GIESEL, J. T. 1988. Effects of parental photoperiod on development time and density sensitivity of progeny in *Drosophila melanogaster*. Evolution 42: 1348-1350.

GIESEL, J. T., C. A. LANCIANI, AND J. F. ANDERSON. 1989. The effects of photoperiod and genotype on metabolic rate in *Drosophila melanogaster*. Florida Entomol. 72: 123-128.

GRIGO, F., AND W. TOPP. 1980. Einfluss von Adaptationstemperatur und Photoperiode auf den Saurstoffverbrauch bei Staphyliniden (Col.) in Diapause und Non-Diapause. Zoologischer Anzeiger 204: 19-26.

VLECK, D. 1987. Measurement of O_2 consumption, CO_2 production, and water vapor production in a closed system. J. Appl. Physiol. 62: 2103-2106.

EVALUATION OF FOOD BAITS FOR PRE-PLANT SAMPLING OF WIREWORMS (COLEOPTERA: ELATERIDAE) IN POTATO FIELDS IN SOUTHERN FLORIDA

RICHARD K. JANSSON AND SCOTT H. LECRONE
University of Florida
Institute of Food and Agricultural Sciences
Tropical Research and Education Center,
18905 S. W. 280 St.,
Homestead, Florida 33031

ABSTRACT

Experiments were conducted during two consecutive growing seasons to evaluate food baits for pre-plant sampling of wireworms that attack potato in southern Florida. Wireworm species studied were: *Melanotus communis* (Gyllenhal), southern potato wireworm, *Conoderus falli* Lane, *C. amplicollis* (Gyllenhal), and *C. rudis* (Brown). Baits evaluated were hybrid sweet corn seed, hybrid sorghum-sudangrass seed, a 1:1 mixture of corn and sorghum-sudangrass seed, a whole sweet corn ear, potato seed pieces, a 1:1 mixture of oatmeal and corn flake, rolled oats, and carrots. In the first year, numbers of wireworm larvae did not differ between food bait and soil samples for most food baits tested. *Melanotus communis* larvae were most numerous in the oatmeal-corn flake and sorghum-sudangrass seed baits. *Conoderus* spp. larvae were most numerous in the sorghum-sudangrass seed and corn ear baits. In the second year, *M. communis* larvae were more numerous in food baits than in soil samples, and more numerous in the oatmeal-corn flake and rolled oat baits than in other food baits. Numbers of *Conoderus* spp. larvae did not differ between food bait and soil samples nor among food baits. In addition to attracting more wireworms, oatmeal-corn flake and rolled oat baits had some of the shorter processing times. The use of one of these two baits is currently recommended for pre-plant sampling of wireworms in potato fields in southern Florida.

RESUMEN

Se hicieron experimentos antes de la siembra durante dos temporadas de crecimiento consecutivos para evaluar cebos como muestreo de gusanos de alambre que atacan la papa en el sur de la Florida. Las especies estudiadas fueron: *Melanotus communis* (Gyllenhal), *Conoderus falli* Lane, *C. amplicollis* (Gyllenhal, y *C. rudis* (Brown). Los cebos evaluados fueron semilla de un híbrido de maíz dulce, semilla de un híbrido de sorgo-hierba de sudán, una mezcla 1:1 de semilla de maíz y sorgo-hierba de sudán, una mazorca completa de maíz dulce, pedazos de semillas de papa, una mezcla de 1:1 de harina de avena y copos de maíz, avena "enrollada", y zanahorias. En el primer año, no hubo diferencia en el número de gusanos de alambres entre los cebos y las muestras de tierra en la mayoría de las cebos probados. Larvas de *Melanotus communis* fueron más numerosas en los cebos de harina de avena-copos de maíz y en semillas de sorgo-hierba de sudán. Larvas de *Conoderus* spp. fueron más numerosas en semillas de sorgo-hierba de sudán y en mazorcas completas de maíz. En el segundo año, larvas de *M. communis* fueron más numerosas en cebos que en muestras de suelo, y más numerosas en la harina de avena-copos de maíz y en avena "enrollada" que en otros cebos. No hubo diferencia en el número de larvas de *Conoderus* spp. entre los cebos y las muestras de tierra, ni entre los cebos. Aparte de que atrayeron más gusanos de alambre, cebos de harina de avena-copos de maíz y de avena "enrollada" tuvieron uno de los tiempos más cortos de procesamiento. Se recomienda el uso de uno de estos dos cebos para el muestreo de gusanos de alambre antes de la siembra de papas en el sur de la Florida.

Irish potato, *Solanum tuberosum* L., is an economically important winter crop in southern Dade County, Florida. Over 2,000 ha of potato are grown in Dade County (Jansson 1987) with a crop value in excess of $12 million (Anonymous 1988). In southern Florida, unlike most other regions of the United States, potatoes are planted between October and December and harvested between February and April.

Wireworms are the most important insect pests of potato in southern Florida (Jansson 1987). Several species attack potato, including *Melanotus communis* (Gyllenhal), *Conoderus falli* Lane, southern potato wireworm, *C. amplicollis* (Gyllenhal), and *C. rudis* (Brown). *Melanotus communis* is the most important wireworm species that attacks potato and the most abundant wireworm species on sugarcane and celery in southern Florida (Wilson 1940). During the 1986-1987 and 1987-1988 growing seasons, the quality of up to 45% of the potato crop in many plantings was reduced from U. S. No. 1 to U. S. No. 2 due to wireworm injury (Jansson, personal observation). Adults of these species oviposit in soil cracks and crevices beneath the summer cover crop, a sorghum-sudangrass hybrid, and larvae that eclose feed on tubers in the following winter potato crop.

Currently, a pre-plant sampling method for wireworms in potato fields in southern Florida is lacking. Historically, growers have sampled for wireworms before planting by removing several soil samples (about 3,540 cm^3 [15.2 cm]^3) from each field. Because potatoes are grown in a heavy, clay soil (Perrine marl), samples are not inspected by hand sorting, but are washed through a series of progressively smaller screens. This procedure is time consuming and its reliability is unknown. For this reason, alternative methods for sampling wireworms in potato fields are needed.

Several studies investigated the use of food baits for sampling wireworms in soil. Apablaza et al. (1977) recommended wheat seed, wheat:corn seed mixtures, and grain sorghum baits for sampling *Melanotus* spp. infesting corn fields in the midwestern United States. Sorghum seed baits were as effective or better than wheat-corn seed baits for sampling wireworms in Texas (Foster & Ward 1976). Oatmeal baits were most attractive to *Ctenicera destructor* (Brown) and *Hypolithus bicolor* Eschscholtz in Canada (Doane 1981). Whole wheat-corn mixtures (1:1) and wheat flour baits were most attractive to wireworms, primarily *Ctenicera pruinina* (Horn), in Washington (Toba & Turner 1983). The present study was conducted to (1) evaluate various food baits for sampling wireworms before planting potatoes in southern Florida, (2) compare the effectiveness of food baits with soil samples for sampling wireworms, and (3) determine the time required to process various food baits.

Materials and Methods

Experiments were conducted 2-3 weeks before potatoes were planted in 1986 and 1987 on two commercial potato farms in southern Dade County Florida. All fields sampled consisted of a Perrine marl soil and had been planted with a sorghum-sudangrass bags. Food baits and soil samples were stored in a cold room until washed as previously described. All *M. communis* and *Conoderus* spp. larvae found per food bait and soil sample and the processing time of each food bait were recorded.

Daily air temperature and rainfall data were monitored using an environmental data logger located at the University of Florida, I.F.A.S., Tropical Research and Education Center approximately 12 km southwest of the study sites.

Data were analyzed using least squares analysis of variance techniques (Neter and Wasserman 1974). Numbers of *M. communis* and *Conoderus* spp. larvae were transformed to $ln(X+1)$, and processing times were square-root transformed to stabilize error variance. The Shapiro-Wilk test and normal probability plots were used to assess homogeneity of error variance (Shapiro and Wilk 1965, Zar 1984). Treatment means were separated using the Waller-Duncan *K*-ratio *t* test (Waller and Duncan 1969). Numbers caught in food baits and soil samples were compared by a *t*-test (Zar 1984). The mean and variance of wireworm numbers in many corresponding soil samples for some food baits were equal to O. For this reason, we assumed the expected values of these samples were equal to O. A 95% confidence interval was calculated for each food bait. Soil and food bait means were significantly different if O was outside the range of the confidence interval of the food bait.

Results and Discussion

1986

More wireworm larvae were found in food baits than in soil samples although results were not consistently significant (Table 1). Numbers of *M. communis* and *Conoderus* spp. larvae did not differ among most food baits. *Melanotus communis* larvae were 3.2- to 4.6-times more numerous in oatmeal-corn flake and sorghum-sudangrass seed baits than in potato and corn seed baits (Table 1). *Conoderus* spp. larvae were more abundant in sweet corn ear and sorghum-sudangrass seed baits than in oatmeal-corn flake and corn-sorghum-sudangrass seed baits. Overall, wireworm larvae were most abundant in the sorghum-sudangrass seed bait followed in decreasing order by oatmeal-corn flake, corn-sorghum-sudangrass seed, sweet corn ear, potato seed, and corn seed. The low attractiveness of corn seed bait was probably related to poor germination (10-20%). During seed germination, seeds respire and release carbon dioxide to the surrounding soil (Currie 1973). Wireworms reportedly orient towards germinating seed by using carbon dioxide gradients in soils (Doane et al. 1975). Although the oatmeal-corn flake bait, which was most attractive to *M. communis* larvae, was not a germinated medium, it did partially decompose. Thus, wireworm larvae probably oriented towards this bait using the carbon dioxide gradient produced in the soil from bait decomposition.

Processing times differed ($F = 31.05$; $df = 5.55$; $P = 0.0001$) among food baits (Table 2). The corn-sorghum-sudangrass seed and the sorghum-sudangrass seed baits required 1.8- to 2.2- and 2.1- to 2.5-times longer to process, respectively, than all other baits. Among the two most attractive food baits, the oatmeal-corn flake bait required about one-half the time needed to process the sorghum-sudangrass seed bait.

1987

As in 1986, more wireworm larvae were found in food baits than in soil samples, although results were not consistently significant (Table 1). Between 1.4-5.4, 0.6-1.8, and 0.1-0.4 *M. communis* larvae were found per food bait in experiments 2-4, respectively, whereas 0-0.1, 0-0.2, and 0 *M. communis* larvae were found per soil sample in the three experiments respectively. Similarly, 0.1-0.6 and 0-0.2 *Conoderus* spp. larvae were found per food bait in experiments 2 and 3, respectively, compared with 0-0.2 and 0-0.1 *Conoderus* spp. larvae per soil sample in these two experiments, respectively. No *Conoderus* spp. larvae were collected in food baits or soil samples in experiment 4.

TABLE 1. MEAN NUMBERS (± SEM)[a] OF *CONODERUS* SPP AND *M. COMMUNIS* LARVAE COLLECTED IN VARIOUS FOOD BAIT AND SOIL SAMPLES IN POTATO FIELDS 2-3 WEEKS BEFORE PLANTING IN HOMESTEAD, FLORIDA.

Bait	*Conoderus* larvae		*M. communis* larvae	
	Bait sample	Soil sample	Bait sample	Soil sample
		Experiment 1		
Corn seed	0.1(0.1)ab,A	0.0(0.0)a,A	0.7(0.2)b,A	0.0(0.0)a,B
Oatmeal-corn flake	0.0(0.0)b,A	0.0(0.0)a,A	3.2(1.2)a,A	0.1(0.1)a,B
Sorghum-sundagrass seed	0.6(0.2)a,A	0.0(0.0)a,B	3.2(1.5)a,A	0.0(0.0)a,A
Corn-sorghum-sundangrass seed	0.0(0.0)b,A	0.2(0.2)a,A	2.5(1.4)ab,A	0.0(0.0)a,A
Corn ear	0.8(0.5)a,A	0.0(0.0)a,A	1.4(0.7)ab,A	0.0(0.0)a,A
Potato seed	0.1(0.1)ab,A	0.1(0.1)a,A	1.0(0.6)b,A	0.1(0.1)a,A
		Experiment 2		
Corn seed	0.4(0.2)a,A	0.2(0.1)a,A	2.5(0.7)ab,A	0.0(0.0)a,B
Oatmeal-corn flake	0.2(0.2)a,A	0.0(0.0)a,A	5.4(1.9)a,A	0.1(0.1)a,B
Sorghum-sundangrass seed	0.6(0.3)a,A	0.0(0.0)a,A	2.5(0.8)ab,A	0.0(0.0)a,B
Corn-sorghum-sudangrass seed	0.1(0.1)a,A	0.0(0.0)a,A	2.3(0.7)ab,A	0.0(0.0)a,B
Corn ear	0.0(0.0)a,A	0.0(0.0)a,A	2.7(0.5)ab,A	0.0(0.0)a,B
Potato seed	0.1(0.1)a,A	0.1(0.1)a,A	1.4(0.8)b,A	0.0(0.0)a,A
Carrot	0.3(0.2)a,A	0.1(0.1)a,A	2.1(0.9)ab,A	0.0(0.0)a,B
Rolled oat	0.1(0.1)a,A	0.2(0.1)a,A	5.4(1.6)a,A	0.0(0.0)a,B

[a]Numbers of *Conoderus* spp. and *M. communis* larvae were transformed to *ln* (X + 1) to stabilize error variance. Nontransformed means are presented. Means within each column of each experiment followed by the same lowercase letter are not significantly different (*K*-ratio = 100; Waller-Duncan *K*-ratio *t*-test). Soil and food bait means for each wireworm species within each experiment followed the same uppercase letter are not significantly different ($P > 0.05$; based on a *t*-test or on 95% confidence interval of food bait when no wireworms were found in soil samples [means differed if 0 was outside the range of the 95% confidence interval of the food bait]).

Wireworms were most abundant in experiment 2 followed in decreasing order by experiments 3 and 4. Differences in wireworm abundance among experiments might be due, in part, to the length of time the cover crop was present in each field. McSorley et al. (1987) found that wireworm abundance and subsequent damage to potato were positively correlated with the length of time that the cover crop was present in potato fields.

In experiment 2 wireworm numbers did not differ among most food baits (Table 1), although they tended to be more numerous (although not significantly) in the oatmeal-corn flake and rolled oat baits. *Melanotus communis* larvae were 3.9-times more numerous in the oatmeal-corn flake and rolled oat baits than in the potato seed bait. Numbers

TABLE 2. MEAN TIME (± SEM) (MINUTES) REQUIRED TO PROCESS VARIOUS FOOD BAIT SAMPLES PLACED IN POTATO FIELDS 2-3 WEEKS BEFORE PLANTING IN HOMESTEAD, FLORIDA.

	Processing time of food bait, min.[a] Experiment			
Bait	1	2	3	4
Corn seed	25.6(2.0)b	26.0(1.2)a	13.3(0.1)a	17.4(1.1)a
Oatmeal-corn flake	29.2(4.2)b	19.9(1.4)b	13.1(0.6)a	15.4(0.4)bc
Sorghum-sudangrass seed	61.9(4.6)a	20.5(2.2)b	13.3(0.3)a	17.2(0.6)ab
Corn-sorghum-sudangrass seed	55.2(4.4)a	26.8(0.7)a	13.6(0.3)a	18.6(1.2)a
Corn ear	25.7(2.4)b	19.6(0.8)b	13.1(0.1)a	12.8(0.7)d
Potato seed	25.7(3.8)b	17.7(0.8)b	13.7(0.2)a	14.0(0.5)cd
Carrot	—	19.0(1.9)b	13.2(0.4)a	14.4(0.4)cd
Rolled oat	—	21.0(0.8)b	14.2(0.5)a	14.9(0.7)c

[a]Means within a column followed by the same letter are not significantly different (*K*-ratio = 100; Waller-Duncan *K*-ratio *t*-test).

of *Conoderus* spp. larvae did not differ (F = 1.3; *df* = 6,49; *P* = 0.27) among food baits. The significant variation found among blocks (F = 3.6; *df* = 7,49; *P* = 0.004) probably reduced the sensitivity of tests. For example, the ranges of *M communis* larvae collected in food baits were 0-5, 0-16, 0-6, 0-4, 1-5, 0-7, 0-6, and 1-14 in corn seed, oatmeal-corn flake, sorghum-sudangrass seed, corn-sorghum-sudangrass seed, sweet corn ear, potato seed, carrot, and rolled oat baits, respectively.

In experiments 3 and 4, numbers of wireworm larvae did not differ ($F \leq 1.8$; df = 7,56; $P \geq 0.11$) among food baits. The lower abundance of wireworms in experiments 3 and 4 probably reduced the sensitivity of tests.

In 1986, insecticide-treated seed baits were used, whereas in 1987, nontreated seed baits were used. However, the use of insecticide-treated seed in 1986 probably had little, if any, affect on the numbers of wireworm larvae collected in seed baits since the use of nontreated seed baits in 1987 did not increase the number of wireworms collected in baits as compared with the oatmeal-corn flake and rolled oat baits.

Processing times differed ($F \leq 6.50$; df = 7,56; P = 0.0001) among food baits in experiments 2 and 4, but did not differ in experiment 3 (F = 12.9; df = 7,56; P = 0.33) (Table 2). In experiments 2 and 4, the corn seed and corn-sorghum-sudangrass seed baits required 1.1- to 1.4- and 1.2- to 1.5-fold more time to process than most other baits. Potato seed, sweet corn ear, and carrot consistently required the least time to process, and their processing times were not significantly shorter than oatmeal-corn flake and rolled oat baits in most experiments.

Processing times of seed baits were considerably shorter in 1987 than in 1986. Germination of corn seed and sorghum-sudangrass seed was high (99%) in 1987. However, when baits were dug, seedlings were only about one-fourth the size of those in 1986. The smaller size of seedlings in seed baits was probably due to cooler mean daily air temperatures in 1987 (averaged between 19.0 and 20.9° C in the three experiments) than in 1986 (24.9° C). Also, less precipitation fell during the experiment in 1987 (4.4 cm of total rainfall) than in 1986 (5.3 cm of total rainfall) which probably affected seedling size and subsequent processing times of seed baits.

The difference in processing times among the 3 experiments in 1987 was probably related, in part, to the order in which samples were processed and to differences in numbers of wireworms collected among experiments. Baits from experiment 4 were processed first, followed by experiments 2 and 3. The consistently shorter processing times in experiment 3 are unclear, but might have been associated with an improved efficiency of the processor. More time was probably needed to process baits in experiment 2 than in experiments 3 and 4 because 3.2 and 15.2 times more wireworms were found in experiment 2 than in experiments 3 and 4, respectively. Differences in processing times between 1986 and 1987 were probably due, in part, to different processors. Nevertheless, in 1987, the two most attractive baits, oatmeal-corn flake and rolled oat, required shorter processing times.

This study showed that food bait samples caught more (although not consistently significant) wireworm larvae than soil samples in the Perrine marl soil of potato fields. Oatmeal-corn flake and rolled oat baits were two of the most attractive food baits tested and required relatively short times to process. We currently recommend the use of one of these two baits for pre-plant sampling of wireworms in potato fields in southern Florida. Because fields are routinely planted with the cover crop during the summer, oatmeal baits should be placed in fields during the short time interval (1-2 months) between the discing of the cover crop in September or October and planting (October-December). Current studies are determining the number of rolled oat bait samples required per field to reliably estimate wireworm larval populations before planting potatoes.

ACKNOWLEDGMENTS

We thank A. G. B. Hunsberger, R. Stover, R. Vives, and C. Kouns for assisting with data collection, K. Portier (University of Florida, I.F.A.S., Statistics, Gainesville) for statistical advice, and R. H. Cherry (University of Florida, I.F.A.S., Everglades Research and Education Center, Belle Glade), R. B. Chalfant (University of Georgia, Coastal Plain Experiment Station, Tifton), and T. L. Archer (Texas A & M University, Agricultural Research and Extension Center, Lubbock) for criticially reviewing the manuscript. This study was supported by a research grant (to R. K. J.) from the South Dade County Potato Growers Association. This is Florida Agricultural Experiment Station Journal Series No. 9075.

REFERENCES CITED

ANONYMOUS. 1988. Dade County agriculture. Dade County/Institute of Food and Agricultural Sciences Cooperative Extension, Homestead, Florida. 1 p.

APABLAZA. J. U., A. J. KEASTER, AND R. H. WARD. 1977. Orientation of corn-infesting species of wireworms toward baits in the laboratory. Environ. Entomol. 6: 715-718.

BRYSON, H. R. 1935. Observation on the seasonal activities of wireworms. J. Kansas Entomol. Soc. 8: 131-140.

BYNUM, E. D., JR., AND T. L. ARCHER. 1987. Wireworm (Coleoptera: Elateridae) sampling for semiarid cropping systems. J. Econ. Entomol. 80: 164-168.

CAMPBELL, R. E. 1937. Temperature and moisture preference of wireworms. Ecology 18: 479-489.

CURRIE, J. A. 1973. The seed-soil system, pp. 463-480. *in* W. Heydcker [ed.], Seed ecology. The Pennsylvania State University Press, University Park, Pa.

DOANE, J. F. 1981. Evaluation of a larval trap and baits for monitoring the seasonal activity of wireworms in Saskatchewan. Environ. Entomol. 10: 335-342.

DOANE, J. F., Y. W. LEE, J. KLINGER, AND N. D. WESTCOTT. 1975. The orientation response of *Ctenicera destructor* and other wireworms (Coleoptera: Elateridae) to germinating grain and to carbon dioxide. Canadian Entomol. 107: 1233-1252.

FOSTER, D. G., AND C. R. WARD. 1976. Wireworm bait traps in grain sorghum. Texas Agric. Exp. Stn. PR-3425.

FULTON, B. B. 1928. Some temperature relations of *Melanotus*. J. Econ. Entomol. 21: 889-897.

JANSSON, R. K. 1987. The east glades: battling frost and wireworms to produce winter potatoes in south Florida. Spudman 25(3): 18, 37-38.

JONES, E. W. 1951. Laboratory studies on the moisture relations of *Limonius* (Coleoptera: Elateridae). Ecology 32: 284-293.

LEES, A. D. 1943. On the behavior of wireworms of the genus *Agriotes* Esch. (Coleoptera: Elateridae). II. Reactions to moisture. J. Exp. Biol. 15: 54-60.

MCSORLEY, R., J. L. PARRADO, R. V. TYSON, V. H. WADDILL, M. L. LAMBERTS, AND J. S. REYNOLDS. 1987. Effects of sorghum cropping practices on winter potato production. Nematropica 17: 45-60.

NETER, J., AND W. WASSERMAN. 1974. Applied linear statistical models. Irwin, Homewood, Ill.

SHAPIRO, S. S., AND M. B. WILK. 1965. An analysis of variance test for normality (complete samples). Biometrika 52: 591-611.

TOBA, H. H., AND J. E. TURNER. 1983. Evaluation of baiting techniques for sampling wireworms (Coleoptera: Elateridae) infesting wheat in Washington. J. Econ. Entomol. 76: 850-855.

WALLER, R. A., AND D. B. DUNCAN. 1969. A Bayes rule for the symmetric multiple comparisons problem. J. Amer. Statist. Assn. 64: 1484-1503.

WARD, R. H., AND A. J. KEASTER. 1977. Wireworm baiting: use of solar energy to enhance early detection of *Melanotus depressus*, *M. verberans*, and *Aeolus mellillus* in midwest cornfields. J. Econ. Entomol. 70: 403-406.

WILSON, J. W. 1940. Preliminary report on wireworm investigations in the Everglades. Florida Entomol. 23: 1-6.

ZAR, J. H. 1984. Biostatistical analysis. Prentice-Hall Inc., Englewood Cliffs, N. J.