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The Influence of Corn Removal Date on Corn Rootworm Pviposition, Resultant Larval Populations and Damage

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THE INFLUENCE OF CORN REMOVAL DATE ON CORN ROOTWORM OVIPOSITION, RESULTANT LARVAL POPULATIONS AND DAMAGE

BY

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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.

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INTRODUCTION

Corn rootworms (Coleoptera, Chrysomelidae) are the major economic insect pests of corn produced in the midwest. The economic loss is two-fold. First the loss of revenue due to larval damage and second, the cost of control measures. Last year in South Dakota, combined losses were an estimated $27,533,892. Of the loss caused by insects to South Dakota corn in 1975, rootworms caused 92% of the total and this amounted to a yield loss of over 6 million bushels (Walgenbach, Personal Communication).

Three species of corn rootworms are found in South Dakota: the western corn rootworm, Diabrotica virgifera LeConte; the northern corn rootworm, Diabrotica longicornis (Say); and the southern corn rootworm, Diabrotica undecimpunctata howardi Barber. In South Dakota the northern and western species have caused the majority of the damage. Until 1961 the northern was the predominant species and economic populations of the western were not very common. However, western adults were collected as early as 1922 in Jones County, and in Butte County in 1930 (Kantack 1965).

The northern corn rootworm was first recognized as injurious to corn by Charles Riley in 1880 (Hill et al. 1948). The western corn rootworm was first reported to damage continuous corn in Colorado in 1909 (Gillette 1912). Tate and

Bare (1946) reported the observation of the western species in Nebraska during 1929. According to Bryson et al. (1953), western corn rootworm damage was observed in Kansas for the first time in 1945. In recent years the western species has spread extensively across the corn belt and is a major problem on continuous corn. The development of rootworm resistance to chlorinated hydrocarbon chemicals coincided with their spread and compounded the problem of holding this major pest of corn in check.

The life cycles of the western and northern corn rootworms are essentially similar, and unless otherwise stated, this paper will concern itself with the western species. The name corn rootworm will be used for the western species with the terms northern and western used where species differences are significant.

Adult corn rootworm beetles lay eggs in the soil of corn fields during late summer and fall. To a lesser extent eggs are also deposited in other fields where weeds and flowering plants are present. The eggs are the overwintering stage and they begin hatching into larvae during June. Following pupation, the adult rootworms begin to emerge in early July and continue to emerge until early September (Kantack et al. 1975).

The corn rootworm damages corn while in both the larval and adult stages. The larvae injure corn roots by feeding on the root system; they tunnel into larger roots and often completely consume smaller roots. Most of this damage occurs during late June and the first three weeks in July. The root feeding, if severe, destroys the root system and lodging of the corn plant occurs (Kantack et al. 1975).

The adult beetle damages corn by feeding on the tassels and developing silks. This feeding impairs pollination which causes ears to fill improperly, decreasing the yield.

Many farmers who raise cattle cut some of their corn for silage before or during the time corn rootworms normally oviposit. Last year 1.2 million acres of corn were removed for silage in South Dakota (Walgenbach, Personal Communication).

The objective of this research was to determine the effect of corn removal for silage on rootworm oviposition and on the resulting populations and damage the following year. If the corn is removed before oviposition occurs, and if the beetles go elsewhere to lay their eggs, damage to the corn roots the following spring should be prevented. This would save farmers insecticide costs the following year.

To determine how adult populations present in the corn field in late summer and fall affect damage to the corn the following spring, corn vegetation was removed on different dates encompassing the time oviposition was taking place.

The damage to the corn from the resulting rootworm populations was correlated to the corn removal dates as affected by fall and spring plowing.

LITERATURE REVIEW

The corn rootworm passes the winter in the egg stage with the eggs beginning to hatch in June. The eggs are found in the soil concentrated in the rows at the base of the plants. Patel and Apple (1967) reported eggs were found in decreasing numbers at 4, 8 and 10 inches from the row and 88% of the eggs were noted in the upper 3 inches of soil. Ball (1957) studied the biology of the rootworm and found that 80% of the eggs were in the upper 6 inches of soil.

To estimate population densities of corn rootworms it is necessary to determine the number of corn rootworm eggs per unit of soil. Chandler et al. (1966) developed a procedure and apparatus in which 98% of the eggs were recovered from the soil. A flotation technique for the removal of _Diabrotica_ spp. eggs from the soil was reported by Matteson (1966). A random soil sampling technique using composites of soil from high density concentrations of eggs around plants offers promise as a means for estimating rootworm egg populations (Howe and Shaw 1972). Variations were reduced when the samples were taken with a bulb setter or a trowel.

Soil temperatures, soil moisture, ground cover, tillage practices, and snow cover are some important variables in determination of hatch and development of corn rootworm eggs. The temperature of the soil is a major factor influencing the time of hatching of rootworm eggs in the spring.

Chiang and Sisson (1968) estimated the threshold temperature at 52° F for egg development of *Diabrotica longicornis*. The thermal constant for the first hatching was about 400 degree-days above 52° F. Patel and Apple (1967) first estimated the threshold temperature for northern corn rootworms in Wisconsin at 49.5° F, but later revised it to 52° F (Apple et al. 1971). The threshold temperature for the western corn rootworms in Minnesota was also estimated at 52° F (Wilde 1971).

Wilde et al. (1972) reported that fewer days were required for the initial hatch of 50% of the eggs of western corn rootworms from South Dakota or Minnesota than from Iowa, Kansas, Missouri, or Nebraska. Genetic heterogeneity of species responses to temperature could be an explanation for these differences. It was shown in a four-year study that the eggs of western corn rootworms began hatching about June 1 in Missouri and proceeded at the average rate of 2.91% per day, until hatch was completed (Musick and Fairchild 1971).

Hatch occurs in rootworm eggs after diapause is broken by low temperatures. But Patel and Apple (1967) found that 21.4% of northern corn rootworm eggs collected in the fall were free of diapause. Eggs of northern corn rootworms have also been shown to go through two winters before hatching (Chiang 1965). An explanation is that eggs deep in the soil did not get enough heat units in the first year. This indicates that exposure to cold in order to stimulate hatching can be continuous for up to two winters, (Chiang 1973).

Temperature, moisture, and tillage practices are interrelated in affecting the survival of overwintering eggs. Rootworm eggs are quite fragile and it's possible that soil manipulations could cause physical damage to the eggs or expose them to adverse environmental conditions near the soil surface (Matteson et al. 1972). Tate and Bare (1946) were the first to study the effect of tillage practices on rootworms. They stated that rootworm damage, as evaluated by counts of lodged corn, was reduced by fall plowing.

Rasmussen and Chiang (1967) reported plowing or any tillage practice which exposed more soil to winter cold tended to decrease the population of western corn rootworms the following year. Results of a single season test showed that tillage had no effect on corn rootworm populations (Matteson et al. 1972). However, they stated that variations involving temperature, snow cover, and soil moisture or type could provide a different picture on the effects of soil tillage on corn rootworms.

The effect of winter precipitation and temperature on overwintering eggs has been studied. It was found that after common tillage practices, eggs were dispersed both vertically and horizontally in the soil (Preuss et al. 1968). According to Calkins and Kirk (1969), lack of winter precipitation causes high mortality of eggs near the surface. This was verified in a Minnesota laboratory test in which continuous exposure to contact moisture resulted in the highest hatching of eggs (Mihm et al. 1974). Calkins and Kirk (1969) found that when winter precipitation was plentiful, plowing in the fall or spring makes little difference in the resulting populations, but when the winter precipitation was light, a higher mortality occurred in those plots not plowed until spring. Because South Dakota winters are so variable, neither fall nor spring plowing could be recommended as reliable methods for controlling corn rootworms.

Some growers practice minimum tillage, and under this method eggs remain concentrated at the site where they were deposited. Patel and Apple (1967) and Sechriest (1969) showed that eggs are concentrated around the corn roots. If corn is planted the following year between the old rows then larval survival may be affected. Short and Luedtke (1970) and Suttle et al. (1967) have shown that regardless of where rootworm eggs are found in relation to the row, they are potentially capable of reaching the corn root system. Even though the larvae are capable of migrating it has been stated that in a minimum tillage field placing corn rows midway between the rows of the preceding year may reduce larval survival and rootworm infestations (Chiang et al. 1971).

Musick and Collins (1971) have reported larval populations decreased approximately 34 percent for each 10 inches the new row was planted from the old row.

The larval feeding period has been found to extend from the middle of June until the latter part of July (Bryson et al. 1953). This period varies with the season, the soil conditions and other environmental factors. Temperature and moisture both affect the development of the larvae. Kuhlman et al. (1970) found a positive relationship between temperature and the time required for larval development. A threshold temperature of 53° F was determined for larval development. Chiang (1973) reported younger instars are more sensitive to higher temperatures than older instars and this is congruent with the fact that younger instars are normally exposed to lower soil temperatures. Soil temperatures increase during the season and so development of larvae which hatch late will be accelerated.

Laboratory tests were undertaken to determine the survival of rootworm larvae in relation to soil texture (Turpin and Peters 1971). The tests indicated that newly hatched corn rootworm larvae in petri dishes moved from sand to clay but not from clay soil to sandy soil. A greater tendency for desiccation in the sandy soil seemed to be the mechanism involved. It is suspected that the larvae suffer from abrasion by sand in the soil and from subsequent desiccation when exposed to air.

The newly hatched larvae migrate to the corn roots and feed primarily on the root hair and outer cortical tissue. As they grow older and need more food, they burrow into the cortical parenchyma (Chiang 1973). Where larval concentrations are high, all the main roots and rootlets may be tunnelled or cut off (Bryson et al. 1953). Often the roots and bases of the stalks are so badly damaged that decay organisms enter and completely destroy the roots.

Tate and Bare (1946) found that yield reductions in fields having similar degree of infestation may vary from practically a total loss to no appreciable loss depending upon stage of growth, moisture conditions, soil fertility and the vigor of the particular variety of corn. If conditions are favorable, corn plants often can replace root systems which had been destroyed. Although these plants will produce satisfactorily, harvesting may be difficult because of lodging.

When determining the larval density, the root system is removed with its surrounding soil (Musick and Fairchild (1971). According to Sechriest (1969), over 90% of the larvae are found within 4 inches of the plant base and in the upper 4 inches of soil. The soil is examined visually for the larvae and the roots are air dried to drive the embedded larvae out. The roots are cut, examined and most of the larvae present at the time of sampling are found. However, there is no assurance that all eggs have hatched at the time of sampling or that all larvae present, especially the younger ones, get counted (Musick and Fairchild 1971).

Damage to roots is assessed indirectly by the force needed to pull a plant from the soil or by a root rating system developed by Hills and Peters (1971). The root rating method is more commonly used with the amount of damage rated on a scale of 1-6. Turpin et al. (1972) considers a damage rating of 2.5 to be the economic damage level and Musick (Personal Communication) considers a rating of 2.8 as the economic level. Researchers don't agree on the specific economic rating level but most have found it to lie between 2.5 and 3.0.

Hills and Peters (1971) on relating yield loss with this root damage rating, found that with a normal yield of 125 bushels/acre there was a reduction of 5.8 bushels/acre for every adjusted root damage rating unit. They adjusted the root damage rating by subtracting the recovery rating, which was based on the amount of root recovery above the damage zone.

Johnson (1969) stated that a relationship exists between root damage and corn plant lodging. He found that lodged plants had a significantly higher mean root damage rating than standing plants.

A prediction equation for rootworm damage has been developed by Turpin et al. (1972). Significant edaphic and agronomic factors available to the farmer at planting time were the basis for this equation. Factors were determined that enhance or limit rootworm damage to corn and mathematical models were designed to predict populations of corn rootworms that would cause economic damage to corn. Use of this predictive equation could reduce the insecticide use in corn growing areas but so far no practical use has resulted.

Before 1967, entomologists had assumed that rootworms were dependent upon corn for the completion of immature stages. Branson and Ortman (1970) showed that rootworms were able to complete their immature stages on 13 of 18 potential hosts. The hosts were all grasses and viable eggs were obtained from females reared on these hosts.

The larvae of corn rootworms pupate in the soil and the pupae have been observed as far as 25 inches from the main roots and 9 inches deep. Chiang (1973) indicated that mature larvae do not necessarily move nearer the ground surface before pupation and adults, upon emergence, must therefore move considerable distances in the soil.

It was found in the Lincoln, Nebraska, area that adult rootworms first appear in the field very early in July (Ball 1957). In another Nebraska test based on caged plants, 90% adult emergence was reached between July 29-August 6 in 1968-1970 (Pruess et al. 1974). These dates agree with a

Nebraska test by Short and Hill (1972) where adults were first collected on July 15 and the peak female emergence occurred August 6. At Brookings, South Dakota, Howe et al. (1963) reported the initial emergence of northern corn rootworms occurred on August 1 and reached a peak on August 15. The emergence continued at a high rate until the end of August and stopped on September 10. The initial emergence of western corn rootworms at Beresford, South Dakota, occurred on July 8, 1975 (Personal Observation).

Kantack et al. (1975) found that adult males emerged 3-5 days prior to females and mating was observed shortly after female emergence. In a laboratory test, no caged females were observed to mate more than once (Hill 1975). It is believed that a female will mate only once and males will mate several times.

In Nebraska opposition studies, Short and Hill (1972) found that the average age of beetles at beginning of oviposition was between 20 and 23 days. In the laboratory, South Dakota collected adults had a mean preoviposition period of 14.3 days (Branson & Johnson 1973). Hill (1975) reported a 12.2 day preoviposition period for beetles collected mating in the field and 15.3 days for beetles emerging in the laboratory. These data seem to agree with those reported by Branson and Johnson.

Ball (1957) found that egg laying commences during the second or third week of August and continues intermittently up to the time of a killing frost. The average number of eggs laid per female during the season varied from 372 in 1954 to 418 in 1955. In a Nebraska oviposition test, approximately 21% of the eggs were laid by August 13 and 29% by August 20, and by September 5, 75% were deposited (Short and Hill 1972).

Branson and Johnson (1973), in laboratory tests, have reported that oviposition began at a very high level with 51.2 eggs being laid per female during the first 5 days of oviposition. This rose rapidly to a peak egg production at 10-15 days and then slowly declined. Some beetles laid eggs until they died and others stopped laying up to 3 weeks before they died. Branson and Johnson found that beetles exhibited much greater fecundity and longevity than had been noted previously by other workers. The beetles in their tests laid on the average 1023 eggs each.

In field collected mating pairs, maintained under controlled laboratory conditions, females lived an average of 78.2 days (Hill 1975). They had a mean fecundity of 1087 eggs laid in 13.5 clutches over a reproductive period of 76.4 days. The egg laying started at a high level with the 3rd clutch the largest. From the beginning of the oviposition period and through the 8th clutch, there were approximately 5 days between clutches. After the 8th clutch when about 75% of the eggs had been laid in 30 to 35 days, oviposition became more irregular and the average time between clutches lengthened. Hill found that 24% of the eggs were laid by August 25, and 57% by September 10, 83% by September 30, and 90% by October 10.

Most of these ovipositional studies have been undertaken where beetles were held under optimum conditions. This probably results in obtaining a shorter oviposition period, more eggs per female, and a greater average longevity than actually prevails in corn fields.

Temperature, moisture, and photoperiod affect the time and location of oviposition. Ball (1957) reported little or no oviposition by rootworms when the daily minimum temperature was 50^{o} F or below. A general relation was also found to exist between higher mean temperatures and increased oviposition. Mihm and Chiang (1974) reported that oviposition is retarded at low temperatures, but resumes at normal rates when warm temperatures return. They also suggested that oviposition in the field will be essentially complete in the fall when temperatures no longer exceed 50^{o} F.

Corn rootworm flight activity is bimodal and it coincides with the 2-3 hour periods after sunrise and before sunset (Witkowski et al. 1975). There was reduced flight activity throughout the night and during the day when the temperature was below ca. 15^{o} C. When early morning or evening temperatures dipped below 22.2 to 27.0^{o} C, the individual activity peaks shifted toward the warmer later morning or afternoon hours.

In laboratory observations, Ball (1971) reported that maximum oviposition occurred during the morning hours, the early part of the photophase. Since rootworms are most active at dawn and dusk, a higher mean number of eggs should also have been deposited during the late afternoon if oviposition is related to general activity.

In the corn field the soil moisture surrounding corn plants is higher during the early morning hours than later in the day. Ball (1971) (Citing Cates 1968) showed that the number of eggs deposited per female is moisture related. Oviposition increased as the substrate moisture increased up to 60% and oviposition decreased when the moisture content approached either zero or saturation.

To discover reasons for the pattern of egg-laying in the field, ovipositional preferences have been studied in the laboratory (Kirk et al. 1968). It was found that the beetles preferred moist soil, large soil particles, and soil cracks for oviposition sites. Clumps of grasses like foxtail were more attractive than either fallen corn leaves or corn stalks. It was concluded that variables of all these factors combine to influence oviposition patterns in a field.

In recent years some work has been done regarding the seasonal and daily activity, flight behavior, and dispersal of the beetle. Cinereski and Chiang (1968) studied the movements of the northern corn rootworm by identifying pollen types in the digestive tracts of the adults and concluded that when food became scarce within the corn field the beetles began to disperse. Branson and Johnson (1973) have reported that beetles begin to disperse shortly after the corn matures and the leaves and silks become unfit for food. It also has been shown that during the latter part of the season the northern species migrated to plantings of later maturing corn (Howe et al. 1963).

In Cinereski and Chiang's study, the dispersed beetles were found in corn fields with younger plants or in fields of other crops in bloom. During the 3 week oviposition period, the female beetles seemingly engaged in trips out of the corn fields for feeding interspersed with oviposition trips back to the corn fields. When the oviposition period was over, the beetles remained in the corn fields in a less active state.

Control Measures

The first control measures recommended for combating the corn rootworm were: crop rotation, fall tillage, planting by listing, proper timing of irrigation, and use of resistant corn hybrids (Tate and Bare 1946). The northern and western corn rootworm were reported to be effectively controlled by these methods.

In recent years many producers have used their most productive land every year for corn production because of the high cash value of corn. The practice of growing corn-on-corn has aided the insect in becoming an economic pest, which necessitated other control measures, specifically chemical.

In Nebraska, Hill et al. (1948) first demonstrated the use of soil insecticides for controlling corn rootworm infestations. Effective reduction of root damage and lodging was obtained using .5 to 2.0 pounds lindane per acre as pre-plowing broadcast sprays. Cox and Lilly (1953) obtained good results using aldrin, chlordane, dieldrin, and heptachlor at the rate of 8 ounces per acre banded over the row at planting time.

Chlorinated hydrocarbon insecticides were the most effective method of corn rootworm control until 1959 when resistance to them in western corn rootworm populations was noted in central Nebraska. Ball and Weekman (1962) stated that the problem continued and increased in Nebraska during 1960 and 1961. Localized resistant corn rootworm populations began appearing in other states with Howe et al. (1963) reporting it in South Dakota in 1962.

Because of the resistance to the chlorinated hydrocarbons, recommendations were changed with emphasis placed on the use of organophosphate insecticides. Now it is believed that the western corn rootworm can develop resistance when annually exposed to any specific insecticide. Since control of the insect is essential, new patterns of insecticide use have been studied. Much research has been undertaken concerning the relationship of chemical insecticides to the different life stages of the insect, in hope of establishing more effective control programs.

South Dakota State University entomologists recommended last year (Kantack et al. 1975) that granular insecticides should be used for larval control. They should be applied in 4 to 7-inch bands over the rows at planting time, and incorporated into the upper 1/2 inch of the soil. It was also recommended that South Dakota corn growers rotate their corn rootworm chemicals each year to try and eliminate the problem of insecticide failures.

Recently the recommendation of crop rotation as a control measure has been placed in a tenuous position (Walgenbach, Unpublished 1975). In 1975 numerous fields of first year untreated corn following small grains and flax were observed with severe damage. Questions on the biology of the rootworm have been raised because of the large number of northern corn rootworm adults found in stubble and volunteer small grain fields in 1975. Walgenbach stated that in South Dakota insecticide treatments should be used on all first year corn following small grains, flax and sorghum.

Because of these control problems and other anticipated future problems, research has and still is being carried out on alternate means of control. Work has been done on the possibility of using insecticides to control the adult beetles before economic populations of eggs have been laid in the field. Preuss et al. (1974) developed a model for timing treatments against adults and found that treatments between August 1-15 should result in adequate population suppression to prevent damage the following spring. The results showed that adult control was a promising alternative to soil insecticides.

Short and Hill (1972) have found that there is a period when female emergence is essentially complete and before many eggs are laid when chemical treatments directed at the adults should effectively curtail egg deposition.

The use of a trap crop to control rootworms has been studied by Hill and Mayo (1974). They found that the planting of trap-corn to concentrate female corn rootworm beetles and their egg deposition to small areas may well be exploited further as a means of reducing the injury potential to corn grown on the remainder of the field the following year.

The effect of removing corn at different dates on corn rootworm populations was evaluated for 2 years at Yankton, South Dakota (Calkins et al. 1970). It was found that when corn was removed before September 1, populations of corn rootworms the next year were below economic proportions. So farmers who cut their corn before September 1 could expect little damage from corn rootworms the following year and might not have to apply insecticides, although this hasn't been confirmed.

METHODS AND MATERIALS

To study the effect of corn vegetation removal on rootworm populations and the resultant damage, research was begun in August, 1974,and continued through October, 1975. A simulated silage operation was undertaken to determine when corn should be removed for silage to escape rootworm damage of economic proportions the following year.

The research was conducted near Beresford, South Dakota, at the Southeast South Dakota Experiment Station. Two plots were established in August of 1974 in corn fields adjacent to one another. In these plots a randomized-complete-block design was used with 5 treatments in Plot 1 and 6 treatments in Plot 2, replicated 4 times.

Plot 1 was planted May 29, 1974,and served as an insecticide evaluation plot during that year. In 1973 it was a corn trap crop to insure a large larval population for evaluating the insecticides in 1974. This plot, measuring 400 x 75 feet, was divided into 5 treatments of 6 rows each with the treatments replicated 4 times in 100 foot lengths.

Plot 2, part of a trap crop in 1974, was planted June 10 and measured 200 x 120 feet. It was set up as 6 treatments of 8 rows each, divided into four 50 foot replicates.

Each treatment consisted of the corn plants being removed on consecutive dates encompassing the period of corn rootworm oviposition. To determine the effects of the corn plant removal on the resulting corn rootworm populations, the plots were replanted in 1975 directly over the 1974 rows.

To determine the differential survival of overwintering eggs in soil plowed in the fall compared with eggs in soil plowed in the spring, a superimposed split plot design was used; half was plowed in November with the remaining half plowed in May. This made possible the evaluation of silage cutting effects on both overwintering conditions of the eggs.

The soil type where this study was undertaken consisted of a silty-clay with 8% sand and 42% clay. In 1975 the plots were fertilized with 80-40-20/A and spring disked twice before planting. For planting, a 4-row John Deere Flexi-Planter was used, equipped with Noble Metering Units. The corn seed variety XL45A was planted in 30-inch rows. To control the weeds in the plots, 4 lb A.I./A of atrazine 4L (2-chloro-4-(ethylamino)-6-(isoprophylamino)-S-triazine) was applied post-emergence.

Alternating rows in both plots were banded with 1 lb A.I./A of the granular insecticide phorate (0,0-diethyl S-[(ethylthio) methyl] phosphorodithioate) during planting. This allowed the evaluation of the vegetation removal effects for the following conditions: treated vs. untreated, fall plowing vs. spring plowing, treated vs. fall and spring plowing, and untreated vs. fall and spring plowing.

Egg counts, larval counts, root ratings, and lodging percentages were used to evaluate the date of corn plant removal and its effect on the resulting rootworm population. The evaluation methods were analyzed individually and collectively to determine the rootworms influence on the corn during the 1975 season.

An analysis of variance was run on the resulting data by Dr. W. Lee Tucker, Experiment Station Statistician at South Dakota State University. He suggested the data be analyzed by orthogonal comparisons since the treatments were related to time.

PROCEDURE

In August, 1974, two plots were established at the Southeast South Dakota Experiment Station in corn fields adjacent to one another. A randomized-complete-block design was used with the treatments being replicated 4 times. Plot 1, 30 rows wide, was divided into 5 treatments of 6 rows each and the corn vegetation was hand removed from a treatment on each of the following dates: August 8, August 15, August 22, August 29 and September 5.

Plot 2 was set up as 6 treatments of 8 rows each with the corn being removed from a treatment on each of the following dates: August 13, August 20, August 27, September 3, September 10 and September 14.

The corn stalks were hand cut, loaded on a truck, and removed from the field. The plots were too small to use an actual corn chopper to remove the corn. By observing the beetles, it was evident that after a few hours the corn stubble was no longer attractive to them.

A larger population of beetles was present in Plot 2 than in Plot 1. The plants in Plot 2 were younger and more desirable for food because of their late planting date.

On September 3, 1974, a heavy frost killed the corn, resulting in its rapid drying. Plot 1, with the corn already drought stricken, was hurt the most by the frost.

To evaluate the silage cutting effects for spring and fall plowing, half of each treatment in both plots was fall plowed on November 7, 1974. This allowed the evaluation of silage cutting effects for both overwintering conditions of the eggs.

The differences in egg numbers caused by vegetation removal were determined by taking soil samples and counting the number of eggs present. Two samples were taken in the fall from each treatment, each consisting of a core of soil ca. 4 inches in diameter and 4 inches deep. The 2 samples from each treatment were mixed together in the laboratory and an aliquot of 1 pint was taken from it.

The eggs were recovered from the aliquot sample through the use of a flotation method at the Northern Grain Insects Research Laboratory in Brookings, South Dakota. The device and procedure used are discussed in the Illinois Natural History Survey Report (Anonymous 1976). The eggs were then counted under a microscope to determine the quantity present for each sample. Since each treatment was replicated 4 times, the eggs were recovered from 44 samples.

On May 1, 1975, the half of each treatment not plowed the previous fall was spring plowed, with the fertilizer 80-40-20 being applied the same day. After two spring diskings, the plots were planted on May 14, with the rows being planted directly over those of the previous year. One lb A.I. of Phorate/A was applied to alternating rows in the plots to prevent overwhelming populations from developing beyond the evaluation techniques.

Both plots were cultivated on June 23 for additional weed control.

Counts of larvae were made on July 9, 10 and 11 by taking soil samples from the middle two rows in each treatment. Four samples were taken from each treatment replicate, one for each of the following: fall plowing vs. untreated, fall plowing vs. treated, spring plowing vs. untreated, and spring plowing vs. treated.

Larval counts were acquired by removing the corn root system and the surrounding soil with a shovel. The approximately 7-inch cubes of soil were bagged separately and transported into the laboratory at the Southeast Experiment Station. In the laboratory the roots and soil were examined on a black topped table to aid in spotting the small larvae. The soil was sifted and the roots cut open to find all the larvae present. All the larvae found were counted and a total of 176 samples were examined.

Damage to the corn roots was determined in late July by utilizing the 1-6 rating system adopted for use in the North Central States as the measure of insecticidal effectiveness. The damage rating criteria are as follows:

Damage Rating	Description of Root System
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 1/2 inches 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.

Twenty roots were tagged and dug from each replicate of each treatment. They were washed under pressure and rated for rootworm feeding damage. In all 880 roots were dug, washed and rated.

In late August the lodging percentage was determined for both plots. Plants bent more than 30^{o} at the base as a result of root feeding and damage were classified as goose-necked (lodged).

Because of the severe drought encountered at the Southeast Experiment Station during the summer of 1975, yield became an invalid test and wasn't used. If the weather conditions had been more favorable, yield tests would have been used as a means of determining the effects of corn removal on the resultant rootworm populations and damage.

The resulting data were analyzed by orthogonal comparisons so selected analysis could be made independent of the rest of the data. Orthogonal comparisons were made of data in which a significant F test occurred. The comparisons made were as follows:

Plot 1

1) August 8 vs. August 15

2) August 29 vs. September 5

3) August 22 vs. August 29 and September 5

4) August 8 and 15 vs. August 22, 29 and September 5

Plot 2

1) August 13 vs. August 20

2) August 27 vs. September 3

3) September 10 vs. September 14

4) August 27 and September 3 vs. September 10 and 14

5) August 13 and 20 vs. Remainder

RESULTS AND DISCUSSION

During the late summer of 1974, higher populations of adult rootworms were found in Plot 2 than in Plot 1 (Table 1). Plot 2 was more attractive to the beetles for feeding and oviposition, resulting in higher populations of beetles per plant. On each date, when the corn was hand removed to simulate a silage operation, the beetles dispersed to the surrounding corn. This resulted in a direct increase of beetle populations in the surrounding corn, being allowed for by the random design of the experiment.

Neither plot exhibited any highly significant differences between the spring and fall plowed areas. However, at the 10% level of significance, there was a difference in larval counts for Plot 1. More larvae were counted in the fall plowed portion than the spring plowed portion. In the fall plowed area of Plot 2, the lodging percentages were also significantly higher at the 10% level.

Egg Counts

The number of eggs counted increased slightly from the early removal dates to the later removal dates in both plots. The egg counts were not significantly different between the dates so orthogonal comparisons could not be made on these data.

Plot 2, because it was a trap crop and more desirable as

Table 1.-Average number of rootworm beetles per corn plant in uncut portions of Plot 1 and Plot 2.

Date	Plot 1		Plot 2
August 1	1.0	Beetles/Plant	0.6
August 8	3.0		1.2
August 16	2.0		4.7
August 23	2.2		5.9
September 1	0.4		8.0
September 9	---		4.0

an oviposition site, contained more eggs than Plot 1 (Figures 1 and 2). This agrees with the higher average number of beetles per plant found in Plot 2 during August, 1974.

Larval Counts

Plot 1 had an average larval count of 10.6 per plant with Plot 2 having an average count of 21 (Figures 3 and 4). The later corn removal dates had more larvae than the corn which had been cut earlier, indicating that the ovipositing beetles preferred standing corn to stubble. But for some unknown reason the larval count decreased on the final removal date in both plots.

In Plot 1, only 1 orthogonal comparison was statistically different (Table 2). The first two removal dates had significantly less rootworm larvae than the final three removal dates.

In Plot 2 the last two removal dates had significantly different numbers of larvae (Table 3). This is due to the large decrease in the number found for the September 14 removal date. Also, because of this decrease the third and fourth removal dates were significantly different from the last 2 dates.

In neither plot were the larval counts significantly different between the two insecticide treatments. Treating with insecticide had no apparent effect on the larval populations.

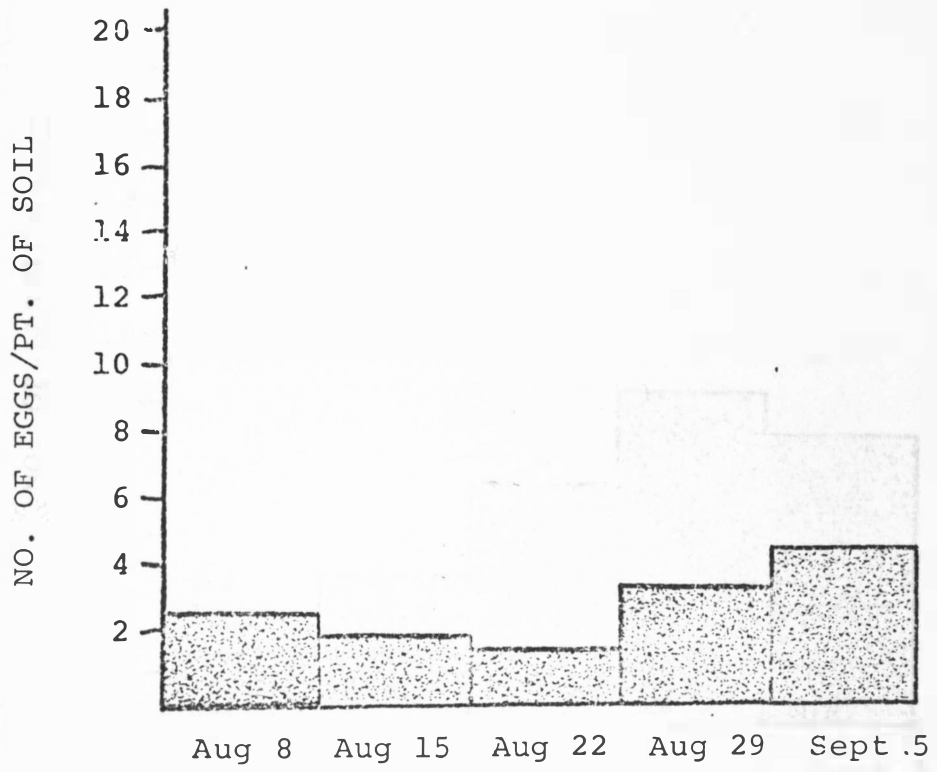


Fig. 1.-Plot 1 egg counts.

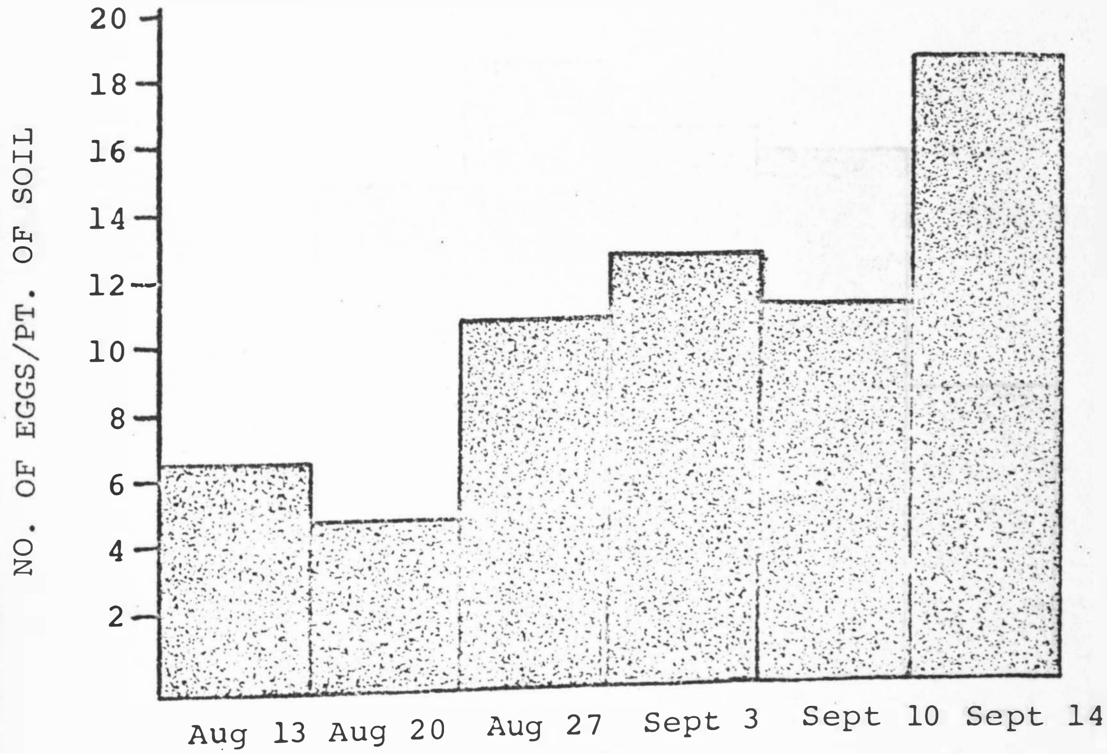


Fig. 2.-Plot 2 egg counts.

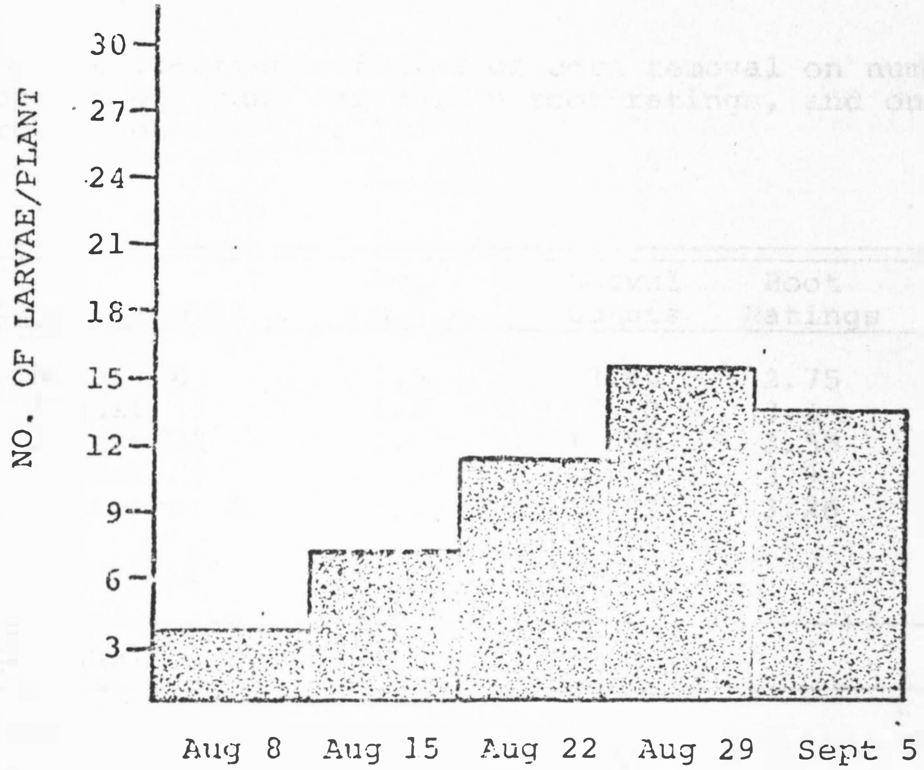


Fig. 3.-Plot 1 larval counts.

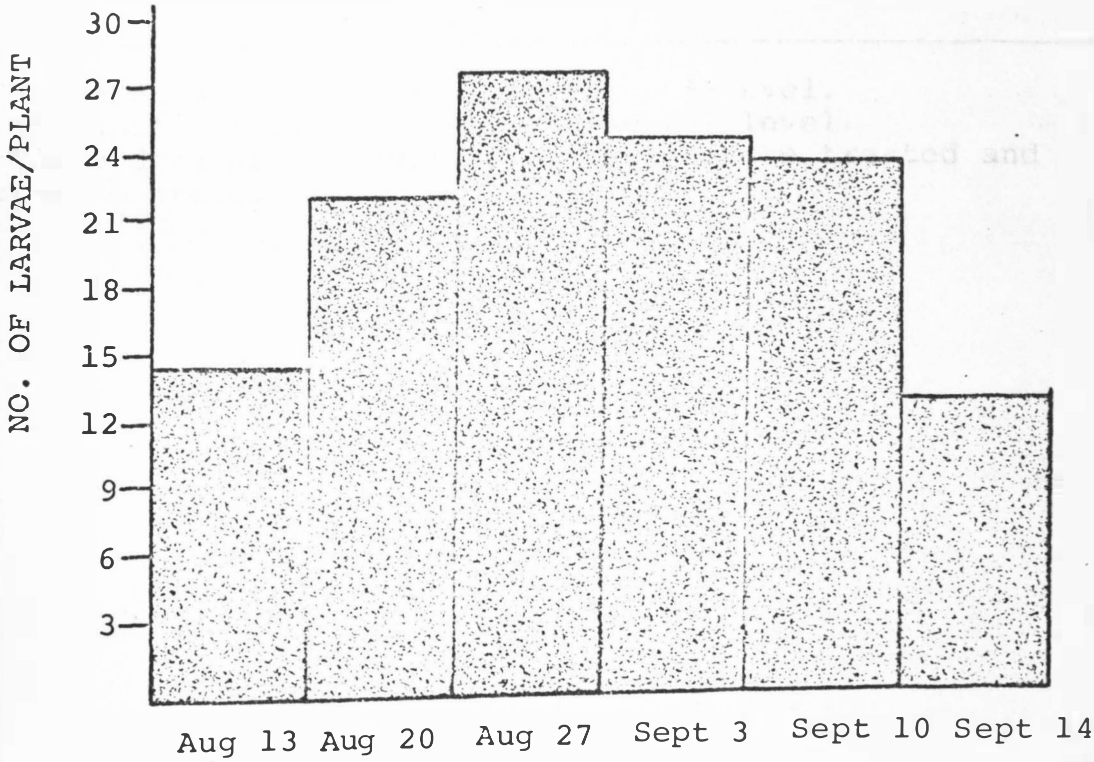


Fig. 4.-Plot 2 larval counts.

Table 2.-Effect of time of corn removal on numbers of corn rootworm eggs and larvae, on root ratings, and on lodging percentages for Plot 1.

Date of Removal	Egg Counts	Larval Counts	Root Ratings	Lodging Percentages
A) August 8	2.5	3.94	2.75	7.75
B) August 15	1.8	7.50	3.1	28.5
C) August 22	1.625	11.90	3.55	41
D) August 29	3.375	15.70	3.9	64
E) September 5	4.25	14.00	3.26	34
Orthogonal Comparisons:				
A vs. B	-	n.s.	n.s.	*
D vs. E	-	n.s.	*	**
C vs. DE	-	n.s.	n.s.	n.s.
AB vs. CDE	-	**	**	**

*Significantly different at the .05 level.
**Significantly different at the .01 level.
These data are an average of the phorate treated and untreated areas.

Table 3.-Effect of time of corn removal on numbers of corn rootworm eggs and larvae, on root ratings, and on lodging percentages for Plot 2.

Date of Removal	Egg Counts	Larval Counts	Root Ratings	Lodging Percentages
A) August 13	6.5	14.5	3.6	58
B) August 20	4.7	22.625	3.6	60
C) August 27	10.75	27.19	3.8	65
D) September 3	12.875	24.8	4.1	79
E) September 10	11.17	23.875	4.4	88
F) September 14	18.375	13.3	4.3	79
Orthogonal Comparisons:				
A vs. B	-	n.s.	n.s.	n.s.
C vs. D	-	n.s.	n.s.	n.s.
E vs. F	-	*	n.s.	n.s.
CD vs. EF	-	*	*	n.s.
AB vs. CDEF	-	n.s.	**	**

*Significantly different at the .05 level.
**Significantly different at the .01 level.
These data are an average of the phorate treated and untreated areas.

Root Ratings

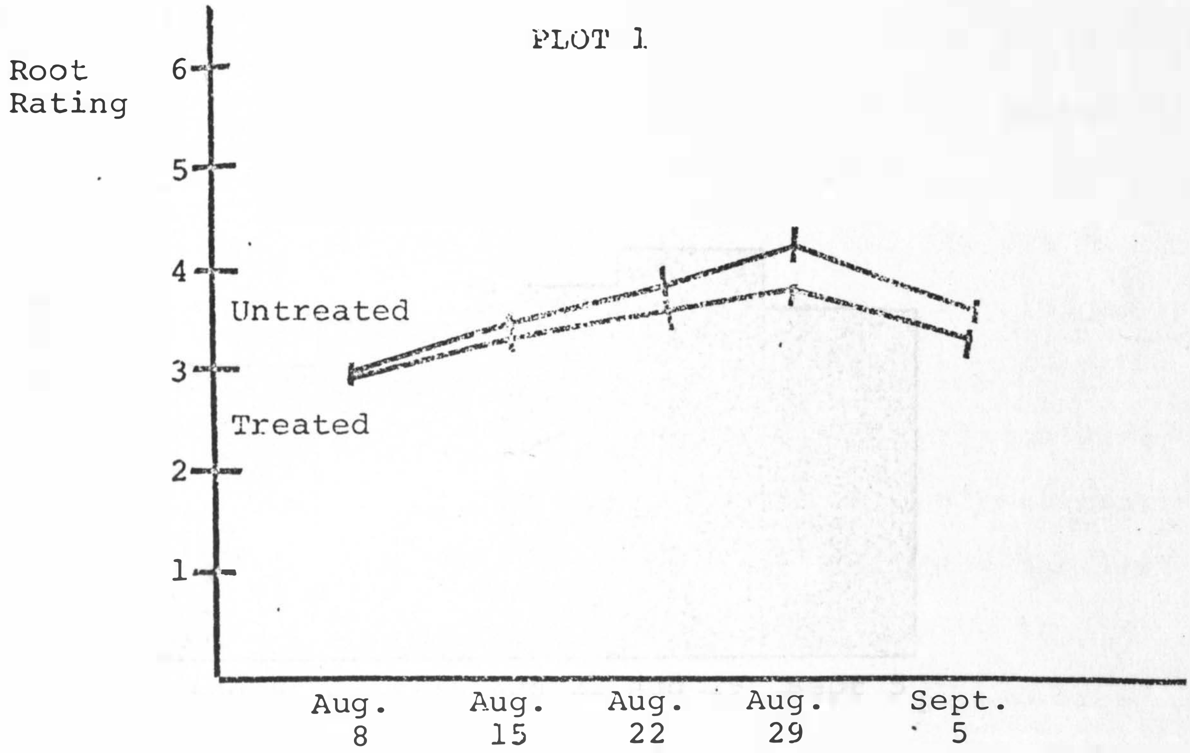
Damage to the corn roots was statistically different between the untreated and treated areas with the untreated corn sustaining more damage resulting in lower root ratings (Figure 5). Combining both plots, the use of an insecticide raised the average root rating .35. In the 1-6 root rating scale, roots with the most damage are given low ratings (high numbers) and high ratings (low numbers) are given to the roots with less amounts of damage.

Plot 1, with an average root rating of 3.31 (Figure 6), had two statistically different orthogonal comparisons (Table 2). The last two removal dates were significantly different from each other with the last date exhibiting a decrease in damage. Also, the roots from the first two removal dates had significantly less damage than the roots from the final three corn removal dates.

Plot 2, with an averate root rating of 3.96 (Figure 7), also had two statistically different orthogonal comparisons (Table 3). The difference between the third and fourth dates and the final two dates was found to be significant with the roots from the last two dates having more damage. Significantly less damage was found for the first two dates when comparing them with the other four removal dates.

Lodging

In evaluating larval damage by the percentage of goose-necked stalks, the treated corn had significantly less lodging



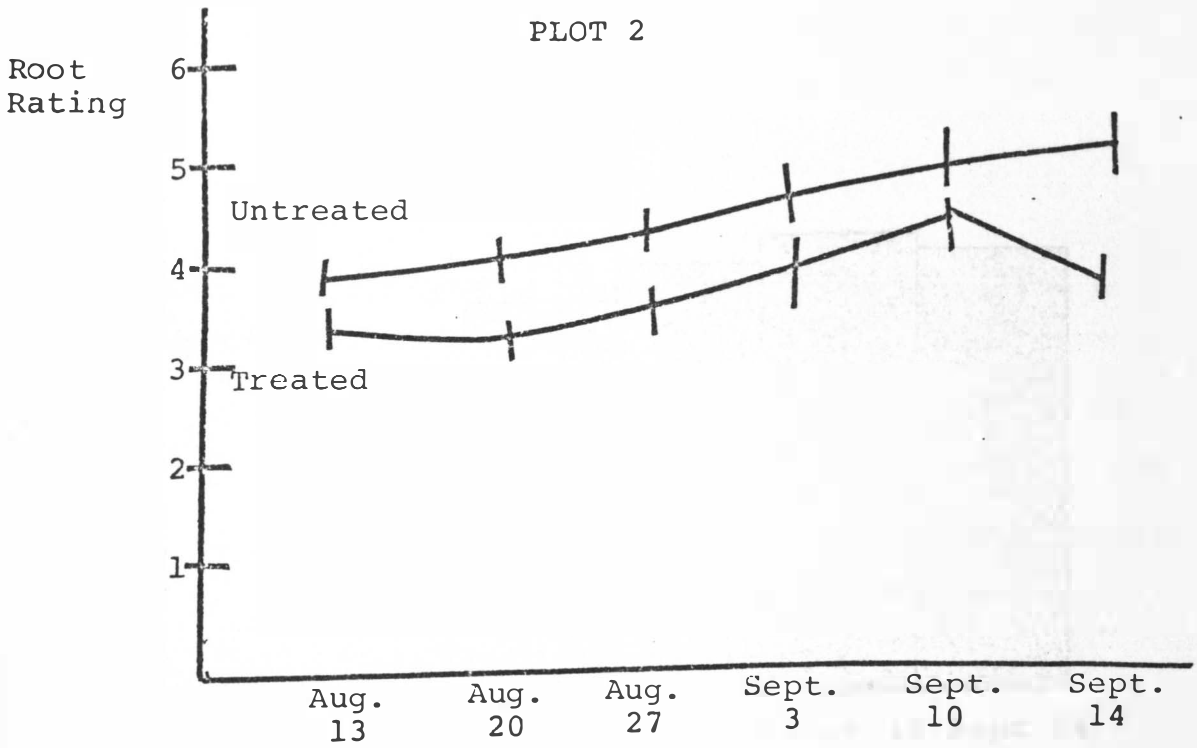


Fig. 5.-Difference in root ratings between phorate treated and untreated areas.

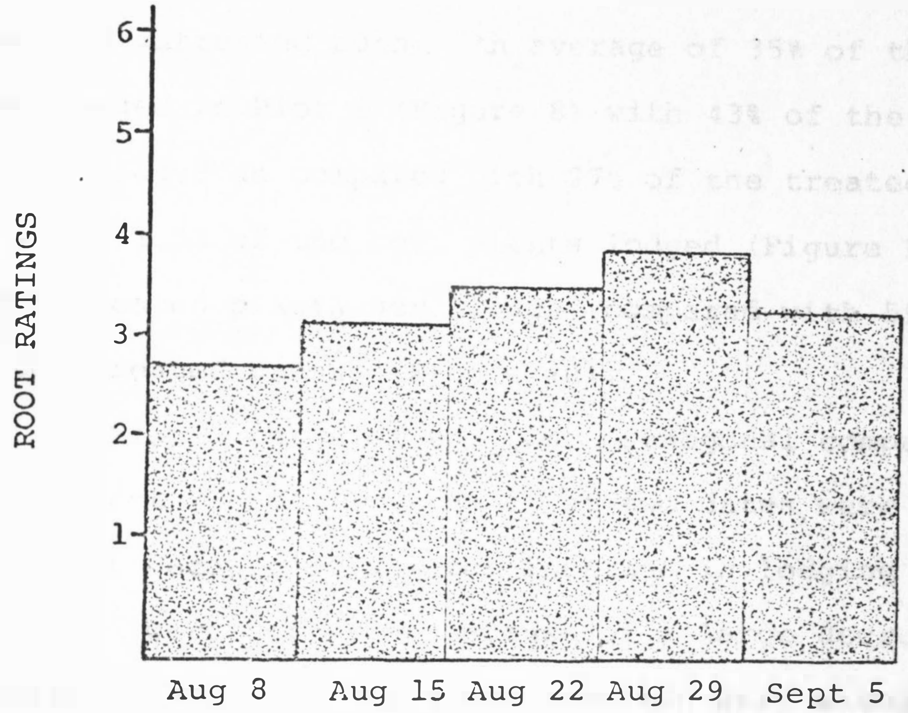


Fig. 6.-Plot 1 root ratings.

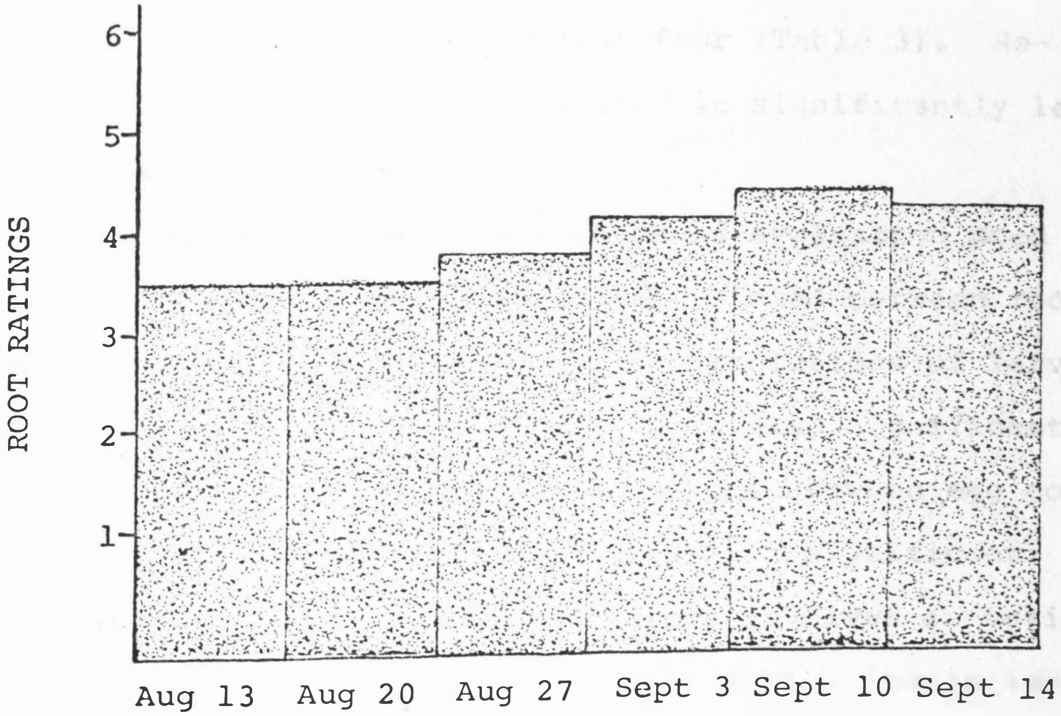


Fig. 7.-Plot 2 root ratings.

than the untreated corn. An average of 35% of the plants were lodged in Plot 1 (Figure 8) with 43% of the untreated plants lodged as compared with 27% of the treated. In Plot 2, with 71.5% of the corn plants lodged (Figure 9), 83% of the untreated plants were lodged compared with 59.5% lodged of the treated plants (Figure 10).

In Plot 1 three of the four orthogonal comparisons were significant (Tabel 2). The first two dates were significantly different because of a large increase in lodging and the last two dates were different because of a large decrease in lodging. The first two dates combined were significantly less lodged than the three other dates combined.

For Plot 2 the only significant difference was between the first two dates versus the last four (Table 3). Removing corn before August 27 resulted in significantly less lodging the following season.

Correlations between the methods of evaluation used (Table 4) shows the closest agreement existed between root ratings and lodging percentage. The correlations of larval counts with root rating and lodging were also significant but to a lesser degree. However, correlations between egg counts and the other methods of evaluation weren't significant.

There are many complicating factors involved in estimating rootworm egg populations. Egg distribution is influenced by patterns of soil cracking, tillage methods,

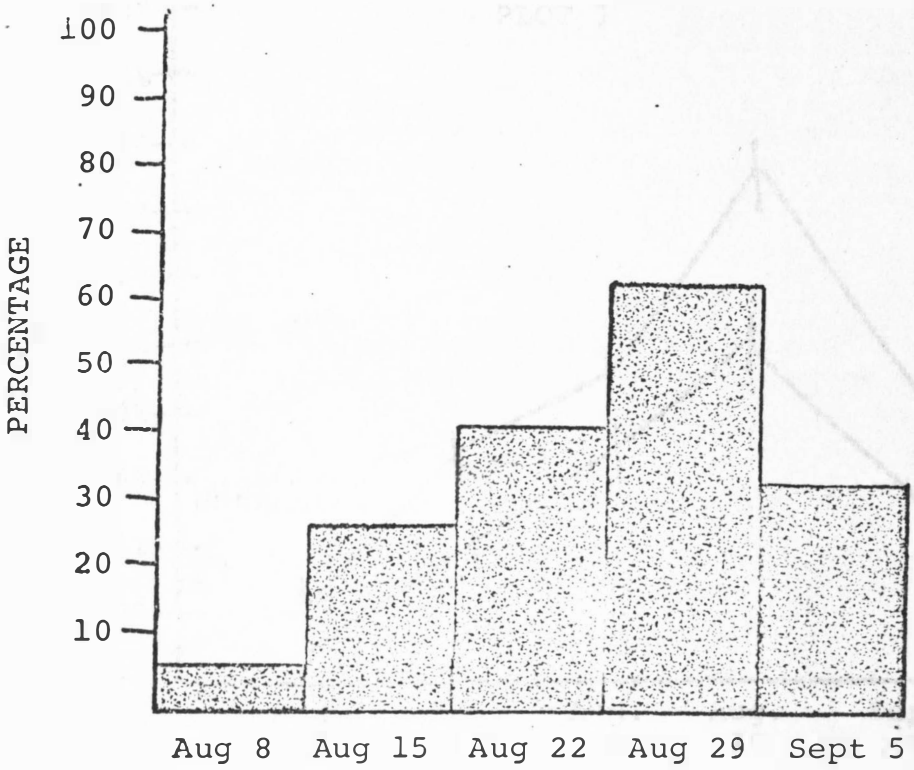


Fig. 8.-Plot 1 lodging percentages.

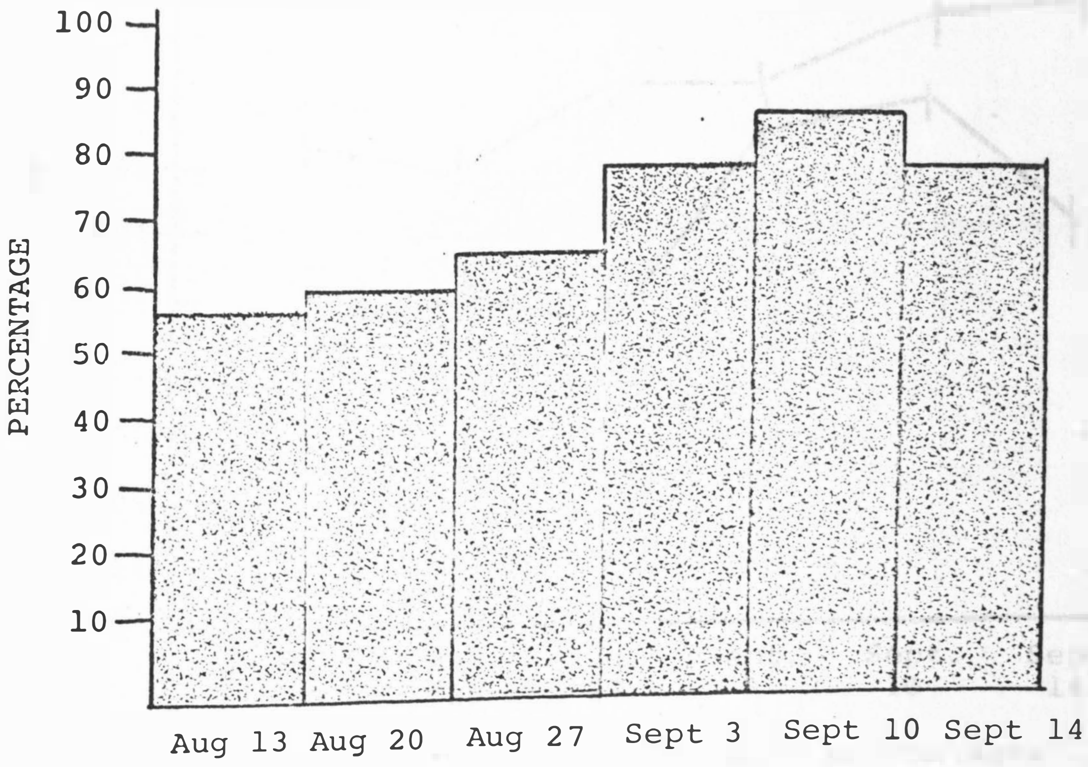


Fig. 9.-Plot 2 lodging percentages.

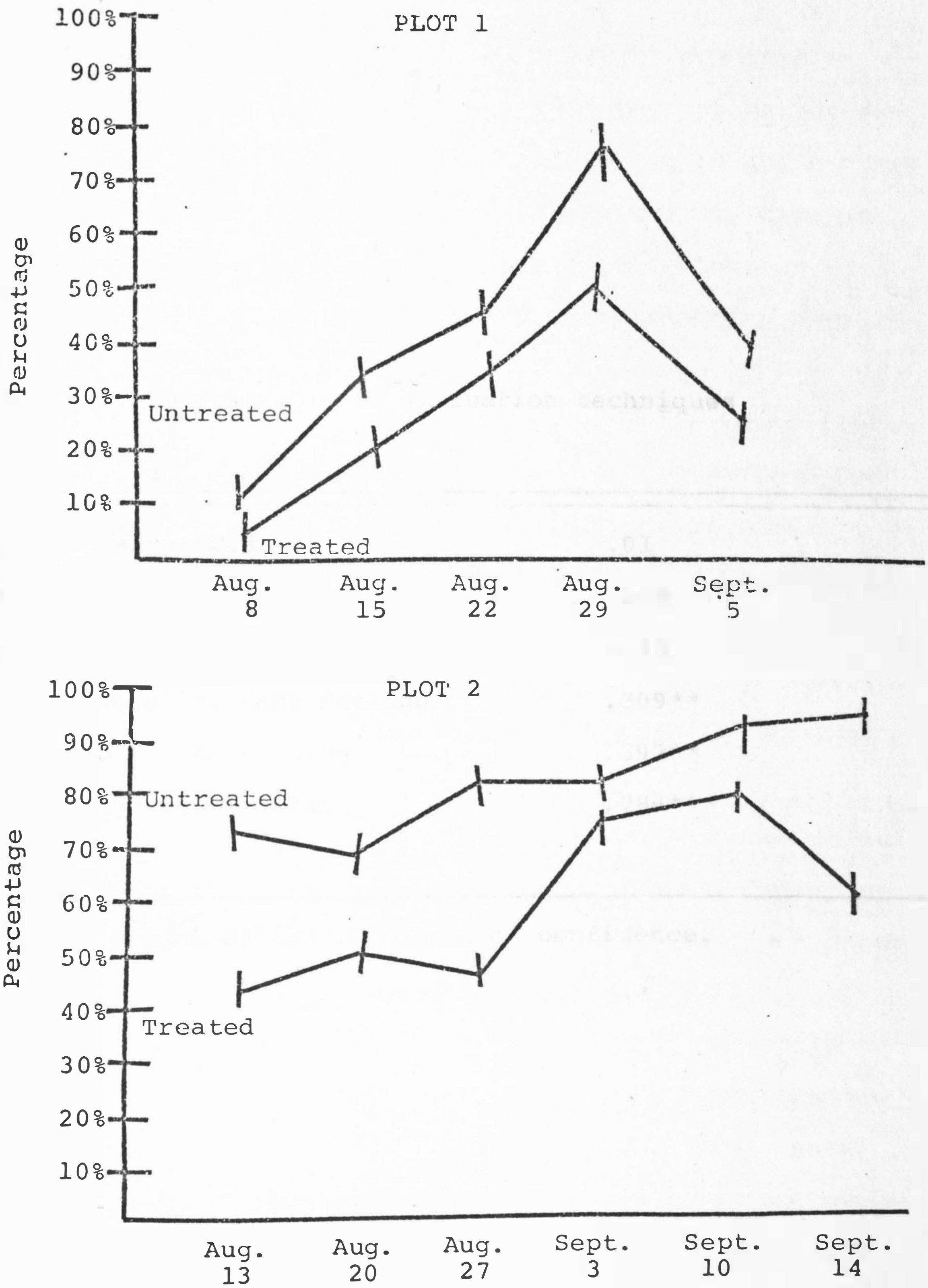


Fig. 10.-Difference in lodging percentages between phorate treated and untreated areas.

Table 4.-Correlations of evaluation techniques.

Eggs vs. Larval Counts	.01
Eggs vs. Root Ratings	.259
Eggs vs. Lodging	.295
Larval Counts vs. Root Ratings	.309**
Larval Counts vs. Lodging	.392**
Root Ratings vs. Lodging	.789**

**Significant at the .01 level of confidence.

lodging, soil type, weed growth and moisture conditions (Howe and Shaw 1972). It has been found that no matter how standardized the procedures, great variations in egg numbers found still occur. This evaluation technique may have potential but in our research it wasn't an efficient or accurate means for determining the resultant rootworm populations.

Larval counts have long been used as evaluation criteria for insecticide control tests. Muma et al. (1949) and Cox and Lilly (1953) used them along with many other rootworm researchers. One problem with this method is a wide range of larval sizes may be present at a given sampling due to a varied rate of hatching and development. It is not certain that all eggs have hatched at the time of sampling or that all larvae present have been found.

Peters (1963) has called counting larvae the most definitive method but also extremely time consuming and expensive. Calkins et al. (1970) stated that counting larvae is tedious though probably the most accurate evaluation used.

Another drawback of this evaluation method is that population counts cannot be directly transformed to root damage relationships (Walgenbach, Unpublished 1975). Some larval mortality has been observed, this mortality being related to insufficient root mass to sustain the larvae. This offers a possible explanation for the decrease in populations on the last removal date. While making the larval counts some roots were observed exhibiting great damage, but very few larvae were present. These were the treatments with the highest egg counts and it is possible that the hatching larvae, after devouring the young corn roots, starved to death. Some of these roots would then have a chance to recover, resulting in higher root ratings and less lodging. The number of larvae present in each root system varied with the ovipositional conditions the previous fall and with the stage of their starvation in the heavily infested areas.

Root ratings may be the most efficient evaluation technique and are most useful with about 10 rootworms per plant (Peters 1963). A population higher than this is of economic proportions and the ratings become less useful due to the variations in amounts of root tissue consumed.

The insecticide treatment was applied in hope of keeping the larval populations down but there were no significant differences between the treated and untreated areas. However, there were significant differences for root ratings and lodging. So the insecticide didn't reduce the number of larvae but it did result in better root control and less lodging. A possible explanation, stated by Sechriest (1969), is that over the season the larvae tend to move to the upper levels of the soil where they are more readily exposed to the insecticide applied as a band over the row.

The high correlation between root ratings and lodging percentages suggests that a survey of the lodging may be an efficient method of estimating numbers of corn rootworms. This method is widely used but seems to be remote in the fact that adverse weather conditions are needed before all the damaged corn plants will lodge.

There is a high degree of variability associated with all of the rootworm evaluation criteria. At the present, root ratings appear to be the most effective method for determining the insect-plant relationship, especially as a measure of insecticidal effectiveness.

CONCLUSIONS

Data from Plot 1 suggest that corn should be removed before August 15 to prevent economic damage from occurring the following year. This is earlier than the September 1 date found in the previous study by Calkins et al. (1970).

Data from Plot 2 indicate that damage would be expected even with corn removed before August 13. This plot had unusually high beetle populations in 1974 because it also served as a trap crop that year. Beetle populations in Plot 1 were more representative of levels expected in farmers' fields so data from this plot can be applied to a typical South Dakota field.

In South Dakota, corn would rarely be cut from silage on the dates indicated by this research as being necessary to prevent economic damage from occurring. Most years it wouldn't be a good silage cutting practice to remove corn this early. However, silage removal at a later date will reduce oviposition in the field and this used in conjunction with soil insecticides would be an effective method of controlling rootworms.

This research can also be applied to the adult control method of using aerially applied insecticides to control the beetles before oviposition. The beetles can be effectively controlled if the application of chemical is timed correctly in the field. The application must be carried out before a large percentage of eggs have been deposited. If the chemical was applied too soon, migration of fecund beetles into the field from surrounding areas would be a problem.

In fields similar to the conditions of Plot 1, application of an insecticide for adult control should occur prior to August 15. After this date economic populations of eggs will already have been deposited in the field.

I found little difference in survival of eggs overwintering in soil plowed in the fall compared with survival of eggs in soil plowed in the spring. There was a trend for spring plowing to cause a small reduction in populations.

Root ratings and lodging percentages were highly correlated as techniques for evaluating corn rootworm populations and damage. This suggests that root ratings are good predictors of the amount of lodging expected in the field. Lodging percentages are also an efficient method of estimating rootworm damage.

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