acknowledged.

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Host-plant resistance

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Sunflower midge, *Contarinia schulzi* Gagné (Cecidomyidae: Diptera), outbreaks have been sporadic but capable of causing severe damage. Outbreaks usually last for several years and have began in1971 (Schulz 1973), 1979 (Lilleboe 1979), 1984, and in 1997. In general, outbreak years are preceded by a year or two of isolated but increasing instance of midge damage and are followed by periods of little or no damage. See Charlet, Sunflower midge: history, biology, and damage, this volume, for a more detailed history of sunflower midge outbreaks.

Because of the periodic nature of midge population cycles, factors affecting midge emergence and activity are poorly understood. As a result, timing of insecticides for controlling adults has not been effective. And the cryptic nature of the larval habitat has made insecticidal controls against them ineffective as well.

Sunflower resistance to the midge is a promising alternative to insecticides which would not depend on detecting midge populations and accurately directing insecticides. The objectives of this paper are twofold. First, to briefly describe plant resistance to insects and the forms it takes and second to discuss progress towards developing sunflower resistance to the sunflower midge.

Plant Resistance to Insects

Plant resistance to insects, with a few exceptions, is not an absolute trait. Unlike the situation for many plant pathogens where disease resistant varieties are commonly asymptomatic, insect resistant plants usually do to some extent support insect development and suffer some damage. Although in insect resistant germplasm the damage is less than that on more susceptible plants. Another major difference between pathogen and insect interactions with plants is that insects actively seek out and preferentially select their hosts. Insect behavior adds a layer of complexity to plant-insect interactions that is lacking in plant-pathogen interactions. Plant resistance to insects is expressed as three broad types or mechanisms.

Antibiosis - plant traits affecting insect development. Symptoms include death, slow growth, small size, and reduced fecundity.

Antixenosis (nonpreference) - plant traits affecting insect behavior. Symptoms include avoidance of the host plant for feeding or oviposition, reduced feeding or oviposition, and restlessness or increased movement.

Tolerance - plant does not affect the insect, there is normal insect development and behavior. Symptoms are expressed by the plant not the insect. The plant responds to insect damage by

replacing tissue or compensating for lost tissue.

Antibiosis and antixenosis are qualitatively different from tolerance in that they have a negative impact on the insect and can exert enough selection pressure in some situations to lead to the development of resistance disabling insect biotypes. Because tolerance does not stimulate biotype development it is often a more desirable resistance mechanism. However, tolerance is not always useful, especially where an insect directly damages the harvested plant tissue or the plant does not have time to compensate for the damage. Tolerance is also usually polygenic and poorly understood genetically, consequently it is difficult to breed for. Antibiosis and antixenosis are more often single or few gene traits and are easier to work with in a breeding program.

Sunflower Midge Resistance

In a 1986 to 1989 study of resistance to sunflower midge in sunflower hybrids, low levels of resistance were detected. The resistance was expressed as combinations of antibiosis, tolerance, and infestation resistance (Anderson and Brewer 1991) (Fig. 1). Infestation resistance was an approximation of antixenosis and was based on egg and larval numbers. Antixenosis was not measured directly because larvae were already present when sampling occurred and because the ratio of eggs to larvae was unknown.

Although resistance to the midge is known to exist in sunflower germplasm, sunflower hybrids with high levels of resistance to the midge have not been developed. While seed companies have eliminated germplasm with obvious susceptibility to the midge, concerted efforts to breed for resistance to the sunflower midge have not progressed because of inadequate screening methods. Screening for insect resistance requires uniformly high insect populations across all germplasm being tested.

Field screening using natural populations of the sunflower midge have failed because populations were inadequate and not evenly distributed. This common difficulty in insect resistance trials is avoided for some insects by artificially infesting plants. Sunflower can be artificially infested using either larvae or adult sunflower midge as the inoculum source. Anderson and Brewer (1991) found that damage ratings obtained following artificial infestation were modest but sufficient to distinguish among germplasm tested (Fig. 2). If higher infestation rates had been used, they probably would have had higher damage levels.

While it is possible to artificially infest sunflower with the sunflower midge, methods to rear sunflower midge are not available. Thus, artificial infestation depends on field collecting insects and transferring them to test plants. This makes the use of artificial infestation methods impractical for all but small numbers of plants.

Another approach to screening for insect resistance is to simulate damage. Typical examples of this approach are to mechanically remove leaf tissue to simulate defoliation. A novel approach to simulate sunflower midge damage uses the synthetic auxin 2,4-dichlorophenoxyacetic acid (2,4-D) to stimulate the abnormal growth response that occurs during a midge infestation (Brewer et al. 1994). This technique requires injecting a 10 molar 2,4-D solution into three equally spaced

points around the sunflower bud. The 2,4-D method identifies midge tolerant germplasm (Fig. 3) but it will not identify other resistance mechanisms and it is a slow, tedious task best suited for use on small numbers of plants.

Simulating midge damage has not been adopted for use in large scale screening of plants. However, it has been used in smaller projects with advanced germplasm and has proved useful in a USDA led project to develop midge resistance germplasm.

Measuring Resistance

A number of damage rating methods have been developed to measure resistance to sunflower midge. Probably the best method is a damage rating scale developed by Bracken (1991). His scale has a number of advantages. It is simple and accurate and if different raters are used to evaluate a trial, they can, with a little training, consistently score damage similarly. Additionally the Bracken method is quick and, very importantly, it is related to yield.

Bracken Scale

0 - no damage visible
1 -light bract damage, may be creases in surface of head, little receptacle thickening.
2 - bract damage and light cupping with some combination of: developing central hole or seedless area, receptacle thickening up to 1/4 head diameter, asymmetrical head.
3 - extreme bract damage and cupping to central hole or seedless area, receptacle thickening up to ½ head diameter.
4 - extreme cupping to large central hole or seedless area, receptacle thickening greater than ½ head diameter, head may be almost completely closed, few seeds present.
5 - head closed, no seeds present.

To allow comparison of damage rating scores among trials with different insect pressure, a relative midge rating is determined. The relative midge rating is calculated by dividing the Bracken score of individual germplasm by the average Bracken damage rating for that trial.

A relative midge rating:

greater than 1 is susceptible,
of 1 is equal to the trial mean and is susceptible,
less than 1 is below the trial average and is resistant.

Because damage ratings are taken after damage has occurred they have the drawback of not being able to identify germplasm until after anthesis has ceased. To overcome this drawback and to allow selections and crossings to be made the same season, a petal index can be used. The petal index (Jerry Miller, personal communication) measures damage in the form of petal growth abnormality. Petal damage is visible at the onset of anthesis which allows sufficient time for selections to be made and crossed the same season. The petal index is a 0 to 10 scale based on percent ray petals lost. In most situations the petal index and the Bracken Scale agree (Fig. 4). However, because the petal index is scored before all damage symptoms develop, it may incorrectly score some germplasm. For example, some hybrids with a high petal index scores

indicating susceptibility outgrow damage and end up with a low relative midge rating. The opposite situation may also exist where germplasm shows low petal damage but relatively high final damage (see circled points, Fig. 4).

Where a number of scorers are involved and there is concern about inconsistent scoring among people, a round index (Brewer et al.1994) can be used. The round index relies on the abnormal growth of midge damaged sunflower heads. It measures damage by comparing the diameter across the sunflower head at two points at right angles to each other. The round index is very accurate, has no scorer bias, and like the Bracken scale is related to yield. However, it is slower than visual damage ratings. The round index is measured after head growth has stopped.

Round Index = (diameter1 - diameter2)/(diameter1 + diameter2)

Conclusion

Because of the difficulty in screening large numbers of germplasm early in a breeding program and because midge damage decreased as growers avoided midge areas and the midge population declined, interest in breeding for resistance to the sunflower midge declined in the mid 1980s. However, the resurgence of midge damage since 1997 and the continued failure of insecticidal controls has refocused interest on developing resistance to the sunflower midge. Because resistance is known to occur and because no responsive controls to manage the midge exist, resistance to the sunflower midge is the most promising solution to a difficult insect management problem.

Acknowledgments

The work reported on has been a collaborative effort among a number of individuals and agencies including Marc Anderson, graduate student North Dakota State University; Gene Schmidt, North Dakota State University; Rama Urs, formerly with Dalhgren Seeds; Garth Bracken, Agriculture Canada; Jerry Miller, USDA-ARS Sunflower Research Unit; and Larry Charlet, USDA-ARS Sunflower Research Unit.

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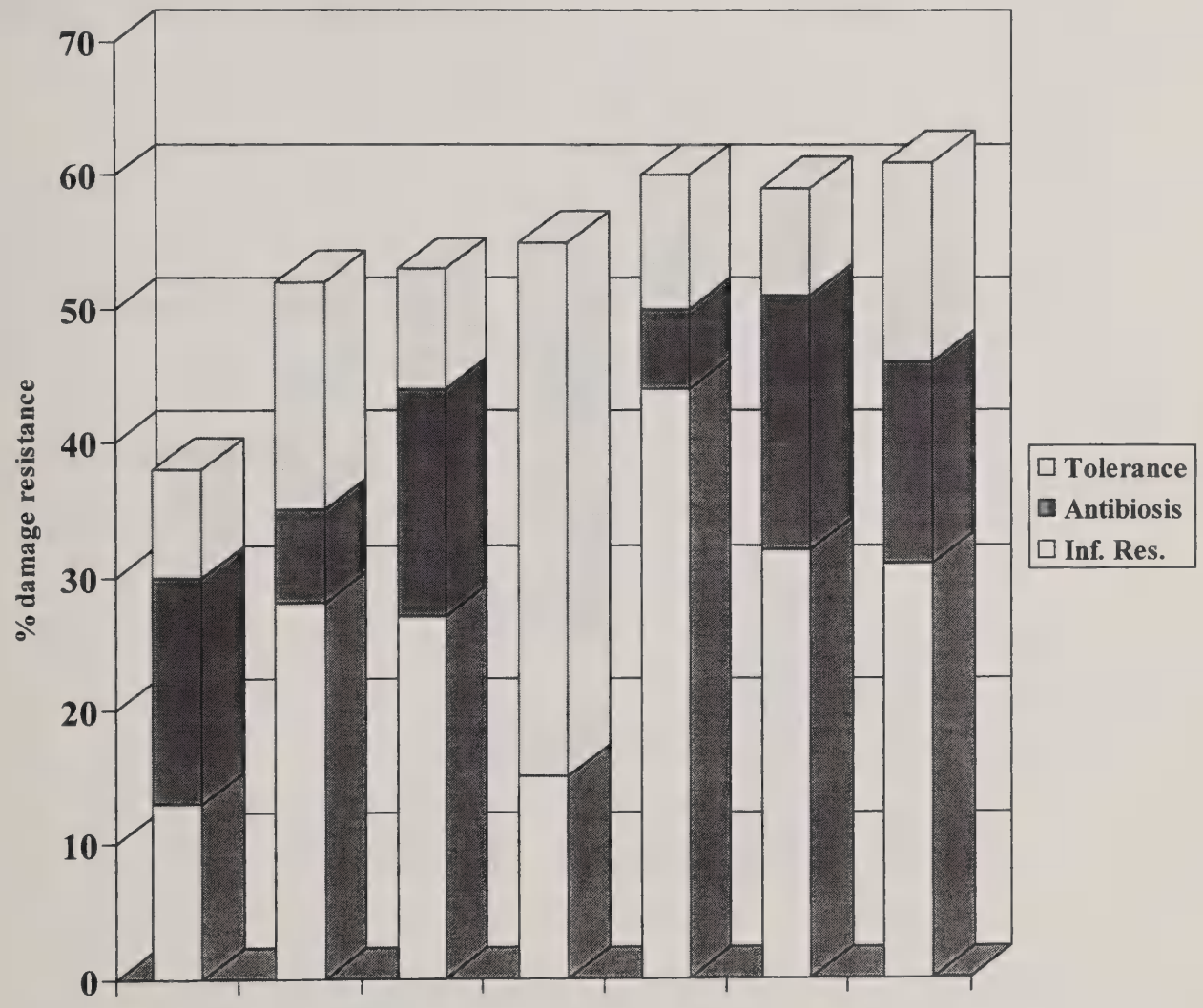
Figure 1. Resistance to Damage Relative to a Susceptible Check and Resistance Components in Sunflower Hybrids.

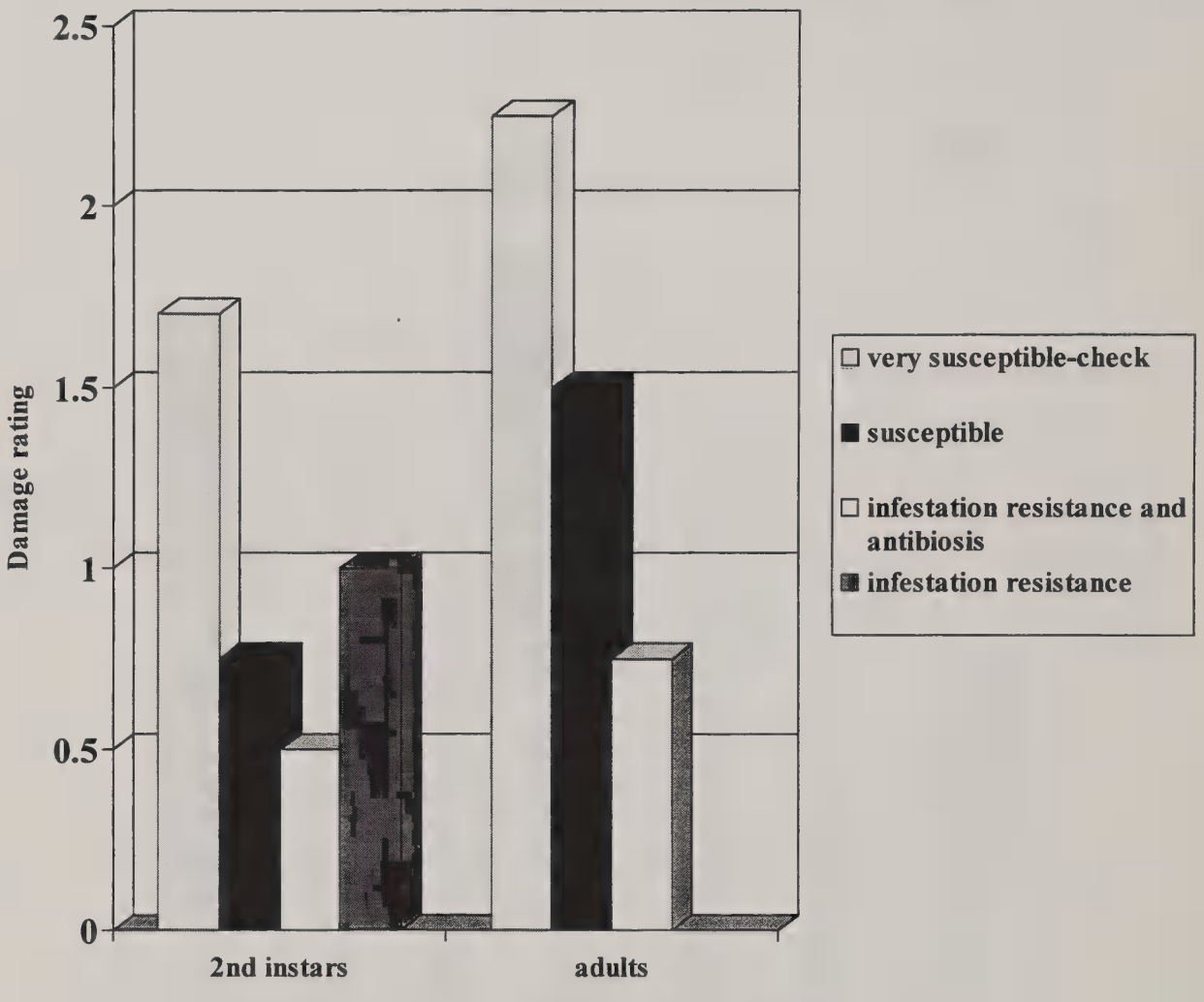


% damage resistance: 1 = no resistance relative to a susceptible check; 100 = germplasm 100% more resistant that the susceptible check.

Infestation Resistance: resistance to infestation measured as numbers of eggs and early instar larvae.

From Anderson and Brewer 1991.

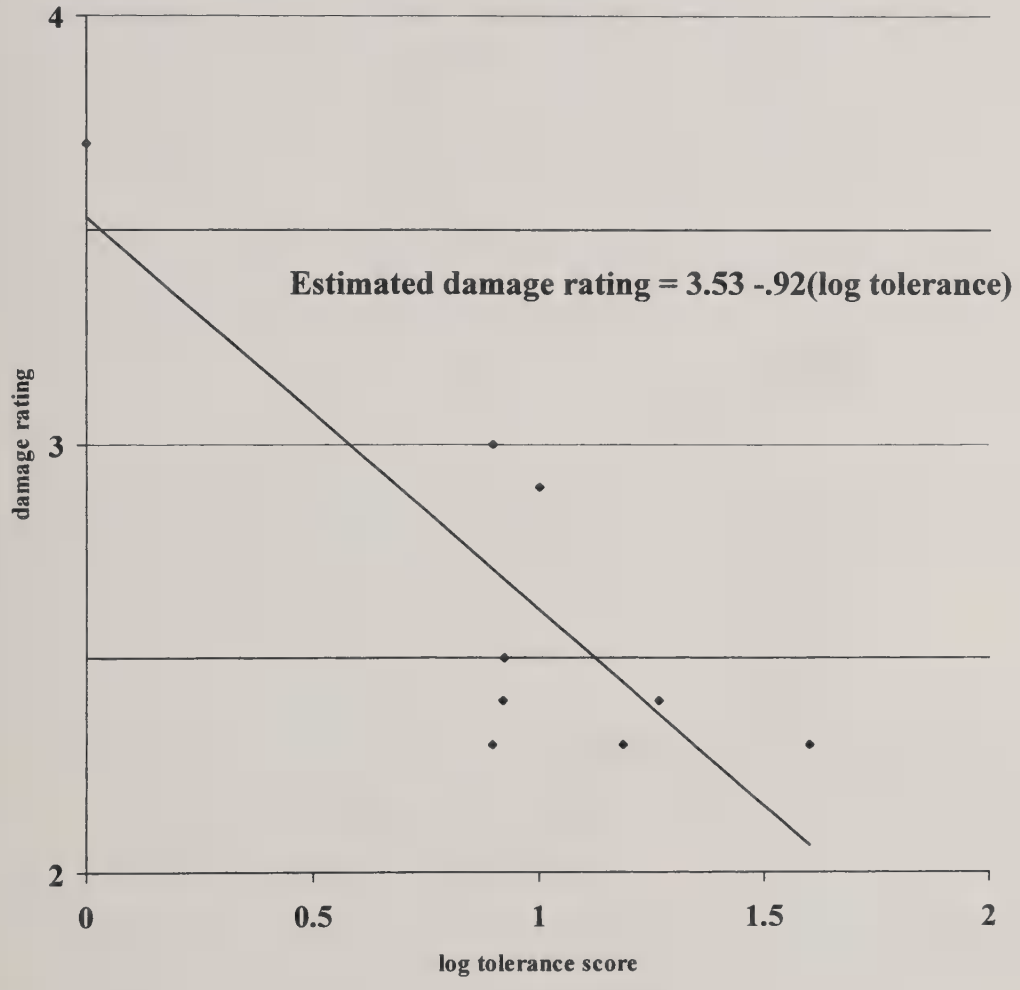
Figure 2. Damage Rating in Sunflower Hybrids of Known Resistance Artificially Infested With 2nd Instars and Adult Sunflower Midge.



Damage ratings according to Bracken 1991, 0 - no damage, 5 - no seed production.

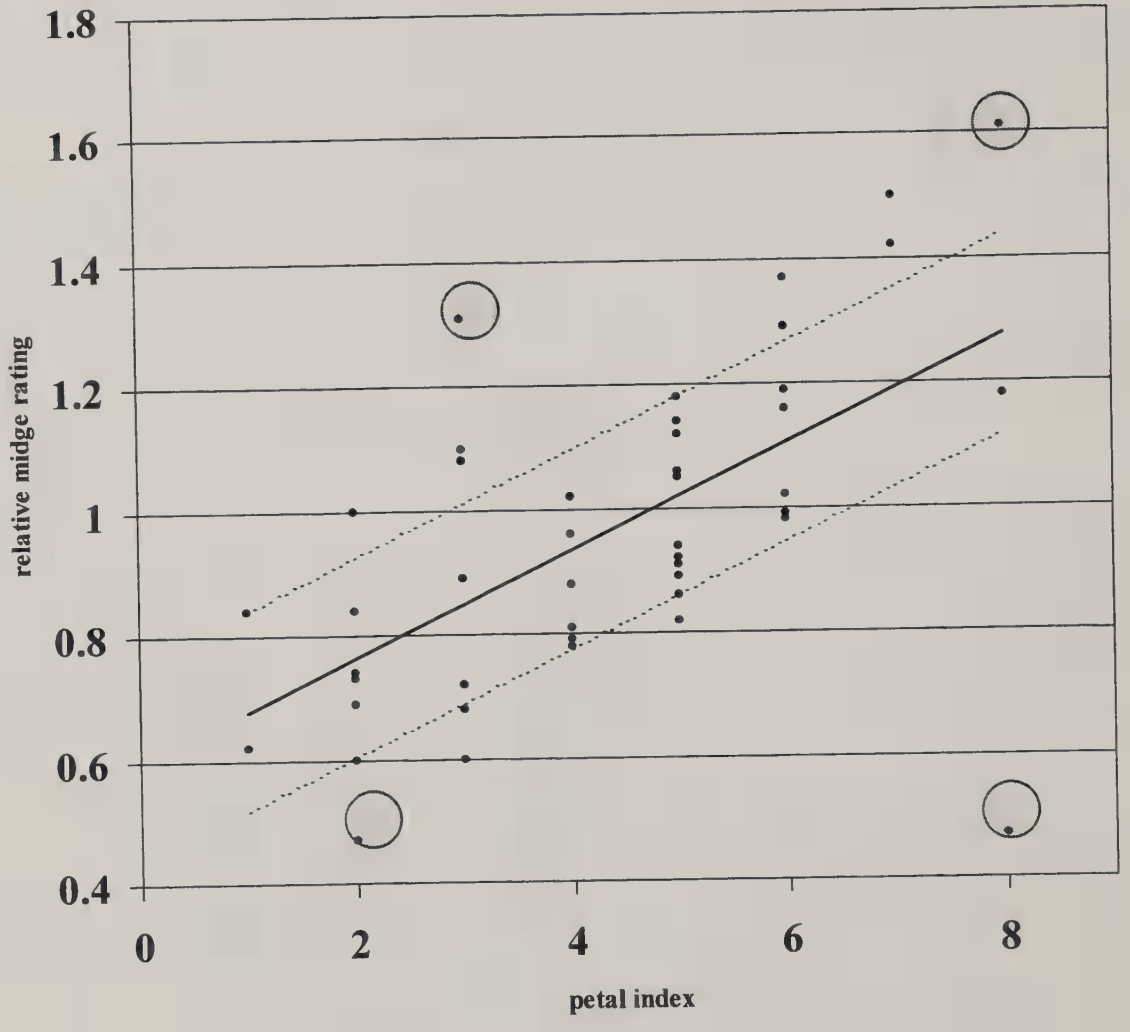
From Anderson and Brewer 1991. Artificial infestation with approximately 200 2nd instars per bud or 26-34 female and 5-23 male adult midge per bud in single plant cages.

Figure 3. Simulating Sunflower Midge Damage by Treating With 2,4-D. Relationship Between Log Tolerance Scores and Damage Ratings in Sunflower Hybrids.



Tolerance scores from Anderson and Brewer 1991.

Figure 4. Comparison of Two Common Scores for Reporting Midge Damage in Sunflower Hybrids.



Data points and predicted (line) +/- standard deviation (dashed lines).

Circled data points are outliers.

Preliminary Work on Making Laboratory Diets for Determining Resistance to Sunflower Moth Using Lyophilized Sunflower Heads

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Using previously established field evaluation techniques, we identified 4 cultivated and 4 wild-type sunflower accessions with resistance and 4 of each type with susceptibility to sunflower moth, *Homoeosoma electellum* (Table 1). Heads were field collected during summer, 1999 when the plants were at the R5.2 stage. The cultivated heads were hand-trimmed to include the corolla tubes with pollen and the top section of immature seed; the wild heads were left intact. The heads were freeze dried (lyophilized), milled to a fine powder, and placed into a -20° C freezer until needed.

The milled sunflower head material was incorporated into standard wheat germ diet used for laboratory rearing of sunflower moth. If the basis for field resistance is antibiotic in nature (affect the insects growth and development), then we hoped to show this using this diet technique.

Materials and Methods

Six different sets of diets were prepared (labeled set 1..... set 6) (Table 2). Data reported are 12 day larval weights as a percent of the standard. In addition, we will obtain larval development times, pupal weights, and pupal development times.

Set 1: Minimal diet

Lyophilized plant material was added, in place of nutrient ingredients. Sorbic acid and methyl paraben were added to help prevent development of mold.

Set 2: One quarter standard diet

Lyophilized plant material was combined with 1/4 the ingredients of a standard diet.

Set 3: Minimal diet plus wheat germ

Plant material and wheat germ were the main ingredients. Mold inhibitors were also added.

Set 4: Standard diet without casein

Plant material, and all nutrient ingredients except casein were added to the test diet.

Set 5: One quarter standard diet with water extract

15 grams of plant material were extracted with water. The extract (about 35 ml) was added to diet made with 1/4 of the standard ingredients.

Set 6: One quarter standard diet with water extract residue added.

This diet incorporated the residue from the water extract, in a diet with 1/4 of the standard ingredients.

Results

Table 3 presents the 12 day larval weights and their percent of the standard diet for all 6 sets of diets prepared. None of the diets prepared had a clear separation between the field resistant and the field susceptible accessions.

The results of Set 2 were interesting. It appears that the addition of plant material to the diet actually enhanced larval development.

So where does this research stand?

1. None of the diets tested separated the field resistant from the susceptible accessions.

2. Data are being collected for other insect growth parameters, e. g., pupal weights, larval development time. It is possible that other resistance mechanisms may be exhibited at later growth stages of the insect, e.g., lack of adult emergence

3. If the basis for the field resistance is antixenosis (nonpreference) or tolerance, the laboratory diet technique will not be a useful tool for determining resistance. Laboratory diets are effective when the resistance mechanism is antibiosis.

4. We will continue testing diet ingredient combinations in order to determine if a resistance response can be identified in the laboratory.

5. Currently we are adding whole lyophilized wild sunflower heads to the laboratory diets. In order to correctly attribute a resistance mechanism, we may have to separate the petals, flower parts, etc. and test these components individually.

Table 1. The accessions tested

Accessions Tested	Sunflower type and field resistance [a]
Ames 7576	C/R
PI 599765	C/R
PI 369357	C/R
PI 253774	C/R
Ames 7573	C/S
PI 599769	C/S
Ames 3363	C/S
Ames 4302	C/S
PI 592358	W/R
PI 586932	W/R
PI 586910	W/R
PI 586912	W/R
PI 531056	W/S
PI 597922	W/S
PI 413175	W/S
PI 549165	W/S

[a] C = cultivated type, W = wild-type, R = field resistant, S = field susceptible

Table 2. Diet ingredients for each of the six sets evaluated

Diet Ingredient[a]	Standard	Set 1	Set 2	Set 3	Set 4	Set 5	Set 6
Agar	7.0	7.0	7.0	7.0	7.0	8.0	7.0
Plant Material	0.0	25.0	15.0	15.0	15.0	15.0 [b]	15.0 [c]
Wheat germ	10.5	0.0	2.6	10.0	10.5	2.6	2.6
Casein	12.2	0.0	3.0	0.0	0.0	3.0	3.0
Salt mix W	3.5	0.0	0.9	0.0	3.5	0.9	0.9
Vitamins	5.2	0.0	1.3	0.0	5.2	1.3	1.3
Sucrose	12.2	0.0	3.0	0.0	12.2	3.0	3.0
Sorbic acid	2.0	0.35	0.5	0.35	2.0	0.5	0.5
Methyl paraben	2.0	0.35	0.5	0.35	2.0	0.5	0.5

[a] Amounts are given in grams; 300 ml water was also used in each diet
[b] Ca. 35 ml water extract from 15.0 g plant material
[c] Residue after water extract taken for set 5

Table 3. Mean twelve day larval weights and their relationship as percent of the standard diet.

Accessions tested	Set 1 Larval weights	Set 1 % of Standard	Set 2 Larval weights	Set 2 % of Standard	Set 3 Larval weights	Set 3 % of Standard	Set 4 Larval weights	Set 4 % of Standard	Set 5 Larval weights	Set 5 % of Standard	Set 6 Larval weights	Set 6 % of Standard
PI 413175 W/S	2.13	30.2	36.40	181.1	15.22	37.0	8.12	21.7	11.50	25.3	13.44	42.0
PI 592358 W/R	4.72	66.9	35.00	174.1	20.44	49.7	7.68	20.6	6.04	13.3	7.82	24.4
PI 586932 W/R	1.50	21.2	27.20	135.3	17.15	41.7	8.44	22.6	13.23	29.1	28.14	87.9
PI 586910 W/R	3.22	45.6	32.00	159.2	17.84	43.4	9.03	24.2	16.49	36.2	13.59	42.4
PI 586912 W/R	2.21	31.3	32.30	160.7	24.43	59.4	10.30	27.6	5.92	13.0	17.50	54.7
PI 531056 W/S	2.85	40.4	33.50	166.7	18.66	45.4	6.53	17.5	12.40	27.2	11.88	37.1
PI 597922 W/S	3.64	51.6	33.60	167.2	18.14	44.1	9.07	24.3	10.10	22.2	20.96	65.5
PI 549165 W/S	2.24	31.7	33.80	168.2	24.90	60.5	9.87	26.4	15.89	34.9	19.62	61.3
PI 253774 C/R	3.34	47.3	36.90	183.6	17.86	43.4	7.78	20.8	11.06	24.3	25.47	79.5
A -3363 C/S	2.60	36.8	35.70	177.6	5.85	14.2	6.90	18.4	11.70	25.7	25.41	79.4
A - 7573 C/S	2.81	39.8	35.00	174.1	21.21	51.6	9.31	24.9	23.10	50.7	17.59	54.9
A - 7576 C/R	3.40	48.2	28.10	139.8	15.94	38.7	7.80	20.9	13.92	30.6	26.65	83.2
PI 369357 C/R	2.02	28.6	28.00	139.3	11.26	27.4	4.27	11.4	7.34	16.1	17.58	54.9
A - 4302 C/S	1.22	17.3	28.20	140.3	12.15	29.5	6.38	17.1	15.78	34.7	13.47	42.1
PI 599765 C/R	3.06	43.3	33.80	168.2	15.30	37.2	8.44	22.6	19.98	43.9	18.14	56.7
PI 599769 C/S	3.44	48.7	29.20	145.3	18.29	44.5	6.02	16.1	11.17	24.5	18.94	59.2
Standard diet	7.06	100.0	20.10	100.0	41.13	100.0	37.38	100.0	45.52	100.0	32.02	100.0

W/R Wild type; field resistant
W/S Wild type; field susceptible
C/R Cultivated type; field resistant
C/S Cultivated type; field susceptible

Integration of honeybee pollination with sunflower insect pest management

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Both honey production and sunflower, *Helianthus annuus* L., are important agricultural crops in North Dakota and in the region. North Dakota leads the nation in sunflower production and in 1998 was second in national honey production with 13% of the crop (North Dakota Agricultural Statistics Service 2000).

Because of their numbers and ease of handling, honeybees, *Apis mellifera* L., are the most important pollinators of sunflower (Sosa 1988, Cirun 1960). In North Dakota sunflower is a major forage crop for honey producers. However, the benefit to sunflower from honeybee activity is less apparent. While sunflower hybrids have been bred for self-compatibility and have a reduced need for cross-pollination, they vary in their levels of self-compatibility (Free 1970, Furgula et al. 1979). Fick (1979) reported that sunflower hybrids which are as high as 80 to 90% self-compatible can benefit from cross pollination.

There is a large body of literature showing that honeybee pollination (Free 1970, Langridge and Goodman 1974, Furgala et al. 1979, Parker 1981, Krause and Wilson 1981) increased sunflower seed production and oil content (Furgula et al. 1979, Langridge and Goodman 1981, Freund and Furgula 1982, Mahmood and Furgula 1983) in the varieties grown in the 1970s and early 1980s. However, the impact of honeybee cross-pollination on current hybrids is not known.

While honeybees can increase sunflower yield and oil content, management of pest insects in sunflower often occurs when honeybees are foraging sunflower and can harm bees. The banded sunflower moth, *Cochylis hospes*, oviposits on sunflower buds and later instars feed on the developing seeds. Seed feeding occurs during anthesis when honeybees are present and if insecticides are used to control the banded sunflower moth, they can kill honeybees as well. Thus, the insecticides used to control the banded sunflower moth may inadvertently result in lower yields because of reduced cross-pollination by honeybees.

Honeybees also interact with their host plants as vectors of microbial organisms. An association between honeybees and fireblight disease of apple (Pierstorff and Lamb 1934) led to the idea of testing honeybees as vectors of *Pseduomonas* and non-pathogenic strains of *Erwinia* as antagonists for fireblight (Thomson et. al. 1992, Johnson et al. 1993a, 1993b). In another system, the antagonist *Gliocladium roseum* was applied to strawberry to suppress gray mold (Peng et al. 1992, Yu and Sutton 1997). The technique of using honeybees to vector biocontrol agents was expanded to insects in a 1994 paper by Gross et al. describing trials using honeybees to vector *Heliothis* nuclear polyhedrosis virus to manage *Helicoverpa zea.*

This study had two components. First was to determine the relative attractiveness of sunflower

hybrids to honeybees and to determine the effect of honeybee cross-pollination on seed traits. The second was to test the potential of honeybees to vector of pest control materials to sunflower.

Materials and Methods

Pollination study. Four bee hives were placed at one end of a 225 x 37 m plot of 50 hybrids. When plants were at stage 5.2 the number of bees per 25 plants of each hybrid and block (5) were counted. Before anthesis, 20 plants of similar development per hybrid and block were marked, 10 were covered with pollination bags and the other 10 plants were left open. At plant maturity, the marked plants were harvested and seed set, seed weight, and seed oil percent determined.

Vector study. This study was done to determine if honeybees can be contaminated with *Bacillus thuringiensis* and can vector *B. thuringiensis* to sunflower heads. This study also compared the efficacy of bee vectored *B. thuringiensis* to other application techniques for control of the banded sunflower moth.

Honeybee hives were modified to accept a *B. thuringiensis* applicator insert (Fig. 1) between the hive bottom board and the first frame. Bees exiting the hive were forced to walk through a tray in the applicator containing a dust formulation of *B. thuringiensis* (Dipel 2X, Abbot Laboratories). Bees reentered the hive through a separate entrance and did not pass through the dust tray.

Honeybees were captured as they exited control hives and hives with applicator inserts, and from sunflower heads 20 minutes after the applicators were filled with *B. thuringiensis*. The bees were double rinsed in distilled water and the rinse was used to contaminate banded sunflower moth diet in 20 ml diet cups. Controls were diet treated with distilled water. A single neonate larva was placed on the diet in each cup. A similar test was done using wash water from sunflower heads.

At plant maturity, sunflower heads exposed to honeybees vectoring *B. thuringiensis* and bee free heads were collected and brought to the laboratory. One group of bee free heads were manually sprayed with *B. thuringiensis* at labeled rates. Another set were uncontaminated with *B. thuringiensis*.

Results

Pollination study. Honeybees exhibited a preference among the sunflower hybrids tested (Fig. 2).The average number of bees per 25 plants was 3.6 with a range of 2 to 7.5. The percent gain in seed set in hybrids exposed to honey bee pollination was 7% compared to plants with bees excluded (Fig. 3). Gains were also seen in bee exposed versus bee-free hybrids in seed weight (7 g/1000 seeds, Fig. 4) and oil percentage (3%, Fig 5).

Vector study. Both honeybees and sunflower capitula exposed to bees were contaminated with *B. thuringiensis* when applicator dust trays were filled with *B. thuringiensis*. Using artificial diet treated with washings from bees or capitula as a source of *B. thuringiensis* contaminant, bioassays of neonate banded sunflower moth larvae were significant. Bees exiting experimental hives and bees collected from sunflower heads caused a four-fold or greater mortality than did

controls in bioassay. Similarly, bee contaminated sunflower capitula caused greater mortality than did uncontaminated capitula or controls and greater mortality than a spray application of *B. thuringiensis* (Table 1).

Table 1. Mean percent mortality of banded sunflower moth larvae after three days on diet treated with wash water from *Bacillus thuringiensis* contaminated and uncontaminated honeybees or capitula

Source of wash water	Mean % mortality (± SE)	
	1996	1997
Contaminated bees exiting hives	98.7 ± 1.1 a	90.0 ± 1.1 a
Contaminated bees captured on capitula	80.8 ± 3.6 b	66.8 ± 1.4 b
Uncontaminated bees exiting hives	18.3 ± 2.7 c	9.4 ± 0.6 c
Control (water)	15.0 ± 1.5 c	7.2 ± 0.5 c
Capitula contaminated by bees	86.7 ± 3.3 a	87.5 ± 1.5 a
Capitula sprayed with *B. thuringiensis*	58.3 ± 5.3 b	68.2 ± 1.3 b
Capitula unsprayed	8.3 ± 1.7 c	10.1 ± 0.7 c
Control (water)	8.3 ± 2.4 c	8.5 ± 0.6 c

Means followed by the same letter in a column are not significantly different ($P \leq 0.05$ %, LSD). N in 1996 was 12, n in 1997 was 24.

Bee-vectored and spray applications of *B. thuringiensis* were compared for prevention of banded sunflower moth damaged seed in field trials. Percent damaged seed on plants exposed to bee-vectors was no more or less than that of spray-treated plants and about half that of controls. The bee-vector treatment also boosted seed set and seed yield (Table 2).

Discussion

Although studies done in the seventies and early eighties showed that honeybee activity could boost yield in sunflower, the impact of honeybee pollination on current hybrids was unknown. Honeybees exhibited a preference among the hybrids tested and were able to increase yield and oil percent despite hybrid self-compatibility. In some cases, gains in yield and oil percentage from honeybee pollination may be sufficient to offset losses from head infesting insects, especially if the cost of an insecticide application is not incurred. This makes honeybee

pollination of sunflower an attractive and novel approach to maximizing economic potential in sunflower production. And because honeybees were able to vector *B. thuringiensis* to sunflower heads for control of banded sunflower moth, growers would not necessarily need to accept damage from pest insects. Instead, bees could be part of an integrated pest management system by delivering pest control materials to sunflower heads and at the same time benefit sunflower by cross-pollinating the flowers.

Table 2. Efficacy of *Bacillus thuringiensis* application methods on mean percentage of damaged seeds, seed set, and seed yield under field conditions, Prosper, ND

	Mean (± SE)			
Method	n	1996	n	1997
	Damaged seeds (%)			
Bee vectored	507	12.1 ± 0.2 b	250	12.2 ± 0.4 c
Sprayed	520	12.5 ± 0.2 b	258	13.2 ± 0.4 b
Control	526	21.1 ± 0.2 a	261	22.3 ± 0.4 a
	Seed set (%)			
Bee vectored	507	78.5 ± 0.2 a	250	78.2 ± 0.3 a
Sprayed	520	74.4 ± 0.2 b	258	74.5 ± 0.3 b
Control	526	74.5 ± 0.2 b	261	74.6 ± 0.3 b
	Seed yield (g / plant)			
Bee vectored	507	61.4 ± 0.9 a	250	60.0 ± 1.3 a
Sprayed	520	58.3 ± 0.9 b	258	57.4 ± 1.2 a
Control	526	51.7 ± 0.9 c	261	51.3 ± 1.3 b

Means followed by the same common in a column letter are not significantly different ($P \leq 0.05$ %, LSD or multiple *t* -tests).

The benefit of honey bee pollination to sunflower growers may be underestimated. Besides their potential use for pest control, there was an increase in seed yield of 8 or more grams per plant in bee-visited plants compared to control plants. For sunflower at selling $ 0.26 /kg (.11/lb) and planted at a rate of 44,460 plants/ha (18,000/acre) and under our test conditions, sunflower exposed to bees carrying *B. thuringiensis* would be valued at $714/ha ($289/acre); sunflower sprayed with *B. thuringiensis* would be worth $677/ha ($274/acre), and sunflower not treated would be worth $603/ha ($244/acre), compared to no treatment. The gain from spraying with *B.*

thuringiensis would be $74/ha ($30/acre) and from using honey bees to vector *B. thuringiensis* would be $111/ha ($45/acre) compared to no treatment. The value of honey bees to sunflower production can be significant. Sunflower growers can increase seed yield, crop value, and perhaps seed oil content by using honey bees to pollinate their oilseed sunflower fields and to vector *B. thuringiensis* for control of banded sunflower moth larvae.

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Figure 1. *Bacillus thuringiensis* applicator inserted into a standard bee hive.

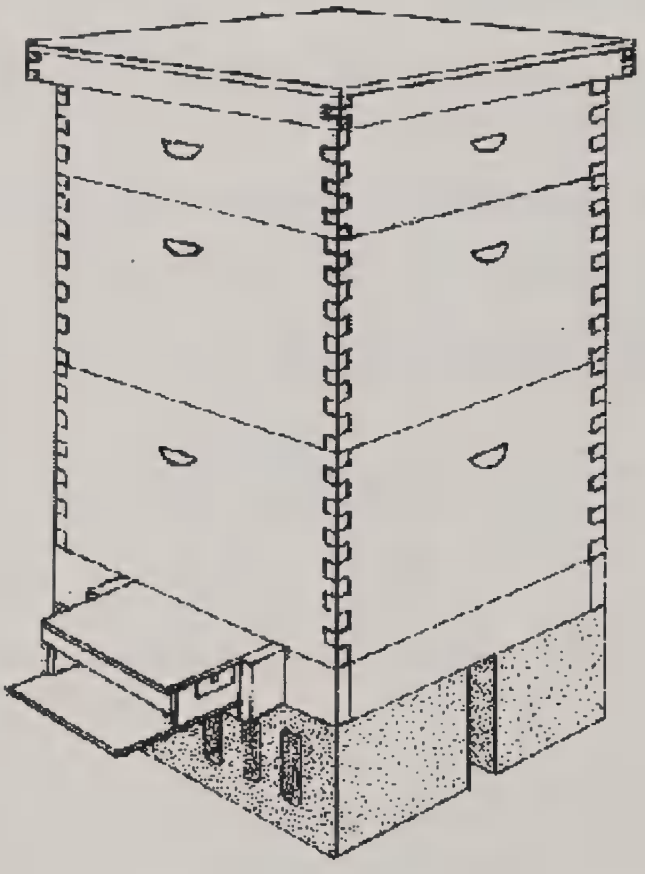


Figure 2. Honeybee preference for a representative sample from 44 sunflower hybrids

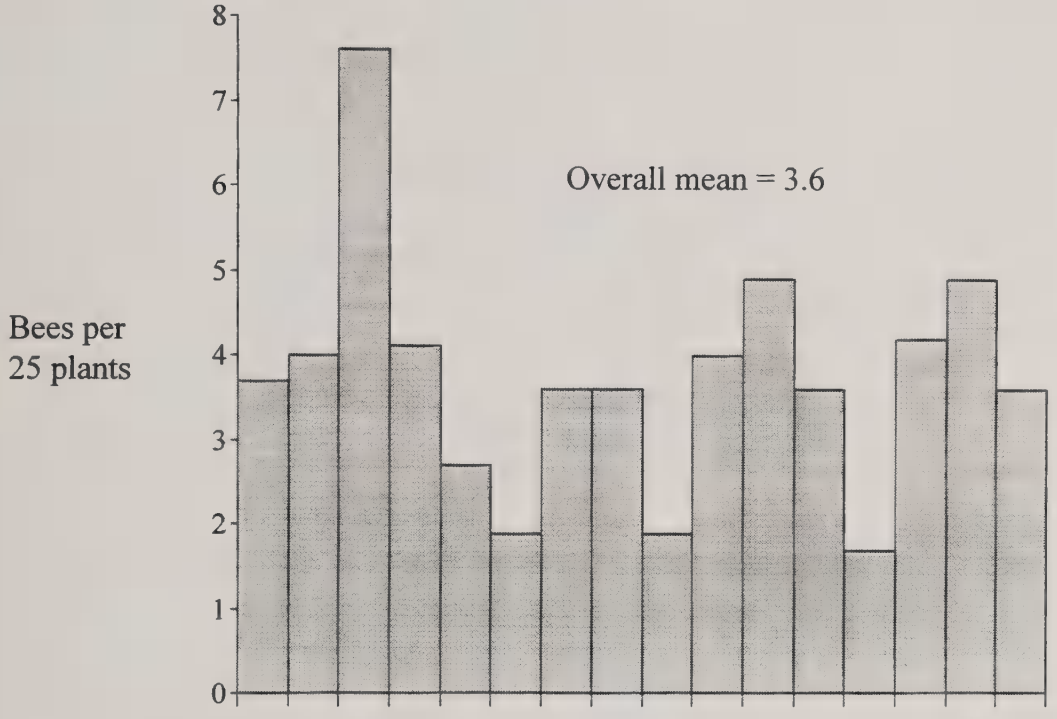


Figure 3. Percent gain in seed set in representative sunflower hybrids relative to plants of each hybrid without bees.

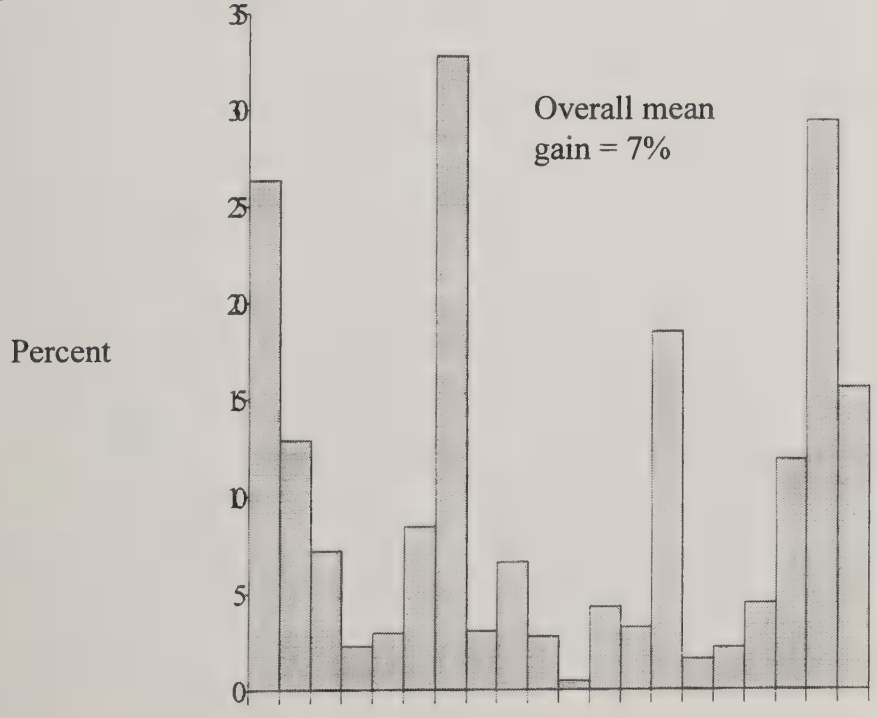


Figure 4. Mean gain in1000 seed weight in representative sunflower hybrids relative to plants of each hybrid without bees.

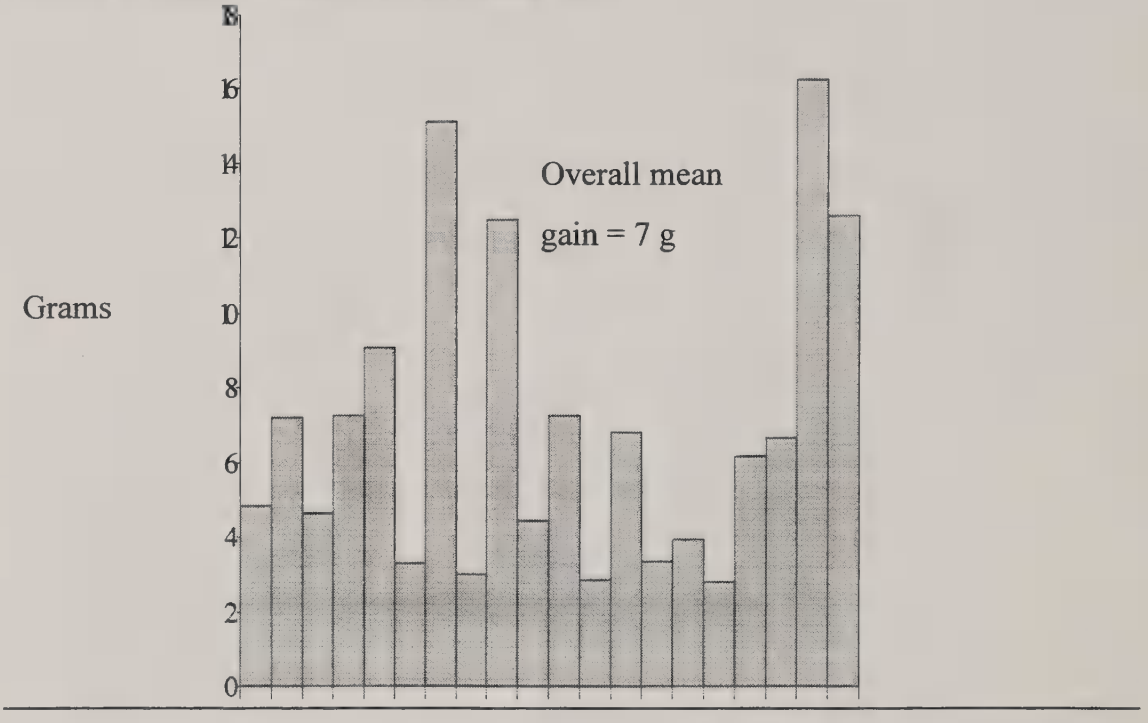
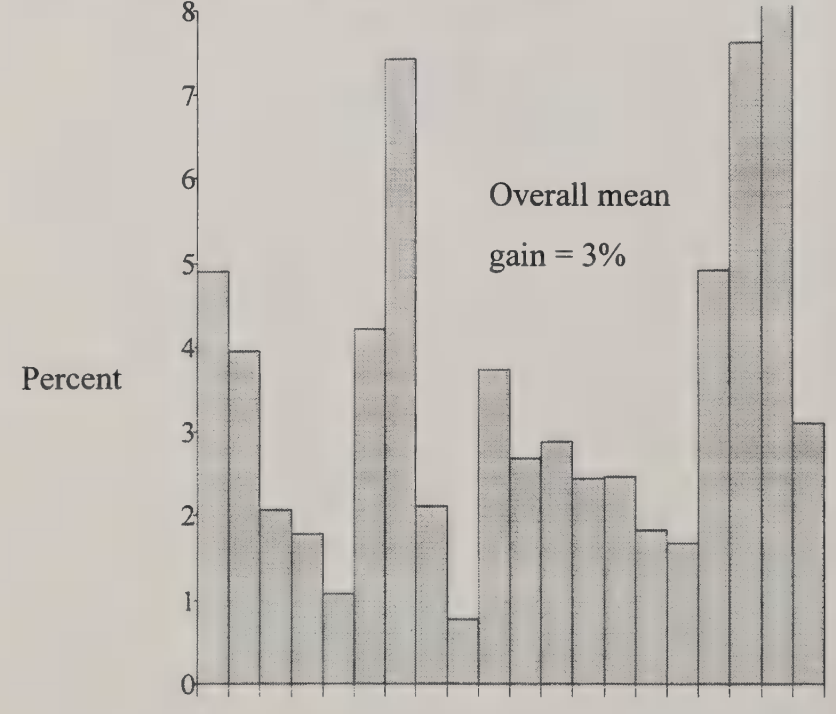


Figure 5. Mean gain in percent oil content in representative sunflower hybrids relative to plants of each hybrid without bees.



Site Specific Pest Management

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Introduction - Agriculture has always adopted new technologies as they have become economical. Larger and more powerful engine and mechanical systems have led to larger, more powerful and more efficient farming equipment. In pest management, the development of resistant varieties, selective pesticides, and transgenic crop varieties have all been readily adopted into commercial agricultural production. Probably the greatest decrease in cost coupled with an accompanying increase in performance has been seen in the computer industry. This increase in available and economic computing power has made it possible to run software applications on desk top systems which previously had been the realm of large mainframes. This in turn has made available several digital tools that can now be economically applied to production agriculture. It is these tools that make Precision (or Site Specific) Agriculture possible.

Digital tools such as Geographic Information Systems (GIS) and Global Positioning Systems (GPS) allow very precise mapping of agricultural areas. These technologies, combined with soil mapping and yield monitors have led to the production methods referred to as "Precision Agriculture" (sometimes also called Site Specific Agriculture). Precision Agriculture began as a method of controlling nutrient input in agriculture. Soil scientists researched the possibility of creating detailed soil maps that would direct variable rate application of fertilizer. The point of Precision Agriculture is applying agrochemicals only *where* necessary. The point of Integrated Pest Management is to apply pesticide only *when* necessary. From these complimentary theories was developed "Site Specific Pest Management", only applying pesticides where *and* when it is necessary. This is not a future technology; many growers, crop consultants and field scouts already use GIS and GPS to create accurate maps of pest populations as references for pest management decisions. This paper presents an overview of some of the tools and applications of Site Specific Pest Management. By targeting pesticides to specific locations rather than broadcast application across the field, less pesticide is utilized. This results not only in a cost savings to the producer, but also has obvious environmental and safety benefits as well.

GIS/GPS – Geographic Information Systems are excellent tools for examining population dynamics. Essentially relational databases, items in the database are related through their physical location, expressed either in real-earth coordinates (e.g. UTM, Latitude/Longitude) or an arbitrary grid (i.e. X,Y coordinates). GIS software combines digital mapping, database functions, and spatial analyses. GIS software assembles, stores, manipulates, and visually displays geographically referenced information. The benefit of displaying population data visually rather than numerically is the ease with which the data can then be interpreted. GIS packages keep different data types separate in layers; for example, different geographical

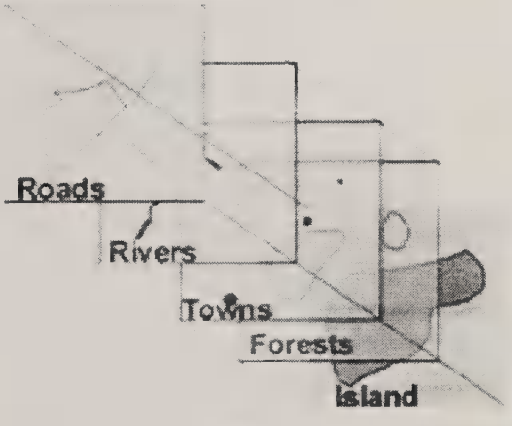

Figure 1. Data 'layers' in a GIS.

features on a map are different items in the database but can be accurately overlaid because the data is spatially related (Fig. 1). In this way, correlations between different types of information can be examined. Another useful feature for pest management of GIS is their ability to use spatial analyses to examine the distribution of populations. Unlike numerical statistics, spatial statistics assume values at one location are influenced by the values at surrounding locations, and in many spatial analyses, the weighting of this influence is generally considered inversely related to the distance. One of the most valuable spatial statistical features of GIS is its ability to interpolate response surface maps which estimate the values in unsampled areas using the value from surrounding sampled points (Fig. 2). This enables GIS to estimate populations within fields from a certain number of sampled points distributed within the field. Obviously the number of sampled points used to create an interpolated estimate has a direct effect on the accuracy of the estimate. Fewer sample sites will result in less accurate estimates, but given sufficient samples, relatively accurate interpolations can be calculated.

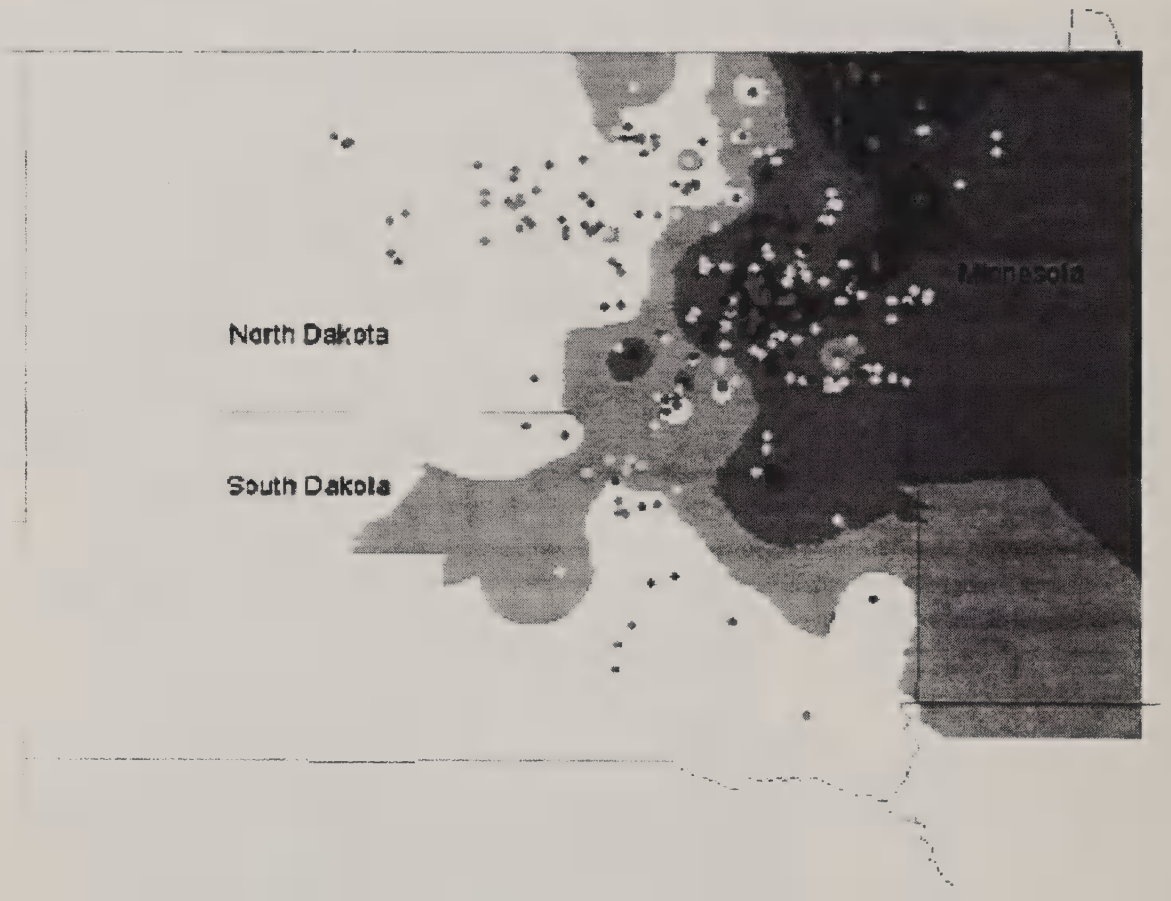

Figure 2. Interpolated surface representing regional sunflower midge, *Contarinia schulzi*, populations as estimated from grower survey returns. Each dot represents a location of a survey return, the darker the dot, the higher the population of sunflower midge was at that location. The gray colored areas are the interpolated estimates of the population of sunflower midge at locations that were not directly sampled.

Global Positioning Systems are satellite-based navigation systems that can provide a user with their location in real-world coordinates. A constellation of satellites orbiting at an altitude

of 11,000 miles transmits signals to receivers on the ground. These signals contain information on the satellite's location relative to the earth and the time the signal was transmitted. By knowing the location of multiple satellites and the time it took for the radio signal to arrive (which can be used to calculate the distance to the satellite), the ground based receivers can use triangulation to calculate their location on the face of the earth. The system was originally developed by the U.S. military for navigation but has been adopted for a number of civilian uses. The precision of the raw satellite signals is usually only within 10-50 m, not fine enough to map within field distributions of pest populations. However, using additional correction signals, known as Differential Correction, GPS can be precise to within centimeters. Such units are used in surveying and are expensive. To map within field pest populations for Site Specific Pest management, GPS units precise to within 1 m should be used.

By using GPS to obtain precise locations of sample points within fields while sampling, the field and the population data associated with those sample points can be mapped. By using the spatial analysis tools in the GIS, an interpolated map estimating the within field distribution and density of pest populations can then be created. This map can be used to evaluate if and where control tactics should be executed.

Population data for these processes can be obtained by a number of different methods. Remote sensing by aerial and satellite photography, trapping, individual field counts and a variety of other methods have all been used to obtain population data for insects, weeds, and plant diseases. The details of these various forms of data collection are lengthy enough top stand as a separate paper, suffice to say that all of these methods have various tradeoffs between time, cost, and accuracy that influence their selection in any given situation.

Application of Site Specific Pest Management - There are two basic ways in which Site Specific Pest Management can be applied: real-time mapping, which involves mapping pest populations just prior to or at the time of treatment, and spatio-temporal mapping, mapping the seasonal distribution of pest populations within fields. Real-time Site Specific management, estimating population densities and distributions at treatment, represents the ultimate goal of Site Specific Pest Management. Although the cost of these technologies has been decreasing, the application of real-time site specific control is likely to remain limited to high value crops in the near future. Spatio-temporal mapping does not actually indicate if a population is over treatment thresholds in any given year but does provide the most probable within-field distribution of pest populations at a given time of the season. It can, therefore, provide insight into where to scout for different pest populations at different times and indicate where to target control efforts. The population dynamics described by these techniques are generally demonstrated by research programs and used by IPM practitioners.

The most successful current research on site specific pest management is in weed control. There are a number of research groups (notably in California and Germany) currently developing systems which use digital imaging apparatus mounted on the front of tractors and linked to onboard computers, to photograph crop canopies as spray equipment is pulled through the field. The digital image of the crop canopy is compared to a database of weed forms and weed leaf shapes are identified. If the presence of weeds is confirmed, the sprayer applies herbicide only to the area in which the weed is present. At the same time, a GIS on the onboard computer constructs a weed map of the field to indicate where there may be problems the following season. Researchers are still developing systems with multiple herbicide applicators and are constantly improving the ability of the system to identify various weed species.

Spatio-temporal mapping is the method investigated by most pest researchers interested in pest population dynamics. This involves using GIS/GPS technology to map the distribution and density of pests within experimental fields over an entire growing season and to investigate the effects of different management tactics on those distributions. Several years

of data are usually required to derive predictive models that are then used for making pest management recommendations. Two examples of this type of research currently being conducted by the author's lab group will be presented.

Within Field Spatio-temporal Distribution of Sunflower Midge, **Contarinia schulzi** – Sunflower midge, *Contarinia schulzi*, has become a major pest of sunflowers in Minnesota and North Dakota. The insect overwinters as cocooned larvae, pupating in the spring with adults of the first generation emerging from last year's sunflower fields by mid-July. Newly emerged adults immigrate into current year's sunflower fields and lay eggs on sunflower buds with diameters greater than 1". Newly hatched larvae initially feed on margins of the head between the bracts and eventually migrate to the base of the developing seeds and to the center of the head as the head develops. As midge larvae become mature, they move to the surface of the head and drop to the ground. A second generation may occur. The populations of sunflower midge vary year to year, apparently causing less damage in drier years. It is difficult to treat larvae with insecticides as it is very difficult to deliver chemistry under the flower's bracts. Consequently, treatment tactics focus on applying insecticides against adults as they fly into fields. The problem with this tactic is that adults emerge over an extended period and live for only a short period (~48 hr). This means that continuous applications of insecticide are necessary to prevent the adults from laying eggs and establishing a population of midge larvae.

Regardless of the population density, because the adults are immigrating into sunflower fields, it was hypothesized that there was a period wherein they first colonize the field's margins, are concentrated there and so vulnerable to a border treatment. If the adult population of sunflower midge can be significantly impacted at the field's margins, it was felt that damage from both the first and second generation of midge larvae could be decreased. To test this hypothesis, commercial sunflower fields were selected whose neighbored fields had significant midge populations the previous year. This process was replicated with different fields over two years. A grid of sample points was established within each field and sunflower midge populations estimated at twice weekly intervals from initial infestation through to the point where the second generation larvae dropped to the ground to overwinter...The

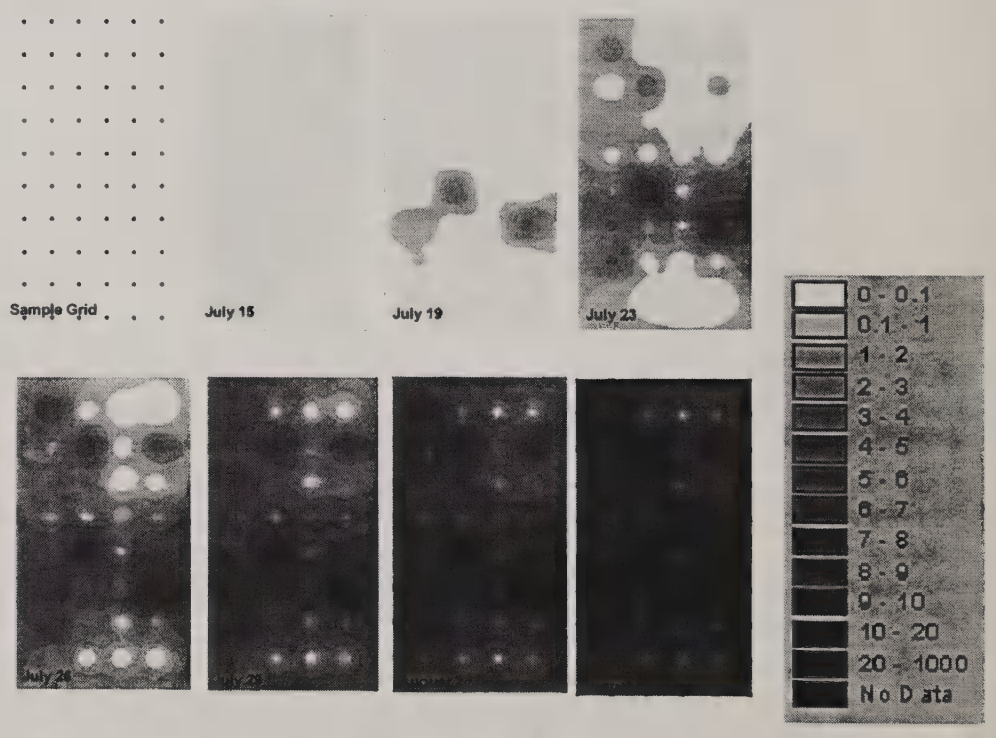

Figure 3. Density and distribution of sunflower midge population in a commercial sunflower field, Shelley, MN. The darker the color, the higher the midge population. Note that populations initially appear to be denser at the margins of the field and eventually become more evenly distributed across the field.

real-earth coordinates of each sample point within the fields was established using a GPS. Heads were clipped from plants close to the sample points within each field and the number of midge on each counted. The resulting data were used to create point maps in the GIS, ArcView. These point maps were then used to create interpolated surface maps which estimated the population of sunflower midge within the field (Fig 3). By repeating this process twice a week, it was also possible to map the rate at which sunflower midge move across a field from the initial colonization point at the field's edge.

Sunflower midge populations apparently increase at the field's margins and over time become more evenly distributed throughout the field (Fig. 3). Data collected at the field edges confirmed that there was a distinct edge effect to the distribution and density of sunflower midge populations. The data used to create the point map upon which these interpolated maps are based were gathered from sample points set ~50m apart within the field and from the field edges. A more refined sample pattern, stratifying sample points at the edges may have resulted in interpolated maps which more accurately reflected the edge effect and subsequent dispersal of sunflower midge into the field. However, for the purposes of demonstration, these data will suffice. Unfortunately, the dispersal rate of sunflower midge into the field appears to be very rapid, leaving a very small window for targeted chemical application against immigrating adults. So, while the distribution of sunflower midge might indicate that site specific management tactics could be applied, the short temporal period wherein the adults are concentrated at the edge may indicate timing will be an important issue.

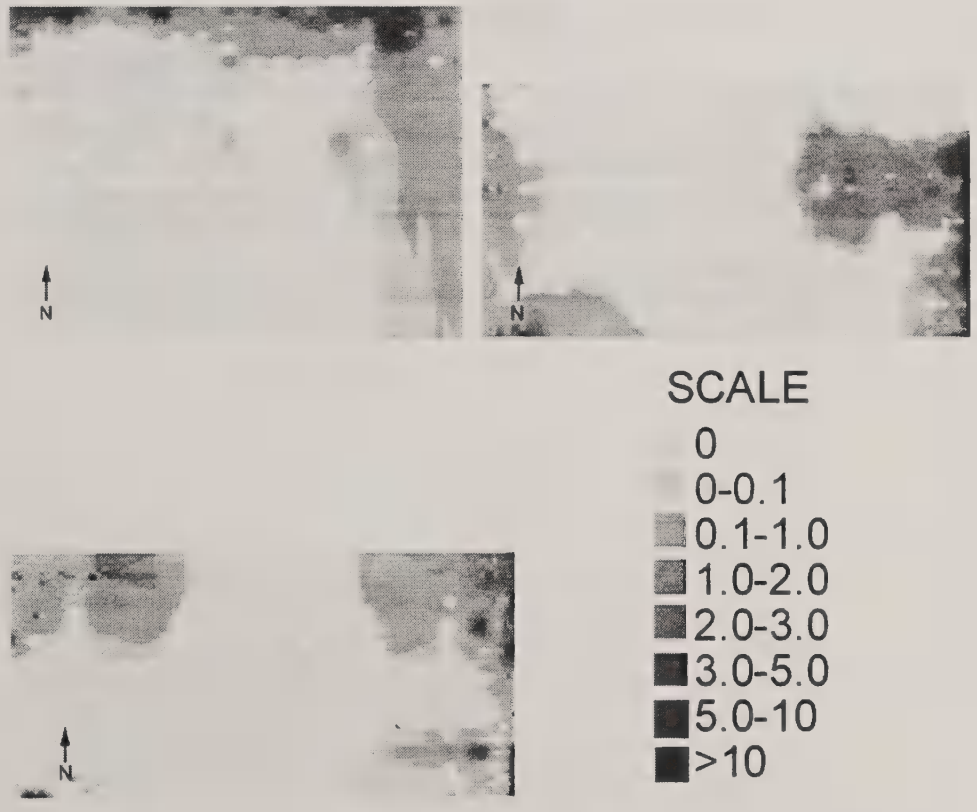

Figure 4. Interpolated surface maps estimating the distribution and density of green peach aphid, *Myzus persicae*, in three commercial seed potato fields in Hoople, N.D. Darker colors represent denser populations of aphids. Note that the distribution and density of aphids is concentrated at the field margins.

Within Field Distribution of Aphid Vectors of Potato Viral Diseases – The Red River Valley of North Dakota and Minnesota has an international reputation for producing high quality seed potatoes. In the past several years, this industry has been threatened with high levels of the viral disease Potato Virus Y (PVY) and Potato Leaf Roll Virus (PLRV), both of which are vectored by aphids. The most important of these vectors is the green peach aphid, *Myzus persicae*, because of it's abundance, resistance to pesticides, and it's high transmission efficiency. Populations of green peach aphids develop in alternate

crops through the summer and immigrate into potato fields in early-mid August. Preliminary data from aphid sampling indicated that these aphids first colonized the perimeters of potato fields and then dispersed into the field. These data further indicated that site specific management tactics, targeting insecticide applications at aphids on the field margins, might prevent the establishment of aphid populations within the field.

To completely describe the within field density and distribution of green peach aphids, three commercial fields, all ~40ha, were sampled with a stratified, sequential sampling plan. The stratification allowed the edge to be sampled more intensively than the middle. The reason for this being that preliminary data indicated the aphids populations would be concentrated at the fields' margins. The sequential plan allowed for adjusting the sampling plan to be more intensive in the middle of the field if aphid populations there were found to be more dense than anticipated. The sampling protocol involved conducting running transects into the field from the margin with samples being taken at 0, 5, 10, 15, 20, 30, 40, 50, 100m and then every 150m into the field. If aphids were found at the extended sampling points (i.e. after 100m into the field) then the subsequent intervals between samples was to be decreased to 10m again. It was not necessary in any field to decrease the sampling interval along the transects. The resulting sample pattern within each field was an uneven grid of sample points. At each point in the grid, the number of aphids/leaf was estimated and the real-earth coordinates recorded with a differentially corrected GPS. These data were used in the GIS ArcView to create point maps representing the aphid populations at each sampled point in each field. ArcView was then used to interpolate response surface maps estimating the population density and distribution of aphids within each field (Fig 4).

Green peach aphid populations were found to be concentrated at the field margins on the sample date. Based on these data, we recommended to the grower that insecticide treatments be quickly targeted at a 20 m border along the field edges. Although our data indicated that the treatment of 20 meters would be sufficient, constraints in the application equipment along with an agressively conservative approach towards aphid management by the grower resulted in a 37 meters wide treatment with methamidophos (Monitor 4F). By targeting treatment to only these areas, the reduction in treatment cost per field was substantial; 67.3% ($867.7), 74.0% ($1,333.9), and 71.4% ($904.7) (in each field of the three fields respectively). It should be noted that we took samples only on one date, the temporal window for this tactic is currently being further refined.

Conclusions – Site Specific Pest Management targets the application of pesticide to the areas within production fields where pest populations exist. Areas in which pest populations do not exceed treatment thresholds do not receive chemical applications. This results in pest control that is comparable to standard methods while decreasing the total amount of pesticide applied in the field. This represents a cost savings to the producer, results in fewer environmental and human safety impacts, and is safer to the applicator. The trick is to accurately describe where within fields pest populations exist and when they are there. In many circumstances, this distribution stays relatively static from year to year; insects entering fields at the margins (e.g. aphids in potato) will continue to do so from year to year. This may not be the case in certain other systems, aphids entering small grain fields fly into the field borne on southerly winds and may establish anywhere within the field. Consequently, describing the spatio-temporal distribution of a pest species within a field may not be enough, real-time mapping may be required for site specific management of some pests. This method is far more costly and may not be economic for some cropping systems. However, although the hardware and software required for this kind of pest management may not currently be affordable for all cropping systems, the costs of computing are decreasing daily and there may soon be a time when real time site specific pest management is possible in all cropping systems.

Sunflower Insect Situation in the Central and Northern Plains, 1999

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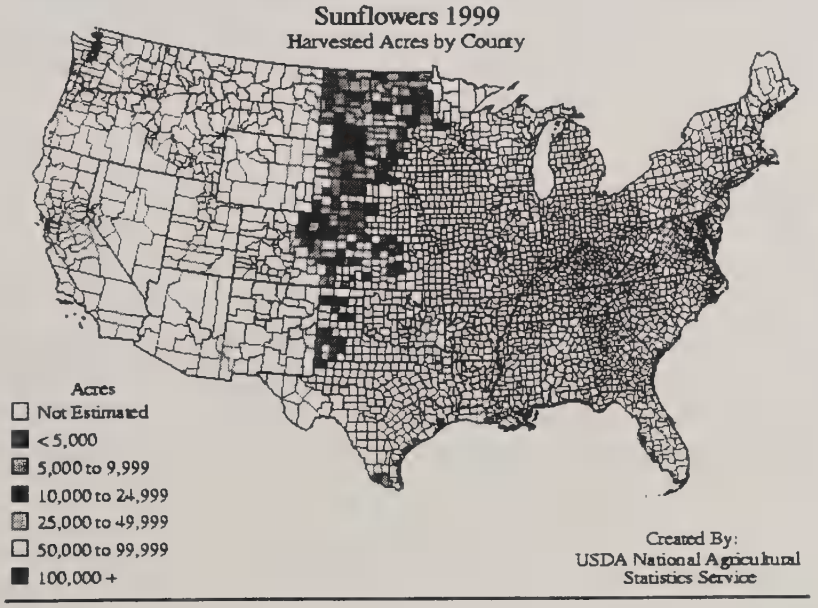
Introduction

National sunflower acreage totaled 3.4 million acres in 1999 (Table 1). Acreage is distributed among seven states with the majority of acres grown in the states of North Dakota and South Dakota. The value of the seed to the farmer was $600 million. When processed, finished products have an estimated value of $4.2 billion nationally.

Table 1. Total sunflower acres grown in the major sunflower producing states, 1999

State	Acres
North Dakota	1,645,000
South Dakota	910,000
Colorado	265,000
Kansas	267,000
Minnesota	120,000
Nebraska	97,000
Texas	67,000



1999 Insect Activity

Insect activity in sunflowers varies throughout the production region. However, insect problems are similar by production area when regions are grouped by north and south. The northern region includes North Dakota, South Dakota, and Minnesota. The southern region includes Colorado, Nebraska, Kansas, and Texas. The 1999 insect situations are summarized by these larger geographic areas.

North Dakota - South Dakota - Minnesota

In the early season, during stand establishment, insects causing concern and prompting some insecticide treatment included black stem weevil, *Apion occidentale*, sunflower beetle, *Zygogramma exclamationis*, and various cutworm species. Populations were not uniformly distributed across this region.

Black Stem Weevil

". . . causing serious stand loss on seedlings."

Mike Catangui, Entomologist
South Dakota State University

Adults of the black stem weevil were abundant in seedling stands of sunflower. Reports from extension agents, crop consultants, and other ag industry indicated field populations were as great as three to four adults per seedling in areas of North and South Dakota. Typical injury appeared as small holes throughout the cotyledon and expanding true leaves. In South Dakota, some stand loss was attributed to the weevil's feeding. In most cases, seedling sunflowers outgrew the early damage without any apparent effects. The weevil does lay eggs in the stem which results in small grubs that tunnel the stalk. Past experience has determined that the larval feeding injury has not resulted in significant yield loss or stalk breakage later in the season. However, since the *Phoma macdonaldii* Boerma organism has been isolated from the adults of black stem weevil, it is highly suspect in vectoring Phoma black stem disease in sunflower fields as demonstrated under greenhouse conditions.

Sunflower Beetle

Sunflower beetle had been the most dominant insect pest problem during the 1990's. In 1999, populations were generally lower throughout the region with only a limited number of acres being treated to manage this insect. In South Dakota, sunflower beetle was not even mentioned as a minor problem. In North Dakota, insecticide treatments to manage beetles were made to acres in the north central counties. In eastern North Dakota and Minnesota, populations great enough to justify insecticide treatment were scattered widely.

Cutworm Species

There were three species of cutworms affecting stand establishment from May until the end of June. Early cutworm problems were Dingy cutworm, *Feltia jaculifera*, and Redbacked cutworm, *Euxoa ochrogaster*. The dingy cutworm overwinters as a partially grown larvae which threatened early seeded fields. The redbacked cutworm overwinters as an egg, causing stand loss in early June. Most of the problems were reported in the eastern areas of the production region, primarily east central North Dakota.

The third species of cutworm which caused problems was the Variegated cutworm, *Peridroma saucia*. This species migrates into the region during the growing season. Large flights migrated into the Red River Valley area of North Dakota and Minnesota in late May. Numerous fields of sunflower, sugarbeet, and alfalfa were infested by this cutworm as a result, prompting insecticide treatments in late June.

By mid-season, insect pests of concern included the sunflower midge, *Contarinia schulzi*, the red seed weevil, *Smicronyx fulvus*, Banded sunflower moth, *Cochylis hospes*, Sunflower moth, *Homoeosoma electellum*, and Thistle caterpillar, *Vanessa cardui*.

Sunflower Midge

The sunflower midge affected very few acres throughout the region. In South Dakota, delayed planting is attributed to reducing the incidence in the northeastern counties where populations had been increasing. In North Dakota and Minnesota, infestations were limited to only small areas.

Red Seed Weevil

Populations were greater in 1999 throughout the region and were ranked as the number one insect pest concern in South Dakota. In North Dakota and Minnesota, confection flowers were generally treated for seed weevil management. The majority of oilseed sunflowers in this same area were not treated. Populations that were treated with insecticide were close to the treatment threshold of 7 to 9 weevils per flower head. South Dakota reported some concern with effective insecticide control. Problems were attributed to aerial applications where less than 2 gallons of water per acre were being used.

Sunflower Moth

The sunflower moth migrates into the region. Occasionally, migrating populations are great enough to result in economic losses. Moths were detected in the region in mid July. Early seeded sunflowers in the western area of the region. Larvae were detected too late to control them effectively in those areas. Populations were generally light and failed to cause widespread losses. In the eastern area of the region, larvae could be detected in flower heads well below economic levels.

Banded sunflower moth

Generally, populations were sub-economic. As in previous years, larvae could be found in maturing flower heads, averaging 3 to 4 per head.

Thistle caterpillar

The adult butterfly of the thistle caterpillar migrates into the region. The storm fronts which aided the migration of other insects also facilitated the movement and early arrival of this insect in north central South Dakota and south central North Dakota. Though no treatments were reported for this caterpillar, some field scouting reports indicated that they were easy to find feeding on the foliage of sunflower plants.

Other insects receiving some mention included wireworm and grasshopper. Wireworm problems have been reported to be increasing in areas where no-till acreage is common and some breakout of CRP acreage occurred. The grasshopper populations have generally been low. Insecticide treatments made to manage grasshoppers have largely been border treatments to manage small grasshoppers in hatching sites or adults migrating to field margins in late summer.

Colorado - Nebraska - Kansas - Texas

The number of different insects mentioned as causing concern from this production region were fewer. The primary insect pests were sunflower moth, red seed weevil, and spotted stem weevil, *Cylindrocopturus adspersus*. Of minor concern were wireworms and cutworms.

Sunflower Moth

"Control problems with head moth . . . due to poor timing of the treatments."

Gary Hein, Entomologist
University of Nebraska

The sunflower moth was still ranked as the number one insect pest concern in this region. It was the insect most frequently targeted for control with insecticides. Confection sunflowers were treated more frequently than oilseed. This insect overwinters in the region and is an annual pest. Some control difficulties were reported from the region. Entomologists attributed the control difficulties to poor timing of applications. Farmers were initiating treatments too late, permitting survival of earlier hatching larvae.

Red Seed Weevil

The red seed weevil was generally ranked as the second most important insect pest in the region. However, it was regarded as a minor problem when compared to sunflower moth concerns. As with sunflower moth, greatest concern and most insecticide treatments were

applied to confection sunflowers.

Spotted Stem Weevil

The spotted stem weevil caused losses due to stalk breakage. The larvae of this stem weevil overwinters in the base of the sunflower stalk, weakening it when larval numbers are great enough. Entomologists from this region reported increasing concern with this insect pest. Greatest concern was associated with conditions where sunflower had been grown for several seasons.

All states reported some level of damage from wireworms and cutworms. Regionally, these problems were considered minor. Phil Sloderbeck, entomologist with the University of Kansas, reported concerns with a cerambycid beetle (long horned beetle) whose larvae girdle the sunflower stalk at its base late in the season.

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