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Source: International Journal of Insect Science, 9(1)

Published By: SAGE Publishing

URL: https://doi.org/10.1177/1179543317709275

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International Journal of Insect Science
Volume 9: 1–11
© The Author(s) 2017
DOI: 10.1177/1179543317709275
SAGE

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ABSTRACT: The basic principles of a reliable integrated pest management program include pest identification, monitoring, and distribution. Selecting the appropriate sampling protocol to monitor wireworm for research or applied entomology depends on the objective, including simply detecting the presence or absence of wireworm, surveying the composition of wireworm assemblages, or estimating spatial and temporal population densities. In this study, the efficacy of pitfall, stocking, pot, and canister traps baited with wheat and barley mixtures was evaluated for monitoring wireworm populations in four commercial cereal fields in Montana. Pitfall and stocking traps collected greater numbers of wireworm (1625 and 1575, respectively) followed by pot-type and canister-type traps (1173 and 725, respectively). The 5098 wireworm collected from four sites included seven species: *Aeolus mellillus*, *Agriotes* sp, *Dalopius* sp, *Hypnoidus bicolor*, *Limonius californicus*, *Limonius infuscatus*, and *S. aeripennis*.

KEYWORDS: *Aeolus mellillus*, *Limonius californicus*, *L. infuscatus*, pitfall, stocking

RECEIVED: May 2, 2016. **ACCEPTED:** March 5, 2017.

PEER REVIEW: Four peer reviewers contributed to the peer review report. Reviewers' reports totaled 2117 words, excluding any confidential comments to the academic editor.

TYPE: Original Research

FUNDING: The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This study was supported in part by funds from the Montana Seed Potato Producers Association and USDA Crops at Risk Grant 2010-51100-21547.

DECLARATION OF CONFLICTING INTERESTS: The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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Introduction

Wireworm, the larval stage of click beetles (Coleoptera: Elateridae), are a serious soil-inhabiting pest of many different field crops grown in North America. Their multiyear larval stages and broad host ranges can make wireworm a perennial problem for crop production. Wireworm can feed on and damage crop seeds and developing seedlings as well as underground tubers and aboveground fruit in contact with the soil. Historically, wireworm have been common pests of a wide variety of field crops worldwide.[1–5] In general, little is known about elaterid biology and ecology with the exception of a few species that have economic importance to agriculture.

Inexpensive broad-spectrum insecticides applied to the soil or as seed treatments[6] managed wireworm effectively for many decades, but most of these insecticides are not available in the market in favor of newer and safer alternatives, such as neonicotinoid insecticides. These newer insecticides, however, do not provide adequate management, and producers are still in need of effective management tools.[7] For wireworm management, producers need alternative approaches based on the principles of integrated pest management (IPM). However, the first critical step, pest species identification, has not been thoroughly addressed for wireworm. For example, in Montana, a survey of adult beetles found 155 elaterid species, of which 21 have been recorded in the literature as crop pests.[8] A systematic survey of the damaging larval stage identified six species infesting cereal cropland in Montana.[9] However, sampling protocols are required to monitor and identify wireworm as well as establish thresholds for IPM programs.[10]

Insects with a subterranean habitat are especially difficult to monitor and manage. Wireworm may burrow and live as deep as 1.5 m below the soil surface.[11] Vertical movement in the soil depends on the species and related cycles of feeding and molting, as well as extrinsic variables such as geography, soil temperature, soil moisture, ground cover (eg, grass vs fallow), and location of food.[2,12–14] The sampling objective, be it simple detection, species census/survey, density estimation, or threshold-based monitoring is an important factor in determining the best sampling protocol. In addition, estimates of wireworm populations in the soil can be highly variable, both spatially and temporally.[14–16] To provide management recommendations, the limitations and accuracy of wireworm sampling methods needed careful consideration.

Wireworm population estimates can be categorized into "absolute" and "relative" sampling methods.[17] Absolute sampling methods, such as soil coring to extract wireworm in situ from their soil habitat, typically require a higher level of expertise, time, infrastructure, and associated expense. The main objective of sampling wireworm using absolute methods has been to estimate the population density, spatial distribution (horizontal and vertical), and temporal movements of wireworm in a field. These studies typically remove soil from a field in layers or as a soil core[18–21] at various depths, sampling times, and locations to provide estimates of wireworm population densities with reasonable accuracy.

Relative sampling methods, including the use of baits or traps to draw wireworm from variable distances in the soil, have mostly been developed to detect the presence of wireworm in a crop field and to provide information about their relative abundance to inform management decisions. Several attractant-based sampling methods have been developed in North America and Europe to reduce the labor associated with absolute sampling methods.[5] Wireworm larvae are attracted to sources of CO_2 production, such as germinating seeds, respiring plants, and decomposing plant material.[22] Doane et al[22] found that *Ctenicera destructor* (Brown) (= *S. aeripennis*) (Coleoptera: Elateridae) can detect and orient to CO_2 sources from as far away as 20 cm. Of the large number of CO_2-producing baits tested, including fruits and vegetables (eg, melons, carrot, and potatoes), processed cereals (eg, bran, rolled oats, and flour), germinating cereal seed (eg, wheat, barley), and/or other seeds (eg, corn, sorghum) have been found most effective and are now most commonly used.[5,14,15,23–28] Vernon et al[29] demonstrated that most (83%) of *Agriotes obscurus* (L.) in field plots aggregate to trap crops of wheat spaced 1 m apart.

Various methods of improving the efficacy of bait traps have been developed, such as covering the traps at the soil surface with black plastic[15,30,33] or charcoal dust.[23,30] These approaches raise soil temperature and thus CO_2 production by encouraging the germination of seed or microbial respiration in nonliving baits. This has allowed earlier trapping dates and higher catches for some wireworm species[23,30] but has also increased the time and cost of sampling. As a first step toward identifying the economically important wireworm species infesting cereal cropland in Montana, in this study, we compared the efficacy of four types of bait traps (pitfall, stocking, pot, and canister) for monitoring wireworm in four commercial fields in Montana for three years.

Materials and Methods

Insect sampling

Four types of baited traps were compared: (1) our custom-designed, 1.3-L white plastic canister with 6-mm-diameter holes evenly distributed over the surface and separated by ~25 mm (33 holes per canister), (2) 1-L green plastic planting pot with eight holes (10 mm diameter) on the bottom, (3) a small stocking (Foot Sox; Montana Leather, Billings, MT, USA), and (4) a traditional wireworm-baited pitfall trap (25-cm deep by 20-cm-wide hole in the field filled with seed). Each trap, with the exception of the stocking, was filled with peat moss (Sunshine® Sun Gro Horticulture Canada Ltd. Agawam, MA) and baited with 120 g of wheat (*Triticum aestivum* L.) and barley (*Hordeum vulgare* L.) seeds (1:1 mix).[5,14,15,23–28] Stockings were filled with 120 g of the seed mixture only (Figure 1). The seed mixtures (traditional pitfall and planting pot traps) or whole traps (canister and stocking traps) were soaked in water for 24 hours prior to field placement to initiate seed germination. Each trap was buried so that the top was 5 cm below the soil surface. With the exception of the canister, all traps were covered with a 0.093-m^2 black plastic sheet secured with four sod staples.[15,30,31] Each of the four traps was placed 30 to 45 cm apart in an arbitrary order, and each set of four traps replicated 10 times along a linear transect (Figure 1). The traps were recovered 14 days after deployment and stored at 4°C.

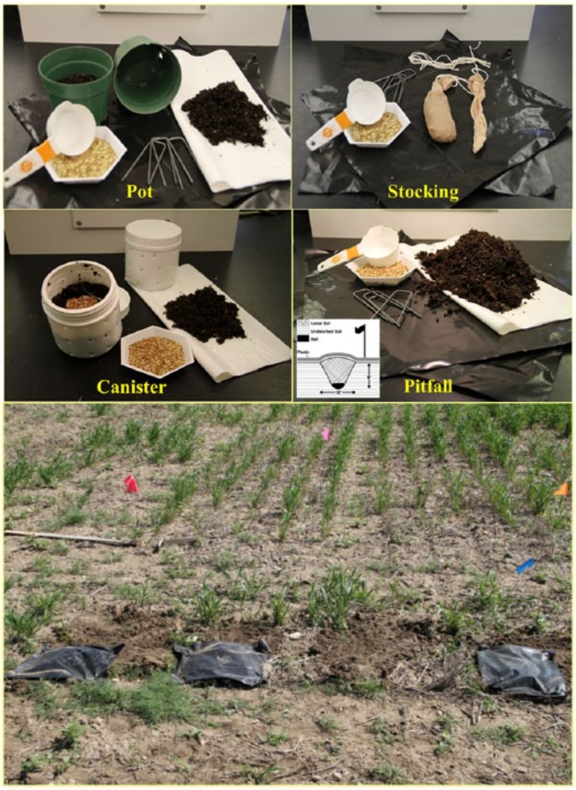

Figure 1. Four bait traps used (top), see “Materials and Methods” section for the description, and display of the traps in the field (bottom).

Sampling began in April when soil temperatures reached 7°C to 10°C at a depth of 5 cm and continued until the end of August. At each sampling date, a new parallel line of traps was deployed approximately 5 m distant from the line of traps that were removed. In this way, a season with nine sampling dates covered an area of approximately 60 m in length and 40 m in width. The sampling was repeated for three years at four different field sites in Montana (Table 1). The same area was used in each of the 3 years that the study was conducted, with exception of the Bozeman field in 2012. Wireworm were extracted from the traps using an array of custom aluminum Berlese funnels, labeled, and preserved in 95% ethanol for future identification.[9] Species were identified using the morphological characteristics and molecular techniques described by Etzler et al[32] and personal consultation with Frank Etzler, a wireworm taxonomist, resident at the Montana Entomology Collection where the insects and DNA were deposited. The specific trap collection date varied between years and location since sampling was initiated when soil temperatures reached about 7°C to 10°C. In some cases, the sampling date was also influenced by the production practices (planting date, tilling, irrigation, etc) conducted in the commercial field. For the Bozeman and Toston sites, four sampling dates were analyzed, and for the Conrad and Denton sites, five sampling dates. The four experimental sites were located in commercial cereal fields selected for their history of wireworm infestation and their geographic diversity (Table 1).

Table 1. Four different types of baited traps were evaluated for their efficacy at collecting wireworm in four different commercial cereal fields in Montana.

LOCATION	ELEVATION (MASL)[a]	CROP HISTORY (2010–2011–2012)[b]	IRRIGATED	SOIL TYPE	DOMINANT WIREWORM SPECIES
Bozeman	1495	SW-SW-SW	No	Clay-sandy	*Limonius infuscatus*
Conrad	1080	Barley-SW-SW	Yes	Clay	*Hypnoidus bicolor* *Limonius californicus*
Denton	1096	SW-WW-lentils	No	Clay-sandy	*L. californicus*
Toston	1232	SW-WW-SW	Yes	Sandy	*L. californicus*

Each site was selected to represent a variety of field characteristics.
[a] Meters above sea level.
[b] SW, spring wheat; WW, winter wheat.

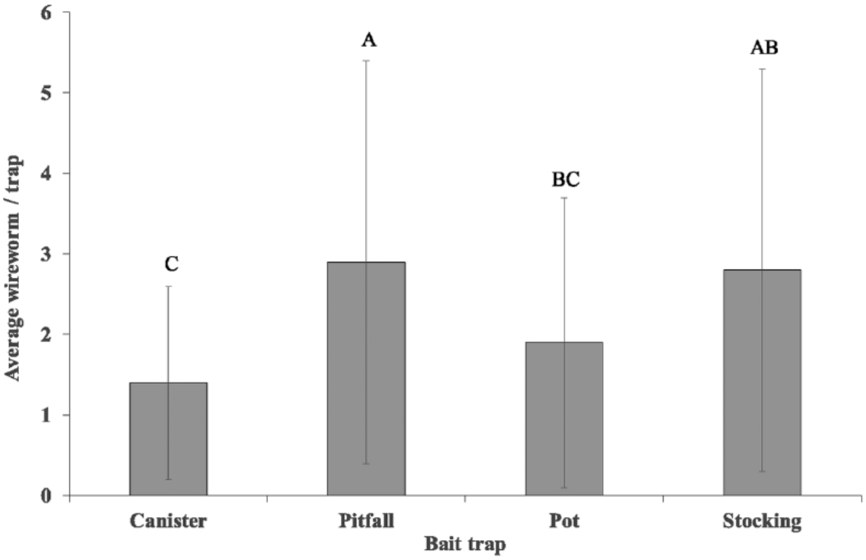

Figure 2. Mean (±95% confidence interval) number of wireworm caught using four different types of baited traps. Trap catch was pooled from four different sites (Bozeman, Conrad, Denton, and Toston) and three different years (2010-2012). Columns with the same letter are not significantly different, Tukey test, $P = .05$.

Data analysis

The total number of larvae per trap at each date and site was evaluated for normality and subsequently transformed using the log(X) function. Relative variation (RV) values were calculated for each trap type using mean larvae counts pooled for location, year, and month in the formula: $RV = (SEM/mean) \times 100$, where SEM indicates standard error of the mean.[33] Mean trap catches were analyzed using the PROC MIXED procedure in the SAS 9.3 software, as least-square means (LSMEANS statement), where repetition was treated as a random effect, and treatment and species were treated as fixed effects within a repeated-measures design, for each field site and year. For each location and year, the treatment effect was evaluated for the main species present, and all minor species were pooled into a category called "others."

Results

Total capture

During a three-year period, 2560 baited traps were processed from four commercial cereal fields in Montana, 880 in 2010, and 840 each in 2011 and 2012. Pitfall and stocking traps caught more total wireworm (1625 and 1575 larvae, respectively) compared with pot-type and canister-type traps (1173 and 725 larvae, respectively). Average catches for each trap type ranged from 2.46 to 1.16 and were significantly different ($F_{3,2560} = 11.41$; $P < .0001$) (Figure 2) when all field sites, years, sampling dates, and species were pooled together. Average trap catches using pooled data support an efficiency relationship where pitfall = stocking ≥ pot > canister (Figure 2). However, the analysis of variance (ANOVA) detected significant interactions: trap*species ($F_{15,15364} = 3.11$; $P < .0001$), location*year ($F_{3,15364} = 73.75$; $P < .0001$), location*sample date ($F_{3,15364} = 33.75$; $P < .0001$), location*species ($F_{15,15364} = 84.48$; $P < .0001$), year*sample date ($F_{1,15364} = 63.19$; $P < .0001$), species*year ($F_{5,15364} = 157.4$; $P < .0001$), and sample date*species ($F_{5,15364} = 37.47$; $P < .0001$). The data were further analyzed, separately, for each field site and year using the PROC MIXED procedure as described in the "Materials and Methods" section. For all field sites and years, trap type was a significant effect, with the exception of the Denton site in 2011 ($F_{3,351} = 1.43$;

Table 2. Percentage of the three main species collected using four different bait traps.

TRAP TYPE	*Hypnoidus bicolor*	*Limonius californicus*	*Limonius infuscatus*	TOTAL NO. OF WIREWORM
Stocking and pitfall, %	10.6	62.7	26.7	3030
Canister and pot, %	6.9	76.1	16.9	1836

Stocking and pitfall traps were pooled together and canister and pot traps were pooled. The proportions of each species was not independent of trap type; χ^2 value = 94.91, $P = .00001$.

$P = .22$) and 2012 ($F_{3,351} = 1.47$; $P = .22$) and the Toston site in 2010 ($F_{3,288} = 1.39$; $P = .25$).

Species diversity

A total of 5097 wireworm were collected from the four sites from 2010 to 2012. In 2010, the 3135 wireworm collected included seven species; in 2011, the 1560 wireworm included six species; and in 2012, the 402 wireworm included seven species. *Aeolus mellillus, Agriotes sp, Dalopius sp, Hypnoidus bicolor, imonius californicus, Limonius infuscatus, and S aeripennis* were the seven different species collected, with *H. bicolor, L. californicus*, and *L. infuscatus* caught at the highest frequencies. *Limonius californicus* was the dominant species at the Denton (97.4%, 85.2%, and 77.1% of the total of wireworm population during 2010, 2011, and 2012, respectively) and Toston (99.3%, 96.8%, and 97.5% of the total of wireworm population during 2010, 2011, and 2012, respectively) locations. *Limonius infuscatus* was the dominant species at the Bozeman location (83.8% and 89.0% of the total of wireworm population during 2010 and 2011, respectively). At the Conrad location, two wireworm species were codominant. *Hypnoidus bicolor* was slightly more prevalent during the last two years of the study (53.7% and 52.4% of the total of wireworm population during 2011 and 2012, respectively), whereas *L. californicus* was more prevalent during the first year (60.4% of the total of wireworm population in 2010). *Aeolus mellillus* was collected at all four locations as a minor component of the total catch. *Agriotes* sp, *Dalopius* sp, and *S. aeripennis* collected in Bozeman, Conrad, and Denton were relatively uncommon.

The percent distribution of each species was tabulated for each trap type from data pooled from all sites and all years (Figure 2). A descriptive comparison shows that the mean values for the canister and pot traps were similar but were different from the pitfall and stocking traps, which were similar to each other. Based on this observation, an a priori 3 × 2 contingency table of pooled data (canister and pots combined and pitfall and stocking traps combined) was analyzed. In this analysis, the other species making up a small (1.5%) minority of the total catch were not included. The distribution of the 3 species was not independent of the pooled trap types ($\chi^2 = 94.91$; $P < .0001$). Stocking and pitfall traps, combined, caught a smaller proportion of *L. californicus* (13.3% fewer) and higher proportions of *H. bicolor* (3.7%) and *L. infuscatus* (9.8%) than canister and pot traps combined (Table 2).

Bozeman site

Limonius infuscatus was the predominant species trapped (Table 3). Mean trap catch of *L. infuscatus* was generally higher in 2011 compared with 2010 and higher during the first two sampling dates of both years. A total of 1095 wireworm were collected from traps deployed in Bozeman, 216 in 2010, 866 in 2011, and only 13 in 2012. Of the 216 wireworm collected in 2010, 50.9% were collected on the first sampling date, 26.9% on the second, 16.7% on the third, and 5.6% on the fourth date. Of the 823 wireworm collected in 2011, 35.7% were collected on the first sampling date, 51.0% on the second, 12.2% on the third, and 1.6% on the fourth sampling date. The 2012 sampling year was not analyzed as the trap catch was very low.

In both 2010 and 2011, trap type ($F_{3,279} = 22.34$; $P < .0001$ and $F_{3,279} = 25.43$; $P < .0001$, respectively, for each year) and sampling date ($F_{3,279} = 45.38$; $P < .0001$ and $F_{3,279} = 88.50$; $P < .0001$, respectively, for each year) significantly affected total catch of *L. infuscatus* and "other" species. There was a significant interaction between trap and sampling date ($F_{9,279} = 5.39$; $P = .0012$; and $F_{9,279} = 2.57$; $P < .0075$) for 2010 and 2011, respectively, and trap*species ($F_{3,279} = 10.87$; $P < .0001$) for 2011 but not for 2010. Because of these interactions, the mean catch displayed in Table 3 is calculated separately for each sampling date and each species. Statistically significant differences (Tukey test) between average catches of *L. infuscatus* for the four different trap types were detected during the first sampling date in 2010 and the first to the third sampling dates in 2011 (Table 3). The general pattern of efficacy between the four trap types was the same as that observed using pooled data (Figure 2), pitfall = stocking ⩾ pot > canister. Catch of "other" species never exceeded 0.8%, on average, and statistical differences between trap types were not detected.

Conrad site

Two wireworm species dominated the trap catch, *L. californicus* and *H. bicolor* (Table 4). Trap catch was generally highest in 2010; 966 wireworm were collected from the four traps types deployed in Conrad, 610 in 2010, 211 in 2011, and 143 in 2012. Of the 610 wireworm collected in 2010, 30.2% were collected on the first sampling date, 46.0% on the second, 14.3% on the third, 2.1% on the fourth, and 7.4% on the fifth sampling date. During 2011, 3.4% of the wireworm were collected

Table 3. Mean number of *Limonius infuscatus* and other larvae collected from four different types of baited trap placed in a commercial cereal field near Bozeman, MT, USA, at four sampling dates in 2010 and 2011.

TRAP TYPE	NO. OF LARVAE IN 2010[a] ($\bar{x}$±SD)		NO. OF LARVAE IN 2011[a] ($\bar{x}$±SD)	
	L. infuscatus[b]	OTHERS	*L. infuscatus*[b]	OTHERS
Sampling time 1				
Canister	0.6 ± 0.8C	0.0 ± 0.0	3.2 ± 3.1B	0.0 ± 0.0
Pitfall	3.3 ± 2.2AB	0.0 ± 0.0	9.6 ± 6.1A	0.1 ± 0.3
Pot	1.3 ± 1.8BC	0.1 ± 0.3	5.3 ± 4.2AB	0.4 ± 0.5
Stocking	5.6 ± 5.7A	0.1 ± 0.3	10.1 ± 5.4A	0.3 ± 0.5
Sampling time 2				
Canister	0.1 ± 0.3	0.0 ± 0.0	5.1 ± 4.2C	0.2 ± 0.4
Pitfall	2.1 ± 2.0	0.6 ± 1.0	15.3 ± 6.9A	0.6 ± 0.7
Pot	0.6 ± 1.3	0.3 ± 0.7	7.3 ± 4.7BC	0.2 ± 0.4
Stocking	1.9 ± 3.4	0.2 ± 0.7	12.8 ± 6.1AB	0.5 ± 0.5
Sampling time 3				
Canister	0.4 ± 0.5	0.0 ± 0.0	0.3 ± 0.5B	0.1 ± 0.3
Pitfall	0.4 ± 0.7	0.5 ± 1.0	4.5 ± 2.1A	0.8 ± 1.3
Pot	0.0 ± 0.0	0.3 ± 0.5	1.0 ± 1.3B	0.3 ± 0.6
Stocking	1.6 ± 2.7	0.4 ± 0.7	2.8 ± 1.3A	0.2 ± 0.4
Sampling time 4				
Canister	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.3
Pitfall	0.2 ± 0.4	0.7 ± 1.3	0.0 ± 0.0	0.6 ± 0.7
Pot	0.0 ± 0.0	0.3 ± 0.5	0.0 ± 0.0	0.3 ± 0.7
Stocking	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.5

[a] Collection dates: 2010: *sampling time 1* = May 10, 2010 to May 24, 2010; *sampling time 2* = June 24, 2010 to June 08, 2010; *sampling time 3* = June 8, 2010 to June 22, 2010; and *sampling time 4* = June 22, 2010 to July 8, 2010; in 2011, *sampling time 1* = May 19, 2011 to June 02, 2011; *sampling time 2* = June 2, 2011 to June 17, 2011; *sampling time 3* = June 17, 2011 to June 30, 2011; and *sampling time 4* = June 30, 2011 to July 20, 2011.

[b] Within a column, for each sampling time, mean values with the same letter are not significantly different, Tukey test ($P = .05$).

on the first sampling date, 0.7% on the second, 25.4% on the third, 38.5% on the fourth, and 32.3% on the fifth sampling date. In 2012, 22.0% were collected on the first sampling date, 0.7% on the second, 46.1% on the third, 22.0% on the fourth, and 9.2% on the fifth sampling date.

During all three sampling years, trap type had a significant effect on catch ($F_{3,540} = 15.16$; $P < .0001$, $F_{3,540} = 15.16$; $P < .0001$; and $F_{3,540} = 9.67$; $P < .0001$ for 2010, 2011, and 2012, respectively). Significant interactions between trap and sampling date and trap and species were also detected for all three years. The last three sampling dates in 2010, first two sampling dates in 2011, and the third sampling date in 2013 yielded higher catch, on average. During 2010, the last two sampling dates yielded statistically significant differences between trap types for mean catch of *L. californicus*, *H. bicolor*, and "other" species (Table 4). The general pattern of trap efficacy was the same as that established in Figure 2, pitfall = stocking ⩾ pot > canister.

Significant differences between traps types were only detected for *H. bicolor* in 2011, during the first three sampling dates. During these sampling dates, the pattern of trap efficacy was more variable, possibly due to lower total trap catches. During the second sampling date, the stocking-type, pitfall-type, and pot-type traps were all equally effective (Table 4). The canister trap was as effective as the pitfall and pot traps during the first sampling date. In 2012, significant differences between trap types were detected only for *H. bicolor* at the first and third sampling dates. A general trend of higher catches in stocking and pitfall traps and fewest catches in canister traps was observed.

Denton site

Limonius californicus was the dominant wireworm species (Table 5). Trap catches was generally highest in 2010. A total of 2403 wireworm were collected from the four traps types

Table 4. Mean number of *Limonius californicus* and *Hypnoidus bicolor* larvae collected from four different types of baited traps placed in a commercial cereal field near Conrad MT, at five sampling dates in 2010-2012.

TRAP TYPE	NO. OF LARVAE IN 2010[a] ($\bar{x}$±SD)		NO. OF LARVAE IN 2011[a] ($\bar{x}$±SD)		NO. OF LARVAE IN 2012[a] ($\bar{x}$±SD)	
	L. californicus[b]	*H. bicolor*[b]	*L. californicus*[b]	*H. bicolor*[b]	*L. californicus*	*H. bicolor*[b]
Sampling time 1						
Canister	0.0 ± 0.0	0.8 ± 1.0	0.0 ± 0.0	0.6 ± 1.2AB	0.0 ± 0.0	0.1 ± 0.3B
Pitfall	0.1 ± 0.3	0.2 ± 0.6	0.6 ± 1.6	0.8 ± 1.3AB	0.0 ± 0.0	1.5 ± 1.8A
Pot	0.3 ± 0.5	0.2 ± 0.4	0.7 ± 1.6	0.5 ± 1.1B	0.0 ± 0.0	0.6 ± 1.3AB
Stocking	0.0 ± 0.0	0.3 ± 0.6	0.5 ± 1.0	1.9 ± 2.0A	0.0 ± 0.0	0.9 ± 1.7AB
Sampling time 2						
Canister	0.1 ± 0.3	0.1 ± 0.3	0.8 ± 0.0	0.2 ± 0.4B	0.0 ± 0.0	0.0 ± 0.0
Pitfall	0.0 ± 0.0	0.0 ± 0.0	1.5 ± 0.0	1.9 ± 3.0A	0.0 ± 0.0	0.0 ± 0.0
Pot	0.0 ± 0.0	0.0 ± 0.0	1.1 ± 0.0	1.3 ± 2.2A	0.0 ± 0.0	0.0 ± 0.0
Stocking	0.0 ± 0.0	0.0 ± 0.0	0.7 ± 0.0	1.0 ± 1.1A	0.0 ± 0.0	0.1 ± 0.3
Sampling time 3						
Canister	0.4 ± 0.5	2.5 ± 2.2	0.0 ± 0.0	0.0 ± 0.0B	0.2 ± 0.4	0.0 ± 0.0B
Pitfall	1.0 ± 1.3	2.0 ± 1.3	0.4 ± 0.0	0.3 ± 0.7AB	0.9 ± 1.2	1.5 ± 1.5A
Pot	1.2 ± 1.9	2.2 ± 2.2	0.4 ± 0.0	0.0 ± 0.0B	0.6 ± 0.7	0.4 ± 0.5AB
Stocking	1.6 ± 1.6	3.0 ± 2.3	0.3 ± 0.0	1.2 ± 2.2A	1.5 ± 2.1	1.4 ± 1.5A
Sampling time 4						
Canister	1.4 ± 1.1B	0.0 ± 0.0B	0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Pitfall	5.6 ± 5.0A	2.0 ± 1.7A	0.0 ± 0.0	0.1 ± 0.3	0.4 ± 0.8	0.4 ± 1.0
Pot	3.6 ± 2.5AB	0.7 ± 0.8AB	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.3	0.5 ± 0.5
Stocking	4.7 ± 3.4A	1.4 ± 1.1A	0.0 ± 0.0	0.1 ± 0.3	0.7 ± 1.9	1.0 ± 1.6
Sampling time 5						
Canister	0.9 ± 1.3B	0.2 ± 0.4B	0.1 ± 0.3	0.1 ± 0.3	0.1 ± 0.3	0.0 ± 0.0
Pitfall	4.1 ± 2.6AB	1.6 ± 1.1AB	0.1 ± 0.3	0.2 ± 0.4	0.2 ± 0.4	0.0 ± 0.0
Pot	3.1 ± 2.3AB	0.4 ± 0.5AB	0.0 ± 0.0	0.1 ± 0.3	0.4 ± 0.5	0.1 ± 0.3
Stocking	5.2 ± 3.1A	2.0 ± 2.4A	0.2 ± 0.4	0.2 ± 0.6	0.1 ± 0.3	0.4 ± 0.7

The frequency of other species was rare and their numbers are not presented.

[a] Collection dates: 2010: *sampling time 1* = March 26, 2010 to April 12, 2010; *sampling time 2* = April 12, 2010 to April 26, 2010; *sampling time 3* = April 26, 2010 to May 12, 2010; *sampling time 4* = May 12, 2010 to May 21, 2010; and *sampling time 5* = May 21, 2010 to June 04, 2010; in 2011, *sampling time 1* = May 17, 2011 to May 27, 2011; *sampling time 2* = May 27, 2011 to June 13, 2011; *sampling time 3* = June 13, 2011 to June 29, 2011; *sampling time 4* = June 29, 2011 to July 13, 2011; and *sampling time 5* = July 13, 2011 to July 26, 2011; and in 2012; *sampling time 1* = March 27, 2012 to April 10, 2012; *sampling time 2* = April 10, 2012 to April 30, 2012; *sampling time 3* = April 30, 2012 to May 18, 2012; *sampling time 4* = May 18, 2012 to June 01, 2012; and *sampling time 5* = June 01, 2012 to June 15, 2012.

[b] Within a column, for each sampling time, mean values with the same letter are not significantly different, Tukey test ($P = .05$).

deployed: 2120 in 2010, 132 in 2011, and 151 in 2012. Of the 2120 wireworm collected in 2010, 51.6% were collected on the first date, 6.3% on the second, 10.1% on the third, 19.3% on the fourth time, and 12.8% on the fifth date. During 2011, 20.5% were collected on the first sampling date, 2.3% on the second, 34.8% on the third, 26.5% on the fourth, and 15.9% on the fifth sampling date. In 2012, no insects were collected on the first sampling date, 43.8% on the second, 36.2% on the third, 11.5% on the fourth, and 8.5% on the fifth sampling date.

Trap type was a significantly affected catch in 2010 ($F_{3,359} = 5.31$; $P = .0014$) and 2012 ($F_{3,359} = 8.67$; $P < .0001$), but not in 2011 ($F_{3,359} = 1.47$; $P = .2225$). No significant interactions between trap and sampling date or trap and species were observed for any of the three sampling years. Because of the lack of interaction, mean catch displayed in Table 5 was pooled

Table 5. Mean number of *Limonius californicus* larvae collected per sampling date from four different types of baited trap placed in a commercial cereal field near Denton, MT, USA, during 2010-2012.

TRAP TYPE	NO. OF *L. californicus* LARVAE ($\bar{x}$±SD)		
	2010	2011	2012[a]
Canister	5.4 ± 8.8	0.4 ± 0.6	0.3 ± 0.9B
Pitfall	8.5 ± 11. 4	0.7 ± 1.2	0.7 ± 1.3AB
Pot	8.0 ± 12.4	0.7 ± 1.1	0.4 ± 1.0B
Stocking	8.4 ± 10.8	0.9 ± 1.3	1.1 ± 1.8A

Sampling dates were pooled because there was not significant interaction between factors in the ANOVA analysis. The frequency of other species was rare and their numbers are not presented.

[a] Mean values followed by the same letter are not significantly different, Tukey test ($P = .05$).

by species and sampling date. The ANOVA of the pooled data found that trap type significantly affected catch in 2012 ($F_{3,239} = 4.80$; $P = .0029$), but not in 2010 ($F_{3,279} = 1.13$; $P = .264$) or 2011 ($F_{3,239} = 1.92$; $P = .127$). In 2012, stocking traps caught the most wireworm followed by pitfall-type, pot-type, and canister-type traps (Table 5).

Toston site

Limonius californicus was the dominant wireworm species (Table 6). A total of 663 wireworm were collected from the four traps types deployed. Trap catch was higher in 2010 and 2011 compared with 2012: 217 in 2010, 351 in 2011, and 95 in 2012. Trap type significantly affected catch in 2011 and 2012 ($F_{3,279} = 4.09$; $P = .0073$ and $F_{3,279} = 6.40$; $P < .003$, respectively, for each year) but was not significant in 2010. Of the 217 wireworm collected in 2010, 29.9% were collected on the first sampling date, 21.9% on the second, 31.6% on the third, and 16.7% on the fourth sampling date. During 2011, 20.5% were collected on the first sampling date, 2.3% on the second, 34.8% on the third, 26.5% on the fourth, and 15.9% on the fifth sampling date. During 2012, 32.9% were collected on the first sampling date, 46.1% on the second, 10.5% on the third, and 10.5% on the fourth sampling date.

During the first two years of sampling (2010 and 2011), interactions between trap and sampling date and trap and species were not significant for any of the sampling dates. Data were pooled for species and sampling date; however, no effect was detected for 2010 ($F_{3,159} = 0.1812$; $P = .1812$), and in 2011, differences among the traps ($F_{3,39} = 4.802$; $P = .0065$) were only found at the first sampling date for *L. californicus* (Table 6). Pitfall traps were the most efficient followed by stocking, canister, and pot traps. For the “other” group of wireworm species, no differences were observed (Table 6). Trap type significantly affected catch only in 2012 ($F_{3,199} = 3.40$; $P = .0187$). Differences among the traps were found in the first (May 11, 2012 to May 23, 2012) sampling date for *L. californicus*. Pitfall traps were more efficient followed by stocking and canister, and pot traps were the least efficient. For the “other” group of wireworm species, no differences were observed (Table 6).

Relative variation

Efficacy of insect traps is most commonly measured by RV, where variability is expressed as the ratio of the standard error of the mean to the mean.[33] Relative variation values for each trap type were near or below 20% during 2010 and 2011 at each sampling location (n = 40-50 for each trap type at each location and year). During 2012, fewer wireworm were caught, and the RV values were much higher, particularly for the canister traps (Figure 3).

Discussion

In this study, we found that the efficacy of baited trap designs varied substantially. Pitfall and stocking traps were the most effective, followed by the pot trap. The canister trap was the least efficient type. In addition, we detected significant variation in the apparent efficacy of the four types of bait traps among years. The pitfall trap commonly used for wireworm sampling was compared with pot and stocking traps reported in the literature[13,25] and a new canister trap designed for this study. When trap catches from different experimental locations, years and sampling dates were analyzed collectively, pitfall and stocking traps caught the most wireworm followed by pots (Figure 2), and canister caught the fewest. Although the design of the traps most likely accounted for the differences in total catches, the traps also varied in the total amount of soil sampled. When retrieved from the field, pitfall and stocking traps included surrounding soil bound to the germinating bait that often included nearby wireworm. In a previous study, Kifman et al[36] found wireworm in the soil around the pot trap and including these numbers in the analysis altered trap efficiency. In this study, canister and pot traps were free of soil when removed from the field. The fact that pot traps caught more wireworm than canisters is most likely explained by the trap design because neither included additional surrounding soil. Our custom-designed canister trap consistently caught the fewest number of wireworm, likely due to its limited amount of open entry points.

Mean trap catch was analyzed separately for each sampling date at each field location and sampling year because ANOVA

Table 6. Mean number of *Limonius californicus* and other larvae collected at four sampling dates from four different types of baited trap placed in a commercial cereal field near Toston MT during 2010-2012.

TRAP TYPE	NO. OF LARVAE IN 2010[a] ($\bar{x}$±SD)		NO. OF LARVAE IN 2011[a] ($\bar{x}$±SD)		NO. OF LARVAE IN 2012[a] ($\bar{x}$±SD)	
	L. californicus[b]	OTHERS	*L. californicus*[b]	OTHERS	*L. californicus*[b]	OTHERS
Sampling time 1						
Canister	0.7 ± 1.3	0.0 ± 0.0	0.7 ± 1.3AB	0.0 ± 0.0	0.4 ± 0.6AB	0.0 ± 0.0
Pitfall	1.1 ± 1.4	0.0 ± 0.0	2.5 ± 2.5A	0.6 ± 0.8	1.0 ± 0.8A	0.6 ± 0.8
Pot	2.5 ± 3.8	0.0 ± 0.0	0.6 ± 0.7B	0.2 ± 0.4	0.5 ± 0.6B	0.2 ± 0.4
Stocking	1.2 ± 1.6	0.1 ± 0.3	0.7 ± 0.8AB	0.1 ± 0.3	0.9 ± 0.8AB	0.1 ± 0.3
Sampling time 2						
Canister	0.8 ± 1.5	0.0 ± 0.0	1.0 ± 1.2	0.0 ± 0.0	1.0 ± 1.5	0.0 ± 0.0
Pitfall	1.8 ± 2.5	0.0 ± 0.0	2.1 ± 1.7	0.2 ± 0.6	2.1 ± 2.6	0.0 ± 0.0
Pot	1.1 ± 1.7	0.0 ± 0.0	2.4 ± 2.8	0.0 ± 0.0	2.4 ± 2.8	0.0 ± 0.0
Stocking	0.4 ± 0.7	0.0 ± 0.0	3.5 ± 2.7	0.1 ± 0.3	3.5 ± 2.6	0.1 ± 0.3
Sampling time 3						
Canister	1.6 ± 1.6	0.0 ± 0.0	0.3 ± 0.7	0.0 ± 0.0	0.3 ± 0.6	0.0 ± 0.0
Pitfall	2.1 ± 2.1	0.0 ± 0.0	0.4 ± 0.5	0.0 ± 0.0	0.4 ± 0.5	0.0 ± 0.0
Pot	1.1 ± 1.2	0.0 ± 0.0	0.2 ± 0.4	0.0 ± 0.0	0.2 ± 0.4	0.0 ± 0.0
Stocking	1.1 ± 1.8	0.0 ± 0.0	0.2 ± 0.4	0.0 ± 0.0	0.2 ± 0.4	0.0 ± 0.0
Sampling time 4						
Canister	0.8 ± 1.3	0.0 ± 0.0	1.3 ± 1.3	0.0 ± 0.0	1.3 ± 1.3	0.0 ± 0.0
Pitfall	1.1 ± 1.5	0.0 ± 0.0	1.5 ± 1.4	0.0 ± 0.0	1.5 ± 1.4	0.0 ± 0.0
Pot	0.6 ± 1.0	0.0 ± 0.0	2.0 ± 2.6	0.0 ± 0.0	2.0 ± 2.6	0.0 ± 0.0
Stocking	0.6 ± 1.1	0.0 ± 0.0	1.8 ± 1.6	0.0 ± 0.0	1.8 ± 1.6	0.0 ± 0.0

[a] Collection dates: 2010: *sampling time 1* = May 17, 2010 to June 02, 2010; *sampling time 2* = June 02, 2010 to June 02, 2010; *sampling time 3* = June 02, 2010 to June 28, 2010; and *sampling time 4* = June 28, 2010 to July 17, 2010; in 2011; *sampling time 1* = May 19, 2011 to June 02, 2011; *sampling time 2* = June 02, 2011 to June 15, 2011; *sampling time 3* = June 15, 2011 to July 05, 2011; and *sampling time 4* = July 05, 2011 to July 19, 2011; and in 2012; *sampling time 1* = May 11, 2012 to May 23, 2012; *sampling time 2* = May 23, 2012 to June 11, 2012; *sampling time 3* = June 11, 2012 to June 25, 2012; and *sampling time 4* = June 25, 2012 to July 12, 2012.

[b] Within a column, for each sampling time, mean values with the same letter are not significantly different, Tukey test (*P* = .05).

detected significant interactions between most factors, with the exception of the Denton field site (Tables 3 to 6). The trend of "pitfall = stocking > pot > canister" obtained from pooled data illustrated in Figure 2 is generally consistent when the data are broken down by sampling date, with a few exceptions. Many sampling dates did not yield a significant treatment (trap type) effect often because trap catches were low during that period. At the Bozeman field site, which was dominated by *L. infuscatus*, the first sampling time (2010) and 1-3 sampling times (2011) had significant treatment effects, and for all four cases, the pattern of trap catches was consistent with Figure 2. The Conrad location was unique in being infested by two species, *H. bicolor* and *L. californicus*. A significant treatment effect for *L. californicus* was detected only for the fourth and fifth sampling times in 2010 (Table 4), and both were consistent with the trend illustrated in Figure 2. For *H. bicolor*, seven sampling dates during the three-year period yielded significant treatment effects, and all followed the established trend of trap catches "pitfall = stocking > pot > canister. Wireworm populations at the Denton location were high in 2010 but low in the following two years. In this analysis, sampling dates were pooled, but trap type was not a significant factor. Pot traps caught as many wireworm as pitfall and stocking traps in 2010; however, variation was much higher at this site. Trap catches at the Toston location were low across sampling dates and did not provide additional information about trap efficiency. Collectively, these data demonstrate the consistent efficiency of each trap type under different field conditions for three different species of wireworm.

An ideal wireworm trap would catch all pest species with equal efficiency, but studies comparing trap efficiency as a function of wireworm species have not been reported. In this study, three species were predominant: *L. californicus*, *L. infuscatus*, and

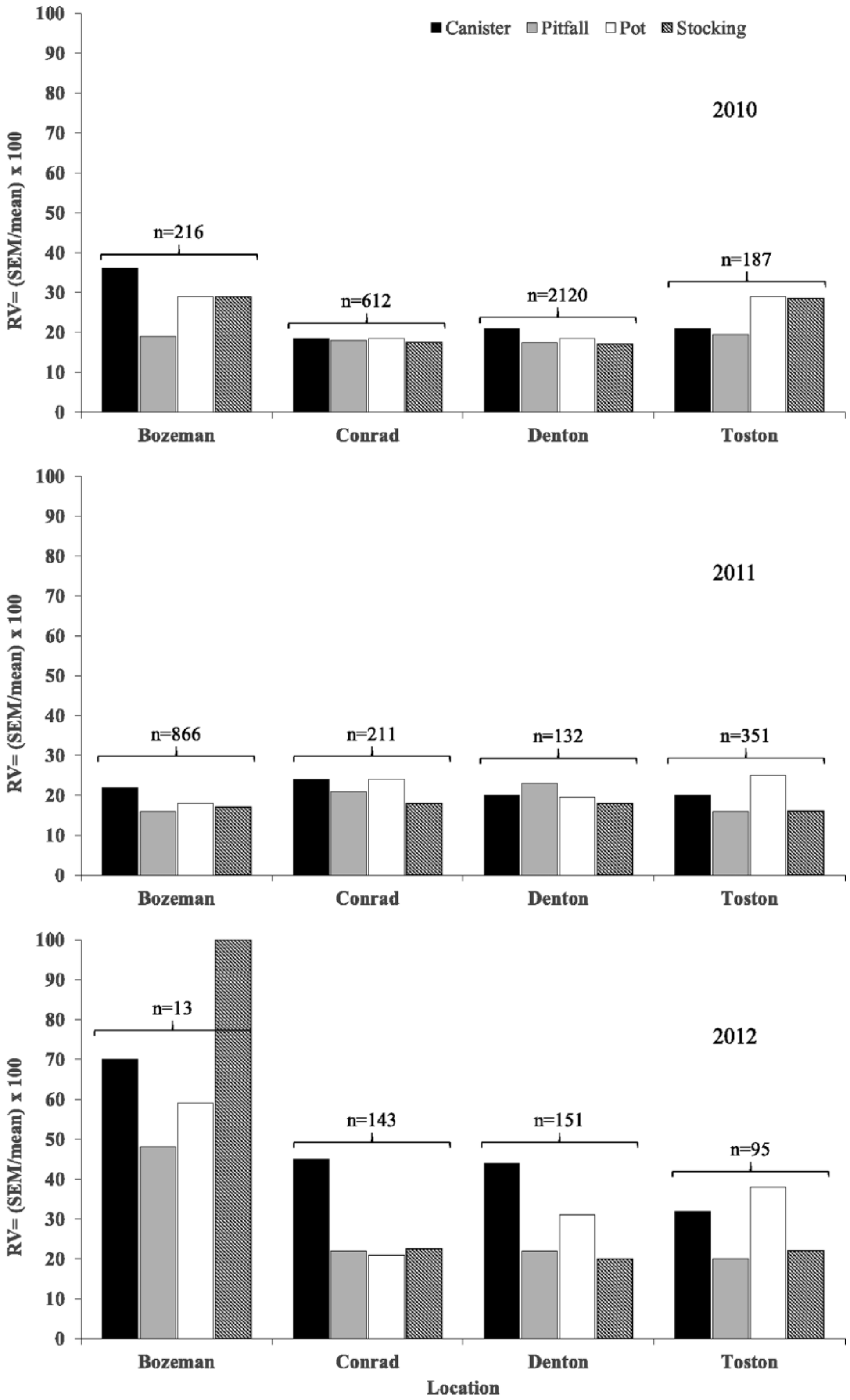

Figure 3. Relative variation values for each trap type and location during 2010-2012 (sampling dates pooled for each year), n = total wireworm collected for the given year and location.

H. bicolor. Four other species were identified at very low abundance: *Aeolus mellillus, Agriotes* sp, *Dalopius* sp, and *S. aeripennis.*. This distribution of species is consistent with a statewide survey of Montanta's cereal cropland.[9] Species-specific wireworm biology and ecology are not well known, but differences in larval behavior between the species are expected, including movement in the soil. Using pooled data, the proportion of wireworm species caught by each trap was analyzed. *Aeolus mellillus, Agriotes* sp, *Dalopius* sp, and *S. aeripennis* were pooled into a single group termed "others" that constituted only 3% to 6% of the species caught. The distribution of wireworm species was not independent of trap type (4 × 4 contingency table, $P < .0001$). Interestingly, the proportion of *L. californicus, L. infuscatus*, and *H. bicolor* caught by canister and pot traps was almost identical but different from pitfall and stocking traps that differed by no more than 2%. These results can be explained by an increased attractiveness of the pitfall and stocking traps to some species, or, by differential species-specific movement into and out of the pitfall and stocking traps. Because the canister traps should reflect a cumulative catch, two hypothesis are likely: (1) *H. bicolor* and *L. infuscatus* have higher thresholds for CO_2 attraction and are proportionally less attracted to the closed-style traps that release less CO_2 or (2) *L. californicus* leaves the open traps at a higher rate compared with *H. bicolor* and *L. infuscatus* but cannot escape the closed traps.

Important characteristics of baited traps used for research or pest management decisions include the following: (1) some control over CO_2 production, (2) ease of trap assembly and deployment, and (3) rapid, accurate methods of wireworm extraction. Of the methods developed, Vernon et al[34] found that traps similar to those described by Chabert and Blot[31] adequately meet these criteria. These consisted of 450-mL plastic pots filled with medium-grade vermiculite, and with 100 mL each of untreated corn and hard red spring wheat spread in layers in the middle of the pot. The traps were soaked in warm water and within 24 hours placed in 15-cm deep holes, covered with soil on all sides and retrieved after 12 to 14 days. Vernon et al[34] found that all sizes of *Agriotes* spp wireworm could be extracted effectively using Tullgren funnels. The potted traps used in this study were similar in design, except that wheat and barley seed mixture was used as bait instead of corn. In this study, pitfall and stocking traps consistently caught the most wireworm, followed by pots, whereas canisters caught the fewest. These results are consistent with the hypothesis that traps with greater CO_2 release will attract more wireworm, and they may be more effective at detecting wireworm when their populations are low. Parker perforated the surface of plastic pots (350-mL size) with 24 evenly spaced holes (4 mm diameter) and filled the traps with a mix of soil and cereals.[14] This custom pot design caught the same number of wireworm as the traditional design. The additional holes may have released more attractive CO_2, and the wireworm can enter through the open top, compared with our canister design.

Trap consistency is another important variable to consider. One suggestion is that traps used for pest management decisions should have a RV value less than 25%.[35] We calculated RV values for each trap type (n = 40-50 traps) at each of the four locations (4-45 sampling dates pooled) and 3 sampling years (Figure 2). With one exception, the RV of each trap type at all four sites was below 25% during 2010 and 2011. During 2012, the RV exceeded 25% for more than half of the observations and was particularly high at the Bozeman site. With the exception of Denton in 2011, these four experimental sites in 2012 caught the fewest number of wireworm. These results are consistent with the fact that RV decreases with increasing trap catches.[15] The lowest RV values were observed at Conrad and Denton in 2010, and Bozeman in 2011, which had the highest trap catches (Figure 2). This trend is confirmed when the RV is calculated for all sites combined within a sampling year. In 2010, 3135 wireworm were collected and the RV was 20.7%, in 2011, 1560 wireworm were collected and the RV was 18.5%, and in 2012, only 402 wireworm were collected and the RV was 41.5%. Simmons et al[15] also noted that the accuracy of a relative sampling method improves when wireworm population are high.

Kirfman et al[36] suggested three desirable factors that an optimal sampling method should have: (1) minimum implementation and labor cost, (2) maximum sample precision and reliability, and (3) maximum sample efficiency. Following these criteria, the stocking traps performed the best in our study. The disposable stockings are inexpensive to purchase, easy to fill with the germinating bait, easy to deploy, and they efficiently trap wireworm. Traditional pitfall traps are similarly easy to use but are more difficult to collect because the germinating seed is not contained. Pot-style traps also contain the germinating seed, but they take more time to deploy and collect and provide no advantage over stocking traps. Plastic canister traps were the most expensive trap to construct and caught the fewest wireworm, but their design may be better suited for certain research trials and surveys. Canister traps can be mailed as a ready-to-deploy unit, and they contain the wireworm in a cumulative catch as exit from the trap is unlikely.[9]

Results obtained from this study illustrate several important criteria that should be considered when designing a wireworm trap for pest management or research purposes. Specifically, traps should be easy to deploy and collect, easy to collect the wireworm trapped, they should collect all species present in the field, and, finally, they should be inexpensive. Given the results of the efficacy of four traps for sampling wireworm in Montana, producers and practitioners now have an essential and reliable tool to sample the wireworm population in cereal fields.

Acknowledgements

The authors thank Mark Grubb (Conrad, Pondera County), Richard Barber (Denton, Fergus County), and Brian Tutvedt (Kalispell, Flathead County) for allowing us to collect wireworm and plant field trials on their cropland. They thank Emily Rohwer, Alix Bold, Branden Brelsford, Ammiel Branson, Meghan McGauley, Ruth O'Neill, Diana Florian, Hannah Johnson, and Laura Morales for their help in conducting this work. Frank Etzler helped to identify wireworm species. Paul S. Robbins and Kevin O'Neill provided comments to improve the manuscript.

Author Contributions

AM-R, AO, and KWW conceived and designed the experiments, agree with manuscript results and conclusions, jointly developed the structure and arguments for the paper, and made critical revisions and approved final version. AM-R analyzed the data and wrote the first draft of the manuscript. AO and KWW contributed to the writing of the manuscript. All authors reviewed and approved the final manuscript.

Disclosures and Ethics

As a requirement of publication, author(s) have provided to the publisher signed confirmation of compliance with legal and ethical obligations including but not limited to the following: authorship and contributorship, conflicts of interest, privacy and confidentiality, and protection of human and animal research subjects. The authors have read and confirmed their agreement with the ICMJE authorship and conflict of interest criteria. The authors have also confirmed that this article is unique and not under consideration or published in any other publication, and that they have permission from rights holders to reproduce any copyrighted material.

REFERENCES

1. Comstock JH, Slingerland MV. *Wireworm*. Geneva, NY: Cornell University Agricultural Experiment Station (Bulletin) 1891:33.
2. Toba HH, Turner JE. Evaluation of baiting techniques for sampling wireworm (Coleoptera: Elateridae) infesting wheat in Washington. *J Econ Entomol*. 1983;76:850–855.
3. Seal DR, Chalfant RB, Hall MR. Effectiveness of different seed baits and baiting methods for wireworm (Coleoptera: Elateridae) in sweetpotato. *Environ Entomol*. 1992;21:957–963.
4. Kohno K, Miyai S. Wireworm sampling by baiting technique. *Ann Rept Plant Prot North Japan*. 1993;44:107–108. https://www.jstage.jst.go.jp/article/kitanihon1966/1993/44/1993_44_107/_pdf.
5. Parker WE, Howard JJ. The biology and management of wireworms (*Agriotes* spp.) on potato with particular reference to the U.K. *Agric For Entomol*. 2001;3:85–98.
6. Toba HH, O'Keeffe LE, Pike KS, Perkins EA, Miller JC. Lindane seed treatment for control of wireworm (Coleoptera: Elateridae) on wheat in the Pacific Northwest. *Crop Prot*. 1985;4:372–380.
7. Vernon RS, van Herk WG, Clodius M, Harding C. Crop protection and mortality of *Agriotes obscurus* wireworm with blended insecticidal wheat seed treatments. *J Pest Sci*. 2013;86:137–150.
8. Seibert CE. *A Faunal Survey of the Elateroidea of Montana* [MSc thesis]. Bozeman, MT: Department of Plant Science & Plant Pathology Montana State University; 1993:320.
9. Morales-Rodriguez A, O'Neill R, Wanner KW. A survey of wireworm (Coleoptera: Elateridae) species infesting cropland in Montana. *Pan-Pac Entomol*. 2014;90:1–10.
10. Furlan L. An IPM approach targeted against wireworm: what has been done and what has to be done. *IOBC/WPRS Bull*. 2005;28:91–100.
11. Andrews N, Ambrosino M, Fisher G, Rondon SI. Wireworm. Biology and non-chemical management in potatoes in the Pacific Northwest. http://hdl.handle.net/1957/20798. Published 2008. Accessed May 15, 2015.
12. Zacharuk RY. Seasonal behavior of larvae of *Ctenicera* spp. and other wireworm (Coleoptera: Elateridae), in relation to temperature, moisture, food, and gravity. *Can J Zool*. 1962;40:697–718.
13. Doane JF. Movement on the soil surface of adult *Ctenicera aeripennis* destructor (Brown) and *Hypolithus bicolor* Esch. (Coleoptera: Elateridae), as indicated by funnel pitfall traps, with notes on captures of other arthropods. *Can Entomol*. 1961;93:636–644.
14. Parker WE. The development of baiting techniques to detect wireworm (*Agriotes* spp., Coleoptera: Elateridae) in the field, and the relationship between trap catches and wireworm damage to potatoes. *Crop Prot*. 1996;15:521–527.
15. Simmons CL, Pedigo LP, Rice ME. Evaluation of seven sampling techniques for wireworm (Coleoptera: Elateridae). *Environ Entomol*. 1998;27:1062–1068.
16. Horton D. Quantitative relationship between potato tuber damage and counts of Pacific Coast wireworm (Coleoptera: Elateridae) in baits: seasonal effects. *J Entomol Soc British Columbia*. 2006;103:37–48.
17. Southwood TRE. *Ecological Methods: With Particular Reference to the Study of Insect Populations*. London, England: Chapman & Hall; 1979.
18. Gibson KE. Wireworm damage to potatoes in the Yakima Valley of Washington. *J Econ Entomol*. 1939;32:122–124.
19. Salt G, Hollick FSJ. Studies of wireworm populations. I. A census of wireworm in pasture. *Ann Appl Biol*. 1944;31:52–64.
20. Yates F, Finney DJ. Statistical problems in field sampling for wireworm. *Ann Appl Biol*. 1942;29:156–167.
21. Anon. Wireworms and food production. A wireworm survey of England and Wales (1939-42). *Bull Minist Agric*. 1948;128.
22. Doane JF, Lee YW, Klinger J, Westcott ND. The orientation response of *Ctenicera destructor* and other wireworm (Coleoptera: Elateridae) to germinating grain and carbon dioxide. *Can Entomol*. 1975;107:1233–1252.
23. Bynum ED Jr, Archer TL. Wireworm (Coleoptera: Elateridae) sampling for semiarid cropping systems. *J Econ Entomol*. 1987;80:164–168.
24. Jansson RK, Lecrone SH. Evaluation of food baits for pre-plant sampling of wireworms (Coleoptera: Elateridae) in potato fields in southern Florida. *Florida Entomol*. 1989;72:503–510.
25. Horton D, Landolt P. Orientation response of Pacific coast wireworm (Coleoptera: Elateridae) to food baits in laboratory and effectiveness of baits in field. *Can Entomol*. 2002;134:357–367.
26. Vernon RS, Kabaluk T, Behringer A. Aggregation of *Agriotes obscurus* (Coleoptera: Elateridae) at cereal bait stations in the field. *Can Entomol*. 2003;135:379–389.
27. Furlan L, Bonetto C, Finotto A, et al. The efficacy of biofumigant meals and plants to control wireworm populations. *Ind Crop Prod*. 2010;31:245–254.
28. Parker WE. Evaluation of the use of food baits for detecting wireworm (*Agriotes* spp., Coleoptera: Elateridae) in fields intended for arable crop production. *Crop Prot*. 1994;13:271–276.
29. Vernon RS, Kabaluk T, Behringer A. Movement of *Agriotes obscurus* (Coleoptera: Elateridae) in strawberry (Rosaceae) plantings with wheat (Gramineae) as a trap crop. *Can Entomol*. 2000;132:231–241.
30. Ward RH, Keaster AJ. Wireworm baiting: use of solar energy to enhance early detection of *Melanotus depressus*, *M. verberans* and *Aeolus mellilus* in midwest cornfields. *J Econ Entomol*. 1977;70:403–406.
31. Chabert A, Blot Y. Estimation des populations larvaires de taupins par un peige attractif. *Phytoma*. 1992;436:26–30.
32. Etzler FE, Wanner KW, Morales-Rodriguez A, Ivie MA. DNA barcoding to improve the species-level management of wireworm (Coleoptera: Elateridae). *J Econ Entomol*. 2014;104:1476–1485.
33. Buntin GD. Developing a primary sampling program. In: Pedigo LP, Buntin GD, eds. *Handbook of Sampling Methods for Arthropods in Agriculture*. Boca Raton, FL: CRC Press; 1994:99–115.
34. Vernon RS, van Herk WG, Clodius M, Harding C. Wireworm management I: stand protection versus wireworm mortality with wheat seed treatments. *J Econo Entomol*. 2009;102:2126–2136.
35. Pedigo LP. Introduction to sampling arthropods populations. In: Pedigo LP, Buntin GD, eds. *Handbook of Sampling Methods for Arthropods in Agriculture*. Boca Raton, FL: CRC; 1994:1–11.
36. Kirfman GW, Keaster AJ, Story RN. An improved wireworm (Coleoptera: Elateridae) sampling technique for Midwest cornfields. *J Kans Entomol Soc*. 1986;59:37–41.