SCIENTIFIC NOTE

Monitoring of western corn rootworm, *Diabrotica virgifera virgifera* (Coleoptera: Chrysomelidae) beetles with pheromone-baited sticky cards in southern British Columbia

W. G. VAN HERK[1],
T. HUEPPELSHEUSER[2],
AND T. MITCHELL[1]

The western corn rootworm, *Diabrotica virgifera virgifera* LeConte (Coleoptera: Chrysomelidae), is one of the most important insect pests of corn, *Zea mays* Linnaeus (Poales), in North America and Europe, with global economic losses exceeding $US 1 billion and expected to increase (Gray *et al*. 2009; Lemic *et al*. 2016). Monitoring for western corn rootworm in North America is typically done with unbaited Pherocon AM yellow sticky cards (Gray *et al*. 2009). This trap is the basis of several economic thresholds, e.g. six, two, and five beetles per trap per day during the peak swarming season when placed in conventional corn, *Bt*-corn (corn genetically modified to express *Bacillus thuringiensis* proteins), or soybean fields grown in rotation with corn, respectively. These thresholds correlate with economic damage by the rootworm larvae to corn planted in that field the following year (Hein and Tollefson 1985; Gerber *et al*. 2005; Dunbar and Gassmann 2013; Calles-Torrez *et al*. 2020).

Western corn rootworm is native to the Americas. It was first discovered in Europe in 1992, which led to the development of new trap designs and new monitoring methods (Bažok *et al*. 2021). These new monitoring methods employ a sex pheromone for attracting male beetles, a floral compound for attracting both sexes, or both the sex pheromone and the floral compound (Tóth *et al*. 2003; Toshova *et al*. 2017). Pheromone baits consist of (2R,8R) 8-methyl-2-decyl propanoate, the actual pheromone, and related enantiomers (Guss *et al*. 1982, 1984; Tóth *et al*. 2003). Flower-derived attractants used for monitoring are 4-methoxy-cinnamaldehyde and indole (Tóth *et al*. 2003), although other attractants have been identified (Metcalf 1994; Metcalf *et al*. 1998). To date, few reports have compared the relative attractiveness of unbaited Pherocon AM yellow sticky cards to traps baited with an attractant (Edwards *et al*. 1998; Lemic *et al*. 2016).

[1]Agassiz Research and Development Centre, Agriculture and Agri-Food Canada, P.O Box 1000, Agassiz, BC V0M 1A0
[2]British Columbia Ministry of Agriculture and Food, 1767 Angus Campbell Rd, Abbotsford, BC V3G 2M3

Western corn rootworm was first detected in British Columbia (BC) in 2016, when corn growers reported extensive plant damage in the Fraser Valley, southeast of Abbotsford. To date (summer of 2022), the pest has not been found in other corn-growing areas in BC, such as the northern Okanagan valley, Creston, or Vancouver Island. In Europe, Tóth *et al*. (2003) recommended using pheromone-baited traps for detecting low populations and for monitoring the pest's spread. Early detection of western corn rootworm beetles in the summer is desirable for BC sweet corn growers who have limited control options, typically do not grow *Bt*-corn, and rely on crop rotation and foliar sprays of insecticides to control the beetles and prevent feeding damage to tassels and ears. To develop a cost-effective monitoring approach that allows for early detection and for quicker identification of new infestations outside of the Fraser Valley, we compared pheromone-baited and unbaited Pherocon AM traps in the Fraser Valley in 2021. This comparison was done in fields located throughout the valley to develop a conversion factor between baited and unbaited trap captures. Lures were either kept up throughout the trapping period or replaced after two weeks to determine how a lure change affects trap attractiveness.

Beetle trapping was done using standard Pherocon AM "cold melt" yellow sticky card traps (Great Lakes IPM, Vestaburg, Michigan, United States of America) in 16 fields in the Fraser Valley in southern BC (Table 1). Fields were chosen based on their known history of rootworm presence or damage and were distributed throughout the valley's corn-growing area. Each field had six traps, placed approximately 10 m apart in a single line in the second row of corn along one edge of the field, with two traps each for three treatments. Traps were attached to corn plants at approximately 1.5 m above the ground when plants were approximately 2 m in height, which accounts for the differences in trap installation dates (Table 1). All traps were replaced 2 weeks (all fields) and 4 weeks (11 of 16 fields) after installation. The study was terminated early (after 4 weeks) in 5 fields due to the early harvesting of corn, and traps in the remaining 11 fields were collected at 6 weeks after installation. Traps were unbaited (2 per field) or baited with a pheromone lure for western corn rootworm (CSALOMON®; Plant Protection Institute, Centre for Agricultural Research, Budapest, Hungary). Lures were attached to the top of the trap using a twist tie, suspending it immediately in front of the trap, and were replaced with new lures after the first 2 weeks (2 traps per field) or used for the duration of the study (2 traps per field). The study was initiated towards the beginning of the beetle activity period (21–29 July; Table 1), and the locations of the different trap types were kept constant throughout the study and were the same in each field.

After they were collected from the field, all sticky traps were cold-stored in plastic bags in the lab until beetle counts and dissections could be completed. The sex of captured beetles was determined through visual inspection of elytral colouration and antennal length and, if necessary, through dissection (Staetz *et al*. 1976; Kuhar and Youngman 1995). The number of beetles collected in different treatments were analysed with a three-factor generalised linear model (Proc GENMOD, SAS Enterprise Guide, version 7.1, SAS Institute, Cary, North Carolina, United States of America), using a log-link function and a negative binomial distribution. Model factors were 'treatment', 'field', and 'replicate', with the latter nested within 'field'. Pairwise comparisons between treatments used the 'lsmeans' statement with Tukey's adjustment.

Table 1. Western corn rootworm beetle monitoring sites in southern British Columbia in 2021 and the dates traps were installed and replaced.

Field				Trap checks		
ID	*Municipality*	*Location*	*Installed*	*First*	*Second*	*Third*
AB_4	Abbotsford	49.031726, –122.200276	23 July	5 Aug	19 Aug	1 Sept
CH_10	Chilliwack	49.149017, –121.918117	23 July	5 Aug	20 Aug	n/a
CH_35	Chilliwack	49.175792, –121.915845	23 July	5 Aug	20 Aug	1 Sept
DE_1	Deroche	49.150106, –122.248148	30 July	13 Aug	27 Aug	n/a
DE_3	Deroche	49.139915, –122.205690	30 July	13 Aug	27 Aug	n/a
DT_12	Delta	49.093770, –122.946404	23 July	6 Aug	19 Aug	2 Sept
DT_13	Delta	49.096168, –122.934857	23 July	6 Aug	19 Aug	2 Sept
GL_10	Glen Valley	49.144855, –122.472508	22 July	6 Aug	19 Aug	2 Sept
MA_3	Matsqui	49.089224, –122.338724	22 July	5 Aug	18 Aug	2 Sept
MA_9	Matsqui	49.109806, –122.272018	22 July	5 Aug	18 Aug	1 Sept
MA_11	Matsqui	49.114523, –122.247127	22 July	5 Aug	18 Aug	1 Sept
MA_14	Matsqui	49.138713, –122.266537	21 July	5 Aug	18 Aug	1 Sept
RI_3	Richmond	49.178942, –123.046093	23 July	6 Aug	20 Aug	3 Sept
RI_5	Richmond	49.168091, –123.023635	23 July	6 Aug	20 Aug	3 Sept
SU_1	Surrey	49.119149, –122.778732	29 July	12 Aug	26 Aug	n/a
SU_4	Surrey	49.075128, –122.845403	22 July	6 Aug	19 Aug	n/a

Trap captures

Nearly all beetles collected in this study (299 of 300 beetles selected at random from traps placed in two fields) were male. For all three collection periods, the number of beetles collected on traps varied significantly ($P < 0.0001$) among treatments and among fields, with the differences between treatments also varying significantly between fields, possibly due to the low number of replicates (Table 2). Overall, traps in the two pheromone treatments collected 10.1× and 10.8× more western corn rootworm beetles than unbaited traps did during the first collection period, and 10.5× and 11.8× more during the third period (Table 2). No significant difference in captures was observed between the replaced and non-replaced lure treatments for these two collection periods ($P > 0.05$). However, during the second collection period, baited traps collected 6.7× and 7.7× more beetles than unbaited traps did, with significantly higher captures in the replaced-lure treatment (Chi^2 = 9.05, P = 0.0026). These data confirm that adding a pheromone lure significantly increases captures but that lure replacement may not be necessary if traps are deployed for only 6 weeks. Comparison of the total number of western corn rootworm beetles collected on unbaited traps (1408) with the number collected on traps for which lures were not replaced in the 11 fields monitored throughout all three collection periods (14 250) indicates baited traps are approximately 10× more attractive. In comparison, a "Hungarian pheromone trap" and Multigard traps captured approx. 4× (1 year) and 14× (mean of 8 years, 1997–2004) more beetles, respectively, than unbaited Pherocon AM traps did (Edwards *et al*. 1998; Lemic *et al*. 2016). Our data suggest pheromone-baited Pherocon AM traps would be suitable for detecting low populations and for monitoring spread of western corn rootworm to other parts of BC. Our data also provide a convenient conversion factor for adjusting the standard unbaited Pherocon AM trap–based economic thresholds used in monitoring programs in North America.

Cost and ease of use

Western corn rootworm beetle monitoring in Europe is done primarily with the pheromone-baited clear sticky PAL trap (CSALOMON®; Tóth *et al*. 2003). Compared to this trap, pheromone-baited yellow Pherocon AM traps appear to be slightly less effective at catching beetles and are slightly less expensive but are easier to install and less prone to beetle drop-off from the trap surface (WvH, unpublished data). At present (August 2022), Pherocon AM traps cost $US 1.82 ($CA 2.33) when purchased in packs of 100 (Great Lakes IPM), and the cost of an individual unbaited PAL trap, pheromone lure, or combination of both from CSALOMON® is €2.49, €2.99, and €4.49, respectively ($CA 3.29, $CA 3.95, and $CA 5.93).

Based on the relatively low cost of pheromone-baited sticky card traps and their increased effectiveness over unbaited traps, we propose their use for monitoring for western corn rootworm in high-value crops such as sweet corn and in corn-growing areas of BC where the pest has not yet established. Placement of such traps along field edges in sweet or forage corn can help determine if and when foliar sprays or other control tactics should be applied to reduce beetle numbers and feeding damage and thereby potentially reduce unnecessary or ineffective management efforts. Monitoring with pheromone-baited sticky cards in corn-growing areas where the rootworm is not yet established would enable more rapid detection with lower monitoring costs and effort than would be required with unbaited traps.

Table 2. Captures of western corn rootworm beetles collected on pheromone baited and unbaited yellow sticky cards (Pherocon AM) in the Fraser Valley, southern British Columbia, in 2021. N = number of traps. Numbers in columns followed by the same letter are not statistically different, Tukey's honestly significant difference ($\alpha = 0.05$).

	Treatment	Trapping period 1	Trapping period 2	Trapping period 3
		n = 96	n = 96	n = 66
Mean (standard error of mean) western corn rootworm captured	Unbaited traps	21.1 ± 5.2 a	25.5 ± 7.3 a	21.7 ± 8.0 a
	Lure changed after first 2 weeks	227.2 ± 26.3 b	197.3 ± 16.9 c	228.3 ± 23.5 b
	Same lure for all 6 weeks	213.8 ± 25.1 b	170.0 ± 16.3 b	256.6 ± 30.6 b
Statistical analysis	*Treatment*	$Chi^2 = 364.1$, df=2,32, $P < 0.0001$	$Chi^2 = 336.4$, df=2,32, $P < 0.0001$	$Chi^2 = 233.5$, df=2,22, $P < 0.0001$
	Field	$Chi^2 = 276.1$, df = 15,32, $P < 0.0001$	$Chi^2 = 258.0$, df = 15,32, $P < 0.0001$	$Chi^2 = 158.3$, df=10,22, $P < 0.0001$
	Treatment × Field	$Chi^2 = 217.4$, df=32,48, $P < 0.0001$	$Chi^2 = 194.3$, df=30,32, $P < 0.0001$	$Chi^2 = 115.4$, df=20,22, $P < 0.0001$

ACKNOWLEDGMENTS

We thank Sam Glasgow and Emily Grove for installing and replacing traps, and Haley Schonhofer, Alyssa Moller, and Gabrielle Bourassa-Tait for processing beetle samples. We also thank the participating farmers who allowed access to their fields and the local BC corn seed dealers who connected us, and two reviewers for their helpful suggestions. Funding was provided by Agriculture and Agri-Food Canada A-base project J-002240, "Management of western corn rootworm in sweet corn", and the Canadian Agriculture Partnership, a federal–provincial–territorial initiative.

REFERENCES

Bažok, R., Lemić, D., Chiarini, F., and Furlan, L. 2021. Western corn rootworm (*Diabrotica virgifera virgifera* LeConte) in Europe: current status and sustainable pest management. Insects, **12**: 195.

Calles-Torrez, V., Boetel, M.A., and Knodel, J.J. 2020. Corn rootworm survey in North Dakota and a comparison of two sticky traps. Journal of Applied Entomology, **144**: 897–910.

Dunbar, M.W. and Gassmann, A.J. 2013. Abundance and distribution of western and northern corn rootworm (*Diabrotica* spp.) and prevalence of rotation resistance in eastern Iowa. Journal of Economic Entomology, **106**: 168–180.

Edwards, C.R., Gerber, C., Bledsoe, L.W., Barna, G., and Kiss, J. 1998. Comparisons of Hungarian pheromone and Pherocon AM® traps under economic western corn rootworm populations in Indiana, USA. Pflanzenschutzberichte, **57**: 52–56.

Gerber, C.K., Edwards, C.R., Bledsoe, L.W., Obermeyer, J.L., Barna, G., and Foster, R.E. 2005. Sampling devices and decision rule development for western corn rootworm (*Diabrotica virgifera virgifera* LeConte) adults in soybean to predict subsequent damage to maize in Indiana. *In*: Western corn rootworm: ecology and management. *Edited by* S. Vidal, U. Kuhlmann, and C.R. Edwards. CABI Books, Boston, Massachusetts, United States of America. Pp.169–187.

Gray, M.E., Sappington, T.W., Miller, N., Moeser, J., and Bohn, M.O. 2009. Adaptation and invasiveness of western corn rootworm: intensifying research on a worsening pest. Annual Review of Entomology, **54**: 303–321.

Guss, P.L., Sonnet, P.E., Carney, R.L., Branson, T.F., and Tumlinson, J.H. 1984. Response of *Diabrotica virgifera virgifera*, *Diabrotica virgifera zeae*, and *Diabrotica porracea* to stereoisomers of 8-methyl-2-decyl propanoate. Journal of Chemical Ecology, **10**: 1123–1131.

Guss, P.L., Tumlinson, J.H., Sonnet, P.E., and Proveaux, A.T. 1982. Identification of a female-produced sex pheromone of the western corn rootworm. Journal of Chemical Ecology, **8**: 545–556.

Hein, G.L. and Tollefson, J.J. 1985. Use of the Pherocon AM trap as a scouting tool for predicting damage by corn rootworm (Coleoptera: Chrysomelidae) larvae. Journal of Economic Entomology, **78:** 200–203.

Kuhar, T.P. and Youngman, R.R. 1995. Sex ratio and sexual dimorphism in western corn rootworm (Coleoptera: Chrysomelidae) adults on yellow sticky traps in corn. Environmental Entomology, **24**: 1408–1413.

Lemic, D., Mikac, K.M., Kozina, A., Benitez, H.A., McLean, C.M., and Bažok, R. 2016. Monitoring techniques of the western corn rootworm are the precursor to effective IPM strategies. Pest Management Science, **72**: 405–417.

Metcalf, R.L. 1994. Chemical ecology of Diabroticites. *In:* Novel aspects of the biology of Chrysomelidae. Series Entomologica. Volume 50. *Edited by* P.H. Jolivet, M.L. Cox, and E. Petitpierre. Springer, Dordrecht, The Netherlands. Pp. 153–169.

Metcalf, R.L., Lampman, R.L., and Lewis, P.A. 1998. Comparative kairomonal chemical ecology of Diabroticite beetles (Coleoptera: Chrysomelidae: Galerucinae: Luperini: Diabroticina) in a reconstituted tallgrass prairie ecosystem. Journal of Economic Entomology, **91**: 881–890.

Staetz, C.A., Ball, H.J., and Carlson, S.D. 1976. Antennal morphology of *Diabrotica virgifera* adults (Coleoptera: Chrysomelidae). Annals of the Entomological Society of America, **69**: 695–698.

Tóth, M., Sivcev, I., Ujváry, I., Tomasek, I., Imrei, Z., Horváth, P., and Szarukán, I. 2003. Development of trapping tools for detection and monitoring of *Diabrotica v. virgifera* in Europe. Acta Phytopathologica et Entomologica Hungarica, **38**: 307–322.

Toshova, T.B., Velchev, D.I., Abaev, V.D., Subchev, M.A., Atanasova, D.Y., and Tóth, M. 2017. Detection and monitoring of *Diabrotica virgifera virgifera* LeConte, 1868 (Coleoptera: Chrysomelidae) by KLP+ traps with dual (pheromone and floral) lures in Bulgaria. Acta Zoologica Bulgarica, **9**: 247–254.