1976

Topical LD50 Determinations for Several Insecticides on Field Collected Larval and Adult Western Corn Rootworms

Leland L. Barthelman

TOPICAL LD_{50} DETERMINATIONS FOR SEVERAL INSECTICIDES ON FIELD COLLECTED LARVAL AND ADULT WESTERN CORN ROOTWORMS

BY

LELAND L. BARTHELMAN

A thesis submitted
in partial fulfillment of the requirements for the
degree Master of Science, Major in
Entomology, South Dakota
State University

1976

302

TOPICAL LD_{50} DETERMINATIONS FOR
SEVERAL INSECTICIDES ON FIELD COLLECTED
LARVAL AND ADULT WESTERN CORN ROOTWORMS

This thesis is approved as a creditable and independent investigation by a candidate for the degree, Master of Science, and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

Thesis Adviser Date

Head, Entomology-Zoology Department Date

ACKNOWLEDGMENTS

The author wishes to express his sincere appreciation to Dr. David D. Walgenbach for his guidance and assistance in carrying out the research and in preparing this thesis.

The author is deeply grateful to Dr. Robert J. Walstrom for his assistance and council throughout this research. Special thanks is due Mr. Mick Holm, fellow graduate student, for his kind words of encouragement and helpful suggestions.

Thanks is also due the staff of the Entomology-Zoology Department and Northern Grain Insects USDA Lab, for providing assistance and facilities to conduct the study.

And a very special thanks to my wife, Maurita, for making it all worthwhile.

LLB

TABLE OF CONTENTS

LIST OF TABLES

INTRODUCTION

The western and northern corn rootworms, Diabrotica virgifera LeConte and Diabrotica longicornis (Say), have caused severe losses to corn producers of the Midwest. Preventive insecticidal treatments for rootworm control comprise the largest pesticide expenditure on corn. An estimated 1.6 million acres of corn are treated annually for rootworm control in South Dakota at a cost of approximately $5.00 per acre (Walgenbach, Personal Communication, 1975). Inadequacies in application and the failure of insecticide performance can cause extreme losses in corn yield.

The rootworm complex in South Dakota is composed of the western and northern corn rootworms. At present the western species is the major pest of the complex; however, its presence in the state dates back many years. Collection of the western corn rootworm dates as far back as 1922 in Jones County (Kantack 1965). Prior to 1961 the northern corn rootworm was the predominant species in South Dakota. The steep rise in the western population can be attributed to favorable weather conditions and their resistance to soil insecticides.

The first recommended control practice for rootworms was a cultural technique, namely crop rotation (Gillette 1912, Hill et al. 1948). In 1948 benzene hexachloride[1] was added as a means of controlling the

[1]All chemical names for insecticides in Appendix A.

rootworm (Hill et al. 1948, Muma et al. 1949).

Following World War II many chlorinated hydrocarbons were implemented for control, such as: aldrin, heptachlor, dieldrin, chlordane and lindane (Burkhardt 1954, Lilly 1954, Bigger and Blanchard 1955, Ball 1956).

Roselle et al. (1959) reported ineffective control with aldrin and heptachlor in Nebraska during 1959. The control problems were on irrigated land where corn and soil insecticides were planted and used annually. With continuous corn and annual applications of persistent chlorinated hydrocarbons to the same soil, conditions for the development of resistance were very favorable.

Research was begun in 1962 by Ball and Weekman with the use of topical evaluations for monitoring insecticide resistance. Ball and Weekman (1962) ran 2-hour topical evaluations with aldrin, heptachlor and diazinon, an organophosphate, on adult western corn rootworms, and indicated that larvae should demonstrate resistance to the same or to a greater degree than shown for the adults. Ball and Weekman (1963) presented adult 24-hour LD_{50} data for aldrin and 2-hour data with diazinon. Field collected beetles from isolated areas were shown to be resistant to the chlorinated hydrocarbon insecticides while other areas showed susceptability. Ball and Weekman indicated there was no appreciable difference between LD_{50} values for adults and larvae with no comparative data presented.

Hamilton (1966) showed that aldrin LD_{50} values for larvae were much higher than those for adults and that the LD_{50} values for the adults decreased as the season progressed. In only one of three collection

sites were the LD_{50} values of the larvae and adults similar. In the remaining sites the larval LD_{50} values were 3 to 4 times greater than the adult values.

Arnold and Whitten (1975), working in Australia with Lucilia cuprina (Wiedemann), Australian sheep blowfly, demonstrated with LC_{50} levels the lack of correlation between the larvae and adults to resistance of diazinon.

The Entomological Society of America published a tentative method for detection of insecticide resistance in Diabrotica species (Anonymous 1972). In this publication only Diabrotica adults were used for evaluating insecticide resistance on a 24-hour basis.

I began studies in 1975 to determine topical data for several insecticides on field collected larvae and adult western corn rootworms. The purpose of this research is to determine if correlations exist between adult and larval LD_{50} levels using organophosphates and carbamates, as well as comparisons of the larval LD_{50} data to field performance data.

LITERATURE REVIEW

The corn rootworm population in South Dakota is composed primarily of the western and northern corn rootworms. The two species have such similar life histories that no distinctions will be made.

There is a single generation per year and overwintering occurs in the egg stage. The larvae first begin to appear in mid-June. It requires several weeks for all eggs to hatch, so larvae of all sizes can be found during late June and early July. Once the larvae become full grown they undergo a change into an inactive stage called the pupae. Pupation occurs in two weeks after which the adults begin to emerge, which is from July to early September (Kantack et al. 1975).

Both the larvae and adults damage corn, with the larval damage being most severe. The larvae feed on the underground portions of the plant where the smaller roots are consumed and the larger roots tunneled. This injury reduces the amount of water and nutrients available to the plant for growth and ear development, consequently reducing yield. Disease organisms often follow the attack by rootworms causing further damage.

The adults feed on all above-ground portions of the plant with the main focus on the tassels and silks. This feeding reduces pollination resulting in improper filling of ears, thus reducing yield.

The first reported western corn rootworm attack was in 1909 in Colorado on sweet corn (Gillette 1912). The insect was not unique to Colorado for in 1922 isolated populations of the western adults were discovered in South Dakota (Kantack 1965).

The rootworm continued to spread and multiply causing severe economic losses to corn producers. Damage to corn was detected in Kansas in 1945 in Norton County (Bryson et al. 1953). Surveys conducted then showed an eastward movement in Kansas.

The first recommended control measure was crop rotation, even Gillette back in 1912 thought crop rotation to be a remedy (Gillette 1912, Hill et al. 1948).

Hill et al. (1948), working in Nebraska during 1946 first demonstrated the use of chlorinated hydrocarbons for controlling corn rootworm infestations. Effective reduction in root damage and lodging was obtained with 0.5, 1.0 and 2.0 pounds per acre of benzene hexachloride (10% gamma isomer) applied as a preplow broadcast spray. DDT applied in the same manner at 5 and 10 pounds per acre was considerably less effective. However, aerial application of a 3% dust of DDT at 25 to 30 pounds per acre gave excellent reduction in adult rootworm populations. Muma et al. (1949) continued to study insecticide effectiveness in Nebraska during 1948 using benzene hexachloride, toxaphene and rotenone. Benzene hexachloride applied at the 1 and 2 pound rates per acre was found to give control for at least two seasons. Toxaphene at 2 and 4 pounds per acre rates was unable to give effective control of the rootworm infestation. Yield increases following insecticidal control seemed to be dependent upon soil fertility as expressed by available nitrogen.

Cox and Lilly (1953) working in Iowa during 1952 tested aldrin, chlordane, dieldrin and heptachlor as broadcast sprays before planting, starter fertilizer mixtures at planting, and fertilizer mixtures

side-dressed after emergence for the control of northern corn rootworms. Reduction in rootworm numbers and plant lodging was obtained with 0.75 pounds per acre of aldrin, chlordane and dieldrin as broadcast sprays. Good control was also obtained with 1.0 pound per acre of aldrin, chlordane and dieldrin when applied as starter fertilizer mixtures. Aldrin, chlordane, dieldrin and heptachlor at 8 ounces per acre applied in a band over the row after emergence gave sufficient control as well. Further investigation by Lilly (1954) in Iowa during 1953 showed that northern corn rootworms could be controlled using 0.5 pounds of heptachlor, 0.6 pounds of aldrin and 0.8 pounds per acre of chlordane mixed with starter fertilizer. In the same study he obtained effective reduction in rootworms and lodging with preplow broadcast sprays of aldrin, heptachlor, endrin and benzene hexachloride at 1.0 pound per acre.

Burkhardt (1954) conducted tests in Kansas on western corn rootworms using reduced dosages of four chemicals mixed with starter fertilizer. Aldrin, lindane and heptachlor each at 0.25 or 0.50 pound per acre rates and chlordane at 0.50 and 1.0 pound rates gave reductions in rootworm numbers and plant lodging. Burkhardt concluded that there were no important differences between the higher and lower rates of application. Bigger and Blanchard (1955) found that 1.0 pound per acre of aldrin or heptachlor controlled northern corn rootworms in Illinois during 1953 and 1954.

Ball (1956) during 1954 in Nebraska conducted a test to determine whether a difference in control existed between surface-planted and listed corn. Both were broadcast treated prior to planting with 0.5

pound per acre of aldrin, benzene hexachloride and heptachlor. Rootworm numbers were significantly reduced in the surface-planted plots as compared to the listed plots, however, lodging and yield data between the two planting techniques were not significantly different.

The chlorinated hydrocarbon insecticides were the most effective means of controlling the corn rootworm until 1959. During 1959, Roselle et al. (1959) found ineffective rootworm control in Nebraska corn fields where aldrin and heptachlor had been applied. The field failures continued to increase and became more severe during 1960 and 1961 (Roselle et al. 1961).

Ball and Weekman (1962) working in Nebraska during 1961 conducted 2-hour topical evaluations on adult western corn rootworms with aldrin, heptachlor and diazinon. The resulting LD_{50} values indicated that approximately 100 times as much aldrin and heptachlor were required to kill beetles from central Nebraska as compared to beetles collected along the eastern border where aldrin and heptachlor were in limited use. Diazinon, an organophosphorus insecticide, showed no significant difference between the two collection sites. Ball and Weekman concluded that the inability of aldrin and heptachlor to provide larval control in conjunction with proven resistance in adults indicates that larvae should demonstrate resistance to the same or greater degree than shown for the adults.

Ball and Weekman (1963) presented 24-hour LD_{50} data for aldrin and 2-hour data for diazinon. The field collected beetles were considered resistant to the chlorinated hydrocarbon insecticide, aldrin, but were susceptible to diazinon, an organophosphate. Ball and Weekman indicated

that there was no appreciable difference between LD_{50} values for adults and larvae, although no comparative data were presented.

The problem of western corn rootworm resistance was discovered in South Dakota in 1962 (Howe et al. 1963). Beetles collected from an area with a history of aldrin and heptachlor treatment had LD_{50} values of 16.7 µg of aldrin per adult. While susceptible beetles had LD_{50} values of 0.38 µg per adult. Bigger (1963) reported similar findings with northern corn rootworm adults in Illinois. Beetles from a field with prior aldrin application had a 24-hour LD_{50} value of 51.0 µg/adult as compared to susceptible beetles having a value of 0.068 µg/adult.

Hamilton (1965) ran topical aldrin and diazinon evaluations on adult corn rootworms collected from a large area in the Northcentral States. He reported that aldrin resistant western adults were apparent over large areas, but that resistant northern adults were found only in isolated areas. No resistance to diazinon could be found in either species of corn rootworm.

Western corn rootworm adults were proven to be resistant by many researchers; however, resistance in the larvae was only presumed. Hamilton (1966) treated both larval and adult forms with aldrin and found that 24-hour LD_{50} values for larvae were considerably higher than those for adults. In addition, he found that the LD_{50} values for adults decreased with later collection dates. In only one of three collection sites were the larval and adult topical data statistically similar. Data from the remaining sites showed the larvae to be approximately 3 to 4 times more tolerant to insecticides than were the adults.

Resistance to the chlorinated hydrocarbons called for changes in recommendations. Since diazinon, an organophosphate insecticide, gave good control on resistant corn rootworms, new recommendations emphasized the use of organophosphates. Weekman (1965) working in Nebraska found that the organophosphates could be applied with a starter fertilizer at planting time.

With increasing concern for the damage caused by the western corn rootowrm along with its resistance to chlorinated hydrocarbons, researchers began monitoring the organophosphates for resistance. Ball (1968) showed LD_{50} values for both diazinon and phorate topically applied to adults of the western corn rootworm. Beetles from many sites in Nebraska were collected and treated throughout the 5-year study, from 1963 to 1967. The mean LD_{50} value of 10.59 µg/g for diazinon in 1963 rose to 16.02 µg/g in 1967, a 66.1% increase. Phorate had a similar increase in LD_{50} values, 15.79 µg/g in 1963 to 26.56 µg/g in 1967, a 61.7% increase. Even though both insecticides had increased LD_{50} values after 5 years, both were still able to provide satisfactory field control.

Sechriest (1968) working in Illinois during 1967 discovered that a band of insecticide over the row gave better performance than fertilizer-insecticide mixtures placed to one side of the row. Sechriest also evaluated several insecticides as to their effectiveness of control. Carbofuran was the best with phorate, fonofos, metalkamate, ethoprop, propoxur and fensulfothion nearly as effective when applied at planting time. Those chemicals resulting in poor to inconsistent control were diazinon, disulfoton, Mobam® and carbaryl.

Ball (1969) collected LD_{50} values for 29 different insecticides from 1963 to 1968. He stated that 7 of the 10 most toxic insecticides were carbamates and the other 3 were organophosphates. All of the carbamates had LD_{50} values below 6.0 µg/g for adult westerns.

While many researchers studied chemical control, a few were investigating the habits and behavior of the corn rootworms, trying to establish a means of cultural control. Ball (1957) studied the biology and egg-laying habits of the western corn rootworm. He found that 23% of the eggs were laid in the upper 2 in. of soil, 58% in the upper 4 in. of soil, 80% in the upper 6 in. and the remaining 20% below the 6 in. level. In addition he discovered that a general relation existed between higher mean temperature and increased oviposition.

Rasmussen and Chiang (1967) found several interesting aspects of rootworm populations in association with different agronomic practices. They found the highest populations of immature stages in early planted corn, as compared to later plantings. Also, the later planted field being most attractive at the peak of the oviposition period would have the highest infestation the following year. In addition, they found that any tillage practice which increased the amount of soil exposed to winter cold tended to decrease the infestation the following year.

Sechriest (1969) studied the biology and behavior of corn rootworms in Illinois during 1968. He observed that even if eggs are evenly distributed in the soil by planting preparation, 98% of the larvae and pupae are found within 4 in. of the corn-stalk base and 90% within the top 4 in. of soil. These findings suggest that continued use of the 7-8 in. band over the row treatment should work best.

The effectiveness of post-planting insecticidal applications compared to planting time applications were studied by both Hantsbarger (1969) and Wilde (1969). Hantsbarger found no significant difference between the two applications in Colorado. Wilde working in Kansas found post-planting applications to be more effective at one location while failing to perform as well at another location. An explanation for these discrepancies was the differences in the amount and time of rainfall for the two locations.

Several researchers were testing many of the new organophosphate and carbamate insecticides; however, they lacked a uniform technique for evaluation. Ortman et al. (1968) reported the use of a vertical-pull technique to evaluate root systems. The corn plant was cut 12-16 in. above ground, and the leaves were removed from the cut stub. An electricians' sock was placed around the corn stub and attached to a recording dynamometer that registered force in pounds. The dynamometer was positioned on the end of a lever that was attached to a tripod. A steadily increasing pressure was applied to the end of the lever until the root system was free from the surrounding soil.

Johnson (1969) used a different technique for evaluating root systems. A cube of soil containing the root system was taken to a water source where the roots were washed clean, then rated. The roots were rated visually on a scale of 1 to 6, 1 being no damage and 6 being severe damage. This system of evaluation appears to be better than the verticle-pull technique. There are many variations possible in evaluating with verticle-pull, those caused by soil moisture, soil type, hybrids and time of sampling. These and many other variations seemed

best to be taken into consideration when the observer visually examines the roots for feeding damage.

The first indication of organophosphate resistance was in 1967 with diazinon in Nebraska (Ball 1968). The topical LD_{50} values for adults showed an approximate 400% increase from 1967 to 1968 and over a 400% decrease in 1969 (Ball 1973). Throughout this period the field performance of diazinon was consistently low, leaving open to speculation the wide deviation in adult susceptibility to diazinon (Walgenbach unpublished 1975).

Field failures of metalkamate occurred in Minnesota in 1970 and became widespread in Kansas, Nebraska, South Dakota and Iowa in 1971, 1972 and 1973. Adult topical LD_{50} data with metalkamate did not show meaningful correlation to field performance. Severe losses were sustained by farmers during this period and explanations were difficult because of a lack of information on rootworm insecticide interaction. In 1974, LD_{50} values were obtained on field collected larvae that showed rootworm resistance to metalkamate. Adults collected from the same field showed no or poor LD_{50} correlation to larval susceptibility and field performance as measured by root damage (Walgenbach unpublished 1975).

Field failures of carbofuran, fensulfothion and phorate occurred in Minnesota, Iowa and Nebraska in 1974. Larval LD_{50} data in South Dakota showed a higher level of tolerance to carbofuran; however, it still provided acceptable root protection in the evaluation plots. At present, insecticidal resistance can only be defined as a consistent field or plot failure. If carbofuran continues to decline in

efficacy, as circumstantial evidence now indicates, all remaining rootworm insecticides will be organophosphates which would increase the likelihood of resistance to these compounds (Walgenbach unpublished 1975).

Since most of the insecticides now used for control of the western corn rootworm are directed toward the larvae, more information on the interaction between larvae and insecticides would be useful in developing future control programs.

MATERIALS AND METHODS

Field data, larvae, and adults were collected from two locations. One was west of Beresford, South Dakota, at the Southeast Experiment Station Farm and the other on the Glen Krog farm 2 mi. west and 1 mi. north of Lake Benton, Minnesota. The Beresford plot was in trap crop during 1974 and treated with several insecticides in 1973, thus the Beresford population had an undetermined history of treatment. The Lake Benton plot was in carbofuran treatment since 1969.

Both fields had histories of large populations of western corn rootworm adults, with few southerns and northerns present. It was assumed that the larval population would be the same.

The materials used in the study include: metalkamate, carbofuran, fensulfothion, fonofos, phorate, CGA 12223, terbufos, diazinon and aldrin. Aldrin was the only chlorinated hydrocarbon, with metalkamate and carbofuran being carbamates while all others were organophosphates.

Topical application of the chemicals to both the larvae and adults was with a Biotronics microapplicator similar to the one described by Hamilton and Dahm (1960). The microapplicator was equipped with a 0.25 ml syringe fitted with a number 27 gauge needle, making it capable of delivering 1.0 µl doses of test solution.

The test solutions were prepared using technical grade insecticide and reagent grade acetone. The stock solutions of each were adjusted to give 100 mg of active insecticide/10 ml acetone. Dilutions were made from the stock solution to the selected microgram amounts per microliter. The proper dilutions for each compound were derived after

and with one cultivation on June 23, 1975, for all planting dates. Soil type was silty-clay, 8% sand and 42% silt.

The Krog plot was spring plowed and disked before planting. A fertilizer treatment of 80-40-20 at 100 lbs/A was applied prior to planting. Dekalb XL44A hybrid corn was planted in 38-in. rows on May 20, 1975. Weed control consisted of an application of Sutan + incorporated and one cultivation on June 24, 1975. Soil type was a clay loam.

Weather conditions were quite variable throughout the South Dakota corn production area. Good weather was prevalent during planting and early growth in most areas until mid-June. Severe drought plagued the Beresford plot whereas the Krog plot received close to normal rainfall.

Larval numbers in the untreated areas were 100 plus per plant at the Beresford farm, with a similar infestation of 80-100 per plant at the Krog farm.

Prior to planting, the test plots were measured and staked according to replicates. Upon completion of planting each individual row was marked with an identification stake.

On July 29, 1975 the roots were rated for rootworm feeding damage. Five plants from each treatment and untreated check in each of the 4 replicates were rated. Each plant to be rated was cut off 1 foot above ground level to facilitate transportation. The five plants in each replicate were marked with small white tags for later identification. The plants were then dug and transported to a water source where they were washed clean of any remaining soil.

The root rating system used provided a measure of insecticidal effectiveness, similar to the one used by Johnson (1969). The 1-6 rating scale was as follows:

1. No noticeable feeding damage.
2. Feeding scars, no root pruning.
3. At least one root pruned but less than an entire node of roots pruned.
4. One node of roots destroyed.
5. Two nodes of roots destroyed.
6. Three or more nodes of roots destroyed.

To qualify as a pruned root, the root must be eaten to within $1\frac{1}{2}$ in. of the plant. It is not necessary for all pruned roots to originate from the same node to qualify as a root system with a full node pruned. The number of roots pruned must be equivalent to that of a full node.

These data were then subjected to analysis of variance and Duncan's new multiple range test to determine differences among the individual insecticidal means.

Adult LD_{50} Determinations.-The technique used to obtain the LD_{50} values on the adult westerns follows the accepted standard method (Anonymous 1972). Adult corn rootworms were collected from the plot areas. To facilitate beetle collection, husks on the developing ears were peeled back, exposing the young white silks. These ears were left undisturbed for a short period of time to allow the adults to congregate and begin feeding. Once high numbers of beetles were seen

feeding on the silks, collection began. By holding a field sweep net under the ear and striking the ear with the hand, many beetles could be easily collected. If the wind was gusting, beetle collection by the above process was slow; however, sweeping the lower leaves and grassy areas between rows produced sizeable numbers. These captured adults were then transferred to 1 x 2 x 1 ft. wooden cages covered with 16-mesh plastic screening. Ample silks and developing ears were added to the cages for food and moisture and the cages transported to the laboratory in an air-conditioned station wagon.

All beetles collected were treated at the Northern Grain Insects Research Laboratory (USDA) located near Brookings, South Dakota. In all cases, application of the insecticides was made within 24 hours after collection.

The corn rootworm adults were aspirated from the cages by means of a vacuum aspirator. At this time the separation of the westerns from the northerns and southerns was accomplished. No attempt was made to sex the beetles. The western adults were anesthetized by passing a small volume of CO_2 gas through the aspirator. Then they were transferred to a Buchner table top suction funnel that had a small volume of CO_2 gas flowing through it.

Once anesthetized each individual adult was picked up by the antennae and treated with a 1.0 µl droplet of an acetone-insecticide mixture to the anterior ventral thoracic area. The treated beetles were held momentarily to allow the acetone to evaporate leaving the insecticide and then placed in marked 100 x 15 mm plastic disposable

petri dishes. An acetone check along with the 6 to 8 dosage rates, depending upon the insecticide, was applied. Three replicates of 10 individuals each were used for each dosage tested.

Each petri dish containing the 10 insects was labeled as to insecticide used, dosage concentration, replicate number and time of application. The dishes were stacked and left undisturbed in a room with an ambient temperature of approximately 27° C until mortality readings were recorded. Mortality readings for each dish were recorded 2, 24 and 48 hours after treatment. At the end of each time interval each dish was held vertically and given a sharp tap. After righting the dish any insect not able to regain its footing or maintain it after several seconds was considered dead.

The mortality data were collected and then subjected to computerized probit analysis to obtain LD_{50} values in µg/g of insect tissue.

Larval LD_{50} Determinations.-Due to a lack of a published accepted method for larvae, a modification of the standard method for determining adult LD_{50} values was used. The corn rootworm larvae were collected from untreated rows planted alongside the field performance plots. The plot locations were checked periodically for the appearance of third instar larvae. Once third instar larvae were appearing in large numbers, collection began. The corn plant was cut off above the soil surface, and by using an 8-in. spade a cube of soil surrounding the root was removed. These cubes of soil were immediately placed in plastic bags and transported to the laboratory in an air-conditioned station wagon. The immediate removal and transportation was necessary

to overcome desiccation by the high temperatures and dry winds present in the field.

Once in the laboratory, the corn and surrounding soil were placed on a large table covered with black plastic. The black plastic aided in the recovery of the small white larvae. By careful examination of the soil and root the third instar larvae were located. The larvae were removed with fine camel hair brushes or delicate surgical tweezers and placed on moist filter paper in a 100 x 15 mm plastic disposable petri dish. The laboratory had an ambient temperature of 27° C, which necessitated the use of moistened filter paper to prevent desiccation.

Three replications of 10 larvae per replicate were used for each concentration and accompanying acetone check. As mentioned earlier, both fields had histories of high western corn rootworm populations; therefore, all larvae were considered westerns.

With the use of delicate surgical tweezers the larvae were individually treated by topical application of 1.0 µl of an acetone solution containing the chemical to the anterior ventral thoracic area. After application the larvae were held momentarily to allow the acetone to evaporate leaving the insecticide. The larvae were then placed in a disposable 100 x 15 mm plastic petri dish on filter paper moistened with 1 ml of distilled water. Artificial diet was added to each dish to provide food until the 48-hour reading (Branson et al. 1975).

Each dish containing the 10 larvae and food was labeled with insecticide used, concentration level, replicate number and time of application. The dishes were stacked in an undisturbed location until

the 2, 24 and 48-hour mortality readings.

Lyle[1] presented LD_{50} data for both adults and larvae. His procedure for obtaining adult LD_{50} data followed the accepted standard method, (Anonymous 1972), ad did mine. My larval procedures were similar except for the determination of death and time at which mortality readings were recorded. Lyle's 24-hour mortality readings considered only larvae showing no movement after prodding with a dull pointer dead. With this technique any larvae showing movement, coordinated or not, were considered alive; as a result, his LD_{50} values were considerably high.

Ball et al. (1975) described a negative phototactic technique to determine larval toxicity to insecticides for western corn rootworm larvae. This technique involves the use of a microscope illuminator with the light source placed 13 cm from the filter paper surface. The treated larvae were placed in the center of the moist filter paper and illuminated with the light source. All the larvae remaining within the 2.5 cm circle of light after a 2-minute interval were considered dead. With close observation it was noted that some of the larvae were able to crawl from within the illuminated circle, only to turn and move back into the light again. These larvae lacked the coordinated rhythmic motion of normal larvae, and moved with short jerky motions.

---

[1]Mark Lyle, MS Thesis, SDSU, 1973.

It was assumed that they were affected by the toxicant and were, therefore, considered dead.

The mortality data were collected and subjected to computerized probit analysis for calculation of LD_{50} and LD_{90} values.

RESULTS AND DISCUSSION

Computerized probit analysis gave LD_{50} and LD_{90} values in terms of µg of insecticide/insect. These values were corrected for weight variability among insects by dividing the average weight of 50 individuals, to give values in µg/g of insect tissue. The weights necessary for this division were obtained and recorded prior to treatment for each dilution series. Once corrected for weight, direct comparisons between larval and adult topical data could be obtained.

Previous researchers used both 2 and 24-hour mortality data in making topical determinations on both larvae and adults, with a majority of the data on a 2-hour basis. For comparative purposes and a better estimate of insect mortality, 2, 24 and 48-hour data were collected.

Table 1 gives the 2, 24 and 48-hour LD_{50} values for adults collected at both locations. The same insects used for the 2-hour mortality reading were read again at the 24 and 48-hour intervals. LD_{50} values from the tables have been rounded off to two decimal places for discussion.

Lake Benton Adults

Carbofuran, a carbamate, had 2, 24 and 48-hour LD_{50} values of 0.30, 0.58 and 0.53, respectively, showing a rapid knockdown with an increase in LD_{50} values between the 2 and 24-hour readings. No substantial difference was evident between the 24 and 48-hour readings. Metalkamate, the other carbamate, with values of 1.31, 2.24 and 2.20 showed the same mortality recovery trend with time as carbofuran.

Table 1. LD_{50} values of field collected western corn rootworm adults.

	µg/g of insect tissue		
	2 hr. LD_{50}	24 hr. LD_{50}	48 hr. LD_{50}
Carbofuran			
Lake Benton	0.295	0.575	0.526
Beresford	0.340	0.610	0.591
CGA 12223			
Lake Benton	0.904	0.668	0.668
Beresford	0.825	0.656	0.622
Fensulfothion			
Lake Benton	1.948	1.153	1.127
Beresford	2.102	1.022	1.073
Metalkamate			
Lake Benton	1.310	2.239	2.201
Beresford	1.454	2.014	1.937
Terbufos			
Lake Benton	6.954	2.769	2.613
Beresford	5.619	2.733	2.534
Phorate			
Lake Benton	10.345	3.346	2.794
Beresford	12.126	3.320	3.283
Diazinon			
Lake Benton	8.890	3.100	3.010
Beresford	8.635	3.269	3.445
Fonofos			
Lake Benton	13.440	5.696	5.258
Beresford	15.182	6.394	6.590
Aldrin			
Lake Benton	82000.000	421.260	431.810
Beresford	NSR*	623.670	350.181

*NSR: Non-significant regression.

CGA 12223, an experimental organophosphate insecticide with no previous field exposure, had a 2-hour value of 0.90. There was a decrease to 0.67 at 24 hours and the mortality readings remained constant. Fensulfothion showed the same decline in LD_{50} values between 2 and 24 hours, with no significant change between 24 and 48 hours.

Terbufos had values of 6.95, 2.77 and 2.61, showing a substantial decline in LD_{50} values from the 2 to 24-hour readings, followed by a slight decline between 24 and 48 hours. Phorate, diazinon and fonofos also showed this continual decline in LD_{50} values over the 2 to 48-hour periods.

Aldrin, the only chlorinated hydrocarbon included in the study, had a large 2-hour value of 82000.0, decreasing to 421.26 at 24 hours, then increasing to 431.81 at 48 hours.

Beresford Adults

Carbofuran gave values of 0.34, 0.61 and 0.59, showing a considerable increase from 2 to 24 hours with a slight decrease between 24 and 48 hours. Metalkamate showed the same response, an increase then a slight decrease.

The phosphates showed 3 trends over the 2 to 48-hour periods with Beresford adults.

CGA 12223 and fensulfothion had decreases in LD_{50} values between 2 and 24 hours and then mortality remained constant.

Terbufos and phorate showed continued declines over the 2 to 48-hour intervals.

Diazinon and fonofos showed a different response. There was a

decrease in LD_{50} values between the 2 and 24-hour readings followed by a slight increase in values at the 48-hour reading.

Aldrin resulted in an NSR or non-significant regression at 2 hours. Due to insufficient adults the run was not repeated, however, a decrease was evident between the 24 and 48-hour intervals.

In general, a significant decline in adult LD_{50} values was noted between the 2 and 24-hour readings for most organophosphorus insecticides, with mortality stabilizing between the 24 and 48-hour periods. The carbamate insecticides applied to adults showed an increase in LD_{50} values between the 2 and 24-hour readings and a slight decline between the 24 and 48-hour intervals. Aldrin showed a decrease in adult LD_{50} values between the 2 and 24-hour periods and an increase between 24 and 48 hours.

As evident from the data presented in Table 1 the registered carbamates were considerably more toxic to the adults than were the registered phosphate materials.

Since resistance to aldrin was established in the 1960's one would expect the large LD_{50} values obtained for aldrin.

Table 2 gives larval LD_{50} values for both populations at the 2, 24 and 48-hour intervals.

<u>Lake Benton Larvae</u>

CGA, terbufos and fensulfothion responded similarly. CGA, for example, with values of 0.41, 0.32 and 0.48 showed a decrease in LD_{50}'s from 2 to 24 hours followed by an increase between 24 and 48 hours.

Table 2. LD_{50} values of field collected western corn rootworm larvae.

	μg/g of insect tissue		
	2 hr. LD_{50}	24 hr. LD_{50}	48 hr. LD_{50}
CGA 12223			
Lake Benton	0.407	0.323	0.484
Beresford	0.178	0.165	0.132
Terbufos			
Lake Benton	1.365	0.590	0.701
Beresford	1.079	0.638	0.614
Fensulfothion			
Lake Benton	0.984	0.709	1.195
Beresford	1.023	0.192	0.891
Diazinon			
Lake Benton	5.020	NSR*	1.241
Beresford	8.355	2.684	2.772
Phorate			
Lake Benton	4.450	1.668	1.627
Beresford	4.502	2.144	2.636
Metalkamate			
Lake Benton	0.680	2.138	1.707
Beresford	NSR*	5.242	3.208
Fonofos			
Lake Benton	5.572	3.189	2.970
Beresford	7.488	2.872	2.845
Carbofuran			
Lake Benton	0.354	2.354	8.682
Beresford	0.342	11.773	21.955
Aldrin			
Lake Benton	3800.000	1000.000	1400.000
Beresford	931.243	88.919	104.571

*NSR: Non-significant regression.

Diazinon had an NSR at 2 hours, but still showed a decrease between 2 and 48 hours.

Phorate showed a decrease from a 2-hour value of 4.45 to 1.67 at 24 hours, however, a 48-hour value of 1.63 did not show a significant decrease between 24 and 48 hours.

Fonofos showed a continual decline in LD_{50} values from 2 to 48 hours.

Metalkamate and carbofuran had differing trends on the larvae. Metalkamate with values of 0.68, 2.14 and 1.71, showed an increase between 2 and 24 hours followed by a decrease between the 24 and 48-hour readings. Carbofuran showed a continual increase in values over the 2 to 48-hour periods.

Aldrin showed the same response seen with the adults, a decrease from 2 to 24 hours and an increase between 24 and 48 hours.

Beresford Larvae

The organophosphates showed the same 3 trends as seen with Lake Benton larvae. Fensulfothion, diazinon and phorate showed a decrease between 2 and 24 hours followed by a substantial increase between 24 and 48 hours.

CGA was the only material showing a continual decrease in LD_{50}'s from 2 to 48 hours.

Terbufos and fonofos showed a decrease between 2 and 24 hours, and then mortality remained constant.

Metalkamate had an NSR at 2 hours; however, a decrease in LD_{50}'s was evident between the 24 and 48-hour readings.

Carbofuran gave the same response seen when applied to the Lake Benton larvae, a continual increase in LD_{50} values.

Aldrin gave the same results as before, a decrease between the 2 and 24-hour readings and an increase between 24 and 48 hours.

In general, the carbamate insecticides again gave a rapid knockdown, with the LD_{50} values increasing substantially from 2 to 48 hours. The organophosphates showed a general decrease in larval LD_{50} values from 2 to 48 hours. Aldrin again showed a decrease between 2 and 24 hours and an increase between 24 and 48 hours.

Carbofuran was the least toxic insecticide, next to aldrin, to the larvae and among the most toxic to adults. Most organophosphate insecticides were more toxic to the larvae than adults.

Because of the variance in mortality readings at the 2 and 24-hour intervals, the 48-hour readings were used for all the following comparisons.

If a direct correlation exists between larval and adult LD_{50} values then the dividend should equal one. The relationship between larval and adult topical data was obtained by dividing the larval LD_{50} values by the adult values; these relationships are presented in Table 3.

Metalkamate with values of 0.78 for Lake Benton and 1.66 for Beresford showed variation in susceptibility between populations. The Lake Benton adults were more tolerant to metalkamate. At Beresford the larvae were more tolerant.

Table 3. Relationship of 48-hour larval LD_{50} values divided by 48-hour adult LD_{50} values.

	Lake Benton	Beresford
Metalkamate	0.776	1.656
Carbofuran	16.506	37.149
Fensulfothion	1.060	0.839
Fonofos	0.565	0.432
Phorate	0.582	0.803
CGA 12223	0.725	0.212
Aldrin	3.242	0.299
Terbufos	0.268	0.242
Diazinon	0.412	0.805

Carbofuran showed the widest variation in susceptibility with dividends of 16.51 for Lake Benton and 37.15 for Beresford. Values larger than 1.0 indicate that the larvae were more tolerant to carbofuran at both locations.

Population differences existed for fensulfothion and aldrin. Larvae from Lake Benton showed more tolerance to fensulfothion and aldrin than the adults from Lake Benton; while adults from Beresford showed more tolerance to fensulfothion and aldrin.

Adults were more tolerant than larvae to the remaining organophosphate insecticides.

Terbufos with values of 0.27 and 0.24 showed approximately the same level of toxicity at both locations. Fensulfothion possibly showed the only direct correlation between adult and larval LD_{50} values at Lake Benton.

No apparent correlation was detected between larval and adult toxicities. Variance existed between compounds and between locations for the same compounds.

Hamilton (1966) made comparisons between larval and adult LD_{50} values on a 24-hour basis. He noted that the larvae had values 3 to 4 times greater than the adults. A similar relationship was evident in this study for the Lake Benton population, showing larval values to be 3.24 times larger than adult values. The Beresford population, however, did not show this response, a value of 0.30 was obtained with the adults showing larger LD_{50} values.

Table 4 presents the adult LD_{50} values and the relationship of adult LD_{90} values divided by adult LD_{50} values.

Table 4. Forty-eight-hour LD_{50} values and relationship of 48-hour LD_{90}'s divided by 48-hour LD_{50}'s for adults.

	Lake Benton		Beresford	
	LD_{50} µg/g	LD_{50}-LD_{90} Ratio	LD_{50} µg/g	LD_{50}-LD_{90} Ratio
Carbofuran	0.526	4.28	0.591	3.19
CGA 12223	0.668	2.42	0.622	2.06
Fensulfothion	1.127	2.03	1.073	1.78
Metalkamate	2.201	3.06	1.937	2.78
Terbufos	2.613	3.19	2.534	1.95
Phorate	2.794	3.48	3.283	2.20
Diazinon	3.010	3.48	3.445	1.88
Fonofos	5.258	2.04	6.590	1.59
Aldrin	431.810	1.59	350.181	5.14

Table 4 shows the toxicity of the insecticides to adults in relation to one another, considering the Lake Benton population only. Carbofuran was the most toxic material to the adults with an LD_{50} value of 0.53 followed closely by CGA 12223 with a value of 0.67. Fensulfothion had a value of 1.13 indicating a further decline in toxicity, followed by metalkamate, terfufos, phorate, diazinon, fonofos and aldrin.

Beresford adults showed the same order of decreasing toxicity seen with Lake Benton adults, however, the values varied.

Lake Benton adults had a slightly lower LD_{50} value of 0.53 compared to Beresford adults with 0.59 for carbofuran. When the relationship between LD_{50} and LD_{90} values are considered the Lake Benton adults show a 4.28 fold increase between LD_{50} and LD_{90} values compared to a 3.19 fold increase for Beresford.

In general, the Lake Benton population showed a wider spread between adult LD_{50} and LD_{90} values, with the exception of aldrin.

Table 5 gives larval LD_{50} data and the relationship between LD_{90} and LD_{50} values.

Again the insecticides are arranged in decreasing toxicity according to their LD_{50} values for Lake Benton. CGA 12223 being the most toxic material to the larvae with a value of 0.48 followed by terbufos, fensulfothion, diazinon, phorate, metalkamate, fonofos, carbofuran and aldrin.

A slight change in order was evident with the Beresford larvae. CGA 12223, terbufos and fensulfothion were the most toxic followed by phorate, diazinon, fonofos, metalkamate, carbofuran and aldrin.

Table 5. Forty-eight-hour LD_{50} values and relationship of 48-hour LD_{90}'s divided by 48-hour LD_{50}'s for larvae.

	Lake Benton		Beresford	
	LD_{50} µg/g	LD_{50}-LD_{90} Ratio	LD_{50} µg/g	LD_{50}-LD_{90} Ratio
CGA 12223	0.484	1.69	0.132	10.54
Terbufos	0.701	2.17	0.614	1.96
Fensulfothion	1.195	3.24	0.891	1.55
Diazinon	1.241	2.84	2.772	1.86
Phorate	1.627	2.25	2.636	1.82
Metalkamate	1.707	6.47	3.208	8.38
Fonofos	2.970	3.18	2.845	3.16
Carbofuran	8.682	17.34	21.955	2.04
Aldrin	1400.000	10.71	104.571	15.30

Gnerally, a wider spread was evident between larval LD_{50} and LD_{90} values for the Lake Benton population, except for CGA 12223, metalkamate and aldrin.

Carbofuran had a lower LD_{50} value of 8.68 at Lake Benton compared to 21.96 at Beresford, yet, a wider spread between LD_{50} and LD_{90} values existed for Lake Benton. A possible explanation could be the late larval development at Lake Benton. Lake Benton larvae were 10 days to 2 weeks later developing than Beresford larvae. This lag in development may explain the generally wider spread in LD_{50} and LD_{90} values seen for Lake Benton with all the insecticides. Late developing larvae would have less insecticidal pressure due to the field degradation curve of the soil insecticides.

Field performance data are presented in Appendix B. Aldrin was not included in the study due to its proven resistance. Five plots were evaluated for the determination of field performance, 4 plots were at Beresford and 1 at Lake Benton. Due to the limitation of available acreage, field evaluation at Lake Benton was restricted to one plot.

Field performance was evaluated by means of visual root ratings. The root ratings were converted to percent root protection (Walgenbach, Personal Communication, 1975) by this formula:

$$\% \text{ root protection} = \left[1 - \frac{(\text{root rating of treatment} - 1}{\text{root rating of UTC}}\right] 100$$

These percentages take into consideration the root rating of the untreated check (UTC) so that direct comparison between locations can be obtained.

Table 6 shows the comparison between larval LD_{50} data and field performance data for both locations. The four plots in Appendix B for Beresford were averaged to give a single percentage of root protection for each insecticide.

CGA 12223 with the lowest LD_{50} value of 0.48 provided the most root protection, 64.3% at Lake Benton. Terbufos followed with an LD_{50} value of 0.70 and 63.1% root protection. Carbofuran provided the next best root protection of 62.0%, yet, it had the largest LD_{50} value of 8.68. Fonofos, diazinon, phorate, metalkamate and fensulfothion all had LD_{50} values lower than carbofuran, but, did not provide as much root protection.

Carbofuran with the largest LD_{50} value of 21.96 at Beresford provided the best root protection, followed in decreasing protection by CGA 12223, terbufos, fonofos, fensulfothion, phorate, diazinon and metalkamate.

Larval LD_{50} data showed a higher level of tolerance to carbofuran; however, this insecticide still provided acceptable root protection in the plots.

Larval LD_{50} data did not correlate to field performance on a comparative basis between locations, except for diazinon and metalkamate. Diazinon and metalkamate showed a correlation between an increase in LD_{50} values and a decline in field performance.

Various edaphic as well as climatic factors affecting field performance of the compounds must be known, before LD_{50} values can be placed in the proper perspective.

Table 6. Larval LD_{50} values and percent root protection.

	Lake Benton		Beresford	
	LD_{50} µg/g	% Protection	LD_{50} µg/g	% Protection Average
CGA 12223	0.484	64.3	0.132	68.10
Terbufos	0.701	63.1	0.614	65.38
Carbofuran	8.682	62.0	21.955	73.25
Fonofos	2.970	54.8	2.845	58.85
Diazinon	1.241	48.9	2.772	36.13
Phorate	1.627	47.6	2.636	52.33
Metalkamate	1.707	46.4	3.208	34.40
Fensulfothion	1.195	44.1	0.891	53.80

CONCLUSIONS

Larval and adult western corn rootworms were evaluated for susceptibility to several widely used insecticides. ESA procedures were followed for adult topical determinations except for using the 48-hour determination for final analysis.

Both larvae and adults showed a decrease in LD_{50} values between the 2 and 24-hour intervals when treated with organophosphates. The carbamate insecticides applied to larvae and adults showed an increase in LD_{50} values between 2 and 24 hours. Because of the variance in mortality readings at the 2 and 24-hour intervals, mortality determinations were made at 48 hours.

In general, the carbamates showed a rapid knockdown followed by recovery, while the organophosphates reacted slower with mortality increasing with time. The carbamates were the least toxic insecticides to the larvae and among the most toxic to adults. Most organophosphate materials were more toxic to the larvae than adults.

No general correlation was evident between larval and adult LD_{50} data. Substantial differences between insecticides and between locations for the same insecticides existed.

Diazinon and metalkamate were the only materials showing a correlation between an increase in larval LD_{50} values and a decline in field performance. With the other compounds larval LD_{50} data showed no apparent relationship to field performance.

Due to the lack of a direct correlation between larval topical data and field performance, more research concerning the interaction

of soil and insecticides would be helpful in understanding this relationship. Once these relationships are known the entomologist can more accurately predict insecticidal resistance.

Further work with larvae is required for insecticide monitoring, and a better understanding of the mortality relationship between larval and adult toxicity.

REFERENCES CITED

Anonymous. 1972. Standard methods for detection of insecticide resistance in Diabrotica and Hypera beetles. Bull. Entomol. Soc. Am. 18:179-82.

Arnold, J. T. A. and M. J. Whitten. 1975. Measurement of resistance in Lucilia cuprina larvae and absence of correlation between organophosphorus-resistance levels in larvae and adults. Entomol. Exp. and Appl. 18:180-6.

Ball, J. J. 1956. Corn rootworm control for surface-planted and listed corn. J. Econ. Entomol. 49:709-10.

_________. 1957. On the biology and egg-laying habits of the western corn rootworm. Ibid. 50:126-8.

_________. 1968. A five year study of potential western corn rootworm resistance to diazinon and phorate in Nebraska. Ibid. 61:496-8.

_________. 1969. Topical toxicity of insecticides to Diabrotica virgifera adults. Ibid. 62:1172-4.

_________. 1973. Western Corn Rootworm: A ten year study of potential resistance to diazinon and phorate in Nebraska. Ibid. 66:1015-8.

Ball, H. J. and G. T. Weekman. 1962. Insecticide resistance in the adult western corn rootworm in Nebraska. Ibid. 55:439-41.

_________. 1963. Differential resistance of corn rootworms to insecticides in Nebraska and adjoining states. Ibid. 56:553-5.

Ball, H. J., C. A. Staetz, and G. L. Rolofson. 1975. Negative phototacic activity used to determine larval toxicity of insecticides to Diabrotica virgifera. Ibid. 68:293-4.

Bigger, J. H. 1963. Corn rootworm resistance to chlorinated hydrocarbon insecticides in Illinois. Ibid. 56:118-9.

Bigger, J. H. and R. A. Blanchard. 1955. Ecology and control of soil insects attacking corn in Illinois. Ibid. 48:255-60.

Branson, T. F., P. L. Guss, J. L. Krysan, and G. R. Sutter. 1975. Corn Rootworms: Laboratory rearing and manipulation. USDA, ARS-NC-28:11-2.

Bryson, H. R., D. A. Wilbur, and C. C. Burkhardt. 1953. The western corn rootworm, Diabrotica virgifera Lec. in Kansas. J. Econ. Entomol. 46:995-9.

Burkhardt, C. C. 1954. Chemical control of the western corn rootworm in Kansas in 1953. Ibid. 47:691-6.

Cox, H. C. and J. H. Lilly. 1953. Chemical control of the corn rootworm. Ibid. 46:217-24.

Daum, R. J., C. Givens, and G. Bearden. 1962. Probit analysis. Biometrical Services, ARS, USDA. (Un-numbered) Beltsville, MD.

Gillette, C. P. 1912. Diabrotica virgifera Lec. as a corn rootworm. J. Econ. Entomol. 5:364-6.

Hamilton, E. W. 1965. Aldrin resistance in corn rootworm beetles. Ibid. 58:296-300.

________. 1966. LD_{50}'s for aldrin against resistant larvae and adults of western corn rootworm. Ibid. 59:473-4.

Hamilton, E. W. and P. A. Dahm. 1960. A versatile automatic microapplicator. Ibid. 53:853-6.

Hantsbarger, W. M. 1969. Field trials to control western corn rootworm in Colorado. Proc. Entomol. Soc. Am., North Central Branch. 24:132.

Hill, R. E., E. Hixson, and M. H. Muma. 1948. Corn rootworm control tests with benzene hexachloride, DDT, nitrogen fertilizers and crop rotations. J. Econ. Entomol. 41:392-400.

Hills, T. M., D. C. Peters, and W. G. Lovely. 1972. Application equipment and techniques used in the evaluation of granular insecticides for control of western corn rootworm larvae. Ibid. 65:1116-9.

Howe, W. L., E. E. Ortman, and B. W. George. 1963. Observations of the northern and western corn rootworms in South Dakota. Proc. Entomol. Soc. Am., North Central Branch. 18:83.

Johnson, R. R. 1969. Corn Rootworm larval damage as a measure of percent lodge potential. Ibid. 24:135-7.

Kantack, B. H. 1965. Western corn rootworm in SouthDakota. Ibid. 20:62.

Kantack, B. H., D. D. Walgenbach, and W. L. Berndt. 1975. Corn rootworm control in South Dakota. Coop. Ext. Ser. USDA, FS 491 (Revised).

Lilly, J. H. 1954. Insecticidal control of the corn rootworm in 1953. J. Econ. Entomol. 47:651-8.

Muma, M. H., R. E. Hill, and E. Hixson. 1949. Soil treatments for corn rootworm control. J. Econ. Entomol. 42:822-4.

Ortman, E. E., D. C. Peters, and P. J. Fitzgerald. 1968. Vertical-pull technique for evaluating tolerance of corn root systems to northern and western corn rootworms. Ibid. 61:373-5.

Rasmussen, D. E. and H. C. Chiang. 1967. Effects of some agronomic practices on corn rootworm populations. Proc. Entomol. Soc. Am., North Central Branch. 22:95.

Roselle, R. E., L. W. Anderson, R. G. Simpson, and M. C. Webb. 1959. Ann. Rept. for 1959, Cooperative Extension Work in Entomology, Lincoln, Nebraska.

Roselle, R. E., L. W. Anderson, and P. W. Bergman. 1961. Ann. Rept. for 1961, Cooperative Extension Work in Entomology, Lincoln, Nebr.

Sechriest, R. E. 1968. Field evaluation of insecticides for control of rootworm larvae in Illinois cornfields. Proc. Entomol. Soc. Am., North Central Branch. 23:113-7.

__________. 1969. Observations on the biology and behavior of corn rootworms. Ibid. 24:129-32.

Weekman, G. T. 1965. The corn rootworm situation in Nebraska. Ibid. 20:63-4.

Wilde, G. E. 1969. Evaluation of corn rootowrm control in Kansas in 1968. Ibid. 24:133-4.

APPENDICES

APPENDIX A

Approved Common Names of Insecticides With Respective Chemical Names

1. aldrin: 1,2,3,4,10,10-Hexachloro-1,4,4a,5,8,8a-hexachloro-1,4-endo-exo-5,8-dimethanonapthalene, not less than 95%.

2. benzene hexachloride: 1,2,3,4,5,6-Hexachlorocyclohexane.

3. carbaryl: 1-Naphthyl N-methylcarbamate.

4. carbofuran, Furadan® : 2,3-Dihydro-2,2-dimethyl-7-benzofuranyl methylcarbamate.

5. CGA 12223, experimental, chemical name not released.

6. chlordane: 1,2,4,5,6,7,8,8-Octachlor-2,3,3a,4,7,7a-hexahydro-4,7-methanoidane.

7. DDT: Dichloro diphenyl trichloroethane.

8. diazinon; Spectracide® , Basudin® : 0,0-Diethyl 0-(2-isopropyl-4-methyl-6-pyrimidinyl) phosphorothioate.

9. dieldrin: Hexachloro-epoxy-octahydro-endo, exo-dimethanonaphthalene (principal constituent, known as HEOD), with not over 15% related compounds.

10. disulfoton, Di-Syston® : 0,0-Diethyl S-(2-(ethylthio) ethyl) phosphorodithioate.

11. endrin: Hexachloroepoxyoctahydro-endo,endo-dimethanonapthalene (principal constituent).

12. ethoprop, Mocap® : 0-Ethyl S,S-dipropyl phosphorodithioate.

13. fensulfothion, Dasanit® : 0,0-Diethyl 0-(4-(methylsulfinyl) phenyl) phosphorothioate.

14. fonofos, Dyfonate® : 0-Ethyl S-phenylethylphosphonodithioate.

15. heptachlor: 1,4,5,6,7,8-Heptachloro-3a,4,7,7a-tetrahydro-4,7-methanoindane.

16. Landrin® : A mixture of 3,4,5- and 2,3,5- isomers of trimethylphenyl methylcarbamate in approx. 4:1 ratio.

17. lindane: Gamma isomer of 1,2,3,4,5,6-hexachlorocyclohexane.

18. metalkamate, Bux® : Mixture of m-(Ethylpropyl) phenyl methylcarbamate and m-(1-methylbutyl) phenyl methyl carbamate in approx. ratio of 1:3.

19. Mobam® : 4-Benzothienyl N-methyl-carbamate.

20. phorate, Thimet® : O,O-Diethyl S-(ethylthiomethyl) phosphorodithiate.

21. propoxur, Baygon® : 2-(1-Methylethoxy) phenyl methylcarbamate.

22. terbufos, Counter® : S-(((1,1-Dimethylethyl)thio)methyl) O,O-diethyl phosphorodithioate.

23. toxaphene: Chlorinated camphene (content of combined chlorine, 67-69%).

APPENDIX B

Field Performance Data

Test I | Beresford, S. D. | Planted 5/5/75

Compound	Rate	Root Rating	% Root Protection	Duncan's*
Carbofuran	1 lb/A	2.20	78.4	a
Terbufos	1 lb/A	2.80	67.6	b
CGA 12223	1 lb/A	2.95	64.9	b
Fonofos	1 lb/A	3.05	63.1	b
Phorate	1 lb/A	3.25	59.5	bc
Fensulfothion	1 lb/A	3.65	52.3	cd
Diazinon	1 lb/A	4.10	44.2	de
Metalkamate	1 lb/A	4.35	39.7	e
UTC	control	5.55	----	f

* Duncan's new multiple range test. Means which share a common letter were not significantly different at the 5% level.

Test II Beresford, S. D. Planted 5/12/75

Compound	Rate	Root Rating	% Root Protection	Duncan's*
CGA 12223	1 lb/A	2.45	72.4	a
Carbofuran	1 lb/A	2.65	68.6	ab
Terbufos	1 lb/A	2.75	66.7	ab
Fonofos	1 lb/A	2.90	63.9	ab
Fensulfothion	1 lb/A	3.05	61.0	bc
Phorate	1 lb/A	3.40	54.0	cd
Diazinon	1 lb/A	3.80	46.7	d
Metalkamate	1 lb/A	4.40	35.3	e
UTC	control	5.25	----	f

* Duncan's new multiple range test. Means which share a common letter were not significantly different at the 5% level.

Test III Beresford, S. D. Planted 5/19/75

Compound	Rate	Root Rating	% Root Protection	Duncan's *
Carbofuran	1 lb/A	2.15	76.8	a
CGA 12223	1 lb/A	2.25	74.8	a
Terbufos	1 lb/A	2.45	70.8	ab
Phorate	1 lb/A	2.65	66.3	ab
Fonofos	1 lb/A	2.85	62.2	bc
Fensulfothion	1 lb/A	3.00	59.6	bc
Diazinon	1 lb/A	3.30	53.6	c
Metalkamate	1 lb/A	4.15	34.4	d
UTC	control	4.90	----	e

* Duncan's new multiple range test. Means which share a common letter were not significantly different at the 5% level.

Test IV Beresford, S. D. Planted 6/2/75

Compound	Rate	Root Rating	% Root Protection	Duncan's *
Carbofuran	1 lb/A	2.20	69.2	a
CGA 12223	1 lb/A	2.55	60.3	ab
Terbufos	1 lb/A	2.70	56.4	bc
Fonofos	1 lb/A	3.10	46.2	cd
Fensulfothion	1 lb/A	3.25	42.3	de
Phorate	1 lb/A	3.75	29.5	ef
Metalkamate	1 lb/A	3.80	28.2	f
UTC	control	3.90	----	f
Diazinon	1 lb/A	4.20	0	f

* Duncan's new multiple range test. Means which share a common letter were not significantly different at the 5% level.

Test V   Lake Benton, MN   Planted 5/20/75

Compound	Rate	Root Rating	% Root Protection	Duncan's*
CGA 12223	1 lb/A	2.50	64.3	a
Terbufos	1 lb/A	2.55	63.1	a
Carbofuran	1 lb/A	2.60	62.0	a
Fonfos	1 lb/A	2.90	54.8	ab
Diazinon	1 lb/A	3.15	48.9	bc
Phorate	1 lb/A	3.20	47.6	bc
Metalkamate	1 lb/A	3.25	46.4	bc
Fensulfothion	1 lb/A	3.35	44.1	c
UTC	control	4.20	----	d

* Duncan's new multiple range test. Means which share a common letter were not significantly different at the 5% level.