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SUMMARY

Investigations were conducted in the Nebraska Sandhills to determine the impact of transition from grassland to irrigated corn on selected insect species, to identify indigenous species that may be economically important to corn production, and to provide a point of reference for future development of pest management programs for irrigated corn.

Webworms, true and false wireworms, white grubs, and cutworms were primary pests of concern.

Based on data collected and interviews with project cooperators, the greatest potential threat occurs during the first year of corn production. Webworms *Crambus ainsliellus* Klots, *C. leachellus* (Zincken), *Thaumatopsis pexellus* (Zeller), and *Pediasia trisecta* (Walker) cause the most damage. No webworm damage was found in corn planted continuously for two or more years.

Three major types of feeding injury were categorized and periods of activity of different life stages identified.

Identifying larvae to generic and specific levels necessitated laboratory rearing of field-collected larvae and subsequent identification of adults. Parasites reared from field-collected webworm larvae included a braconid, *Macrocentrus crambivorous* (Viereck); an ichneumonid, *Pristomerus spinator* (F.); and two tachinids, *Lydina areos* (Walker) and *Euphorocera* sp.

Differences in abundance of Carabidae, Scarabaeidae, Teneb-

rionidae and Elateridae, as indicated by pitfall trap samples, were used to determine the environmental impact on insects as a result of growing irrigated corn in Sandhills rangeland. Greater numbers of carabids were collected in cornfields than in pastures, but diversity coefficients, calculated by a modification in Shannon's formula, were greater for pastures. However, in general, more scarabs, tenebrinonids, and elaterids were collected in pastures.

The insect fauna of the Sandhills region is not well known and research during 1972 and 1973 indicated that an intensive sampling of this area is needed. For example, the range of *Harpalus indigens* Casey (Coleoptera: Carabidae) is not well known and was originally thought to be confined to the northeastern United States (Ball, personal communication). Specimens collected at two locations provided new state records, thus extending the known range of this species. Other state records included the scarabs, *Pleurophorus atlanticus* Cartwright and *Cremastocheilus variolosus* Kirby, and the leodid, *Apheloplastus egenus* (LeC.).

Linear regression analyses of sweep-net sampling data provided estimates of the effects of an irrigated cornfield on insect populations in adjacent prairie. These data indicated that certain indigenous species were favored by the establishment of the cornfield.

Comparisons of populations of the leafhoppers *Indria inimica* (Say) and *Macrosteles fascifrons* (Stal) showed no significant differences in numbers of these leafhoppers on corn treated with various fertilizer rates. However, a t-test comparison of these data showed that a significantly greater number of *I. inimica* were present in slot-planted corn than in till-planted corn. No significant differences were evident in nunbers of *M. fascifrons* on corn in the two tillage systems.

The western corn rootworm, *Diabrotica virgifera* LeC., the European corn borer, *Ostrinia nubilalis* (Hübner), and other known pests of corn were sampled in cornfields along a north-south transect running from the Niobrara River Valley to the Platte River Valley. Although these and several other potential pests of corn were present in the fields sampled, economic damage was not found in Sandhills cornfields.

Bionomics of Insects Associated with Corn in the Nebraska Sandhills

John L. Wedberg, John B. Campbell, Thomas J. Helms[1]

INTRODUCTION

The Sandhills of Nebraska, a vast natural grassland, is experiencing a period of rapid agricultural development. This area occupies 20,000 square miles of north central Nebraska and is characterized by rounded dunes interspersed with small valleys and numerous shallow lakes (34). These relatively flat interdune areas are suitable for corn production by use of center pivot irrigation systems. Because of the abundance of groundwater, high-yielding irrigation wells can be obtained by drilling to depths of less than 300 ft. (13).

Investigations were conducted in the region during 1972 and 1973 to delineate the impact of the transition from prairie to irrigated corn on selected insect species. Primary emphasis was placed on identifying indigenous species that may be economically important to corn production.

Investigations included: transect surveys for the presence of corn pests in cornfields cultivated for various periods of time; comparisons of seasonal activity of insect species found in corn and grazing land; studies on the impact of irrigation on insects in the adjacent prairie; and examination of cornfields during the first year of production for damage by insects associated with native grasses.

Land-use changes have often resulted in a drastic disturbance of the environment of the local insect fauna and consequent changes in its composition. According to Uvarov (36), the essential feature of these changes is a radical reconstruction of the injurious fauna of useful plants. Results reported herein provide a point of reference for future development of pest management programs for corn in the Nebraska Sandhills.

Description of the Study Area

The study area included 12 fields in the Sandhills and 3 fields in non-sandhill locations. Non-sandhill fields were included to complete the north to south transects of cornfields from the area of the Nio-

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brara River to the area of the Platte River Valley. The majority of the cornfields are irrigated by center pivot systems, each of which irrigated approximately 135 acres. Study fields were located in Cherry, Keith, Lincoln, Logan, and McPherson Counties.

A serious problem associated with corn production in sandy soils is wind erosion. If the soil is left without cover, severe wind erosion results in drifts of sand and large eroded pockets called "blowouts." To reduce wind erosion, some growers sow a cover crop of ryegrass immediately after harvest.

Porosity is a second serious problem associated with sandy soil. The poor water holding capacity of this porous soil dictates the almost continuous provision of irrigation water which in turn causes leaching. Fertilizer is usually applied at planting time, but must also be injected into the irrigation system during mid- and late summer because of leaching. This continual addition of water and fertilizer results in a nearly hydroponic culture.

A few corn growers routinely use soil insecticides as insurance against the western corn rootworm (WCR), *Diabrotica virgifera* LeConte, although the insect is not known to be of economic importance in this area. Use of soil insecticides during the first year of cultivation is a common practice.

METHODS AND MATERIALS

Webworm Sampling and Rearing

Webworm collections were made at two locations during 1972 and at three locations during 1973. Larvae were taken from soil surrounding coleoptiles of damaged corn plants during May–July, 1973, and transported to the laboratory in 2-dram vials containing moist sand. The difficulty of identifying webworm larvae to the generic and specific levels necessitated larval rearing and subsequent adult identification before damage could be attributed to individual species.

Field-collected larvae were successfully reared on an artificial diet, Riddiford's modified diet (11), and were held in a growth chamber.

Eggs were obtained from webworm moths. Larvae hatched from these eggs were fed leaf tips of seedling corn.

Webworm damage to corn, and resulting stand reduction, was studied at weekly intervals in three replicates (50 ft. long and 4 rows wide) that had been randomly selected from a large webworm-infestd area during 1972 (Table 1). To provide estimates of larval numbers, damaged plants in the second row of each plot were removed from the soil and examined. Infestations at other localities during 1973 were similarly sampled.

Five-minute counts were made of webworm moths which flew along or across transects of pastures adjacent to two test fields in an attempt to measure periods of peak flight activity (Fig. 1). Fifty moths

Table 1. Webworm damage to corn plants. Lincoln County, June 8, 1972.

Date	Plants/50′ of row (avg.)	% plants damaged
June 8	56	34
June 15	46	20
June 22	44	10
% stand reduction	21	

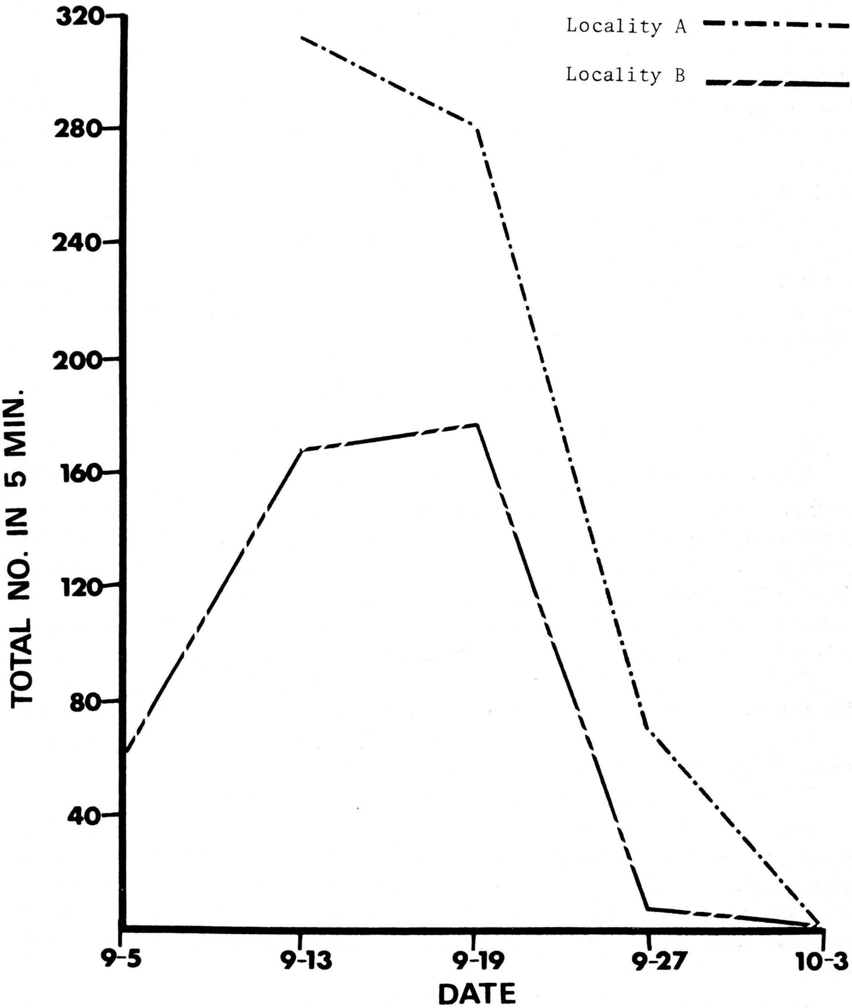

Figure 1. Weekly totals of webworm moths observed along linear transects of pastures during 1973. No data taken at Locality A on September 5.

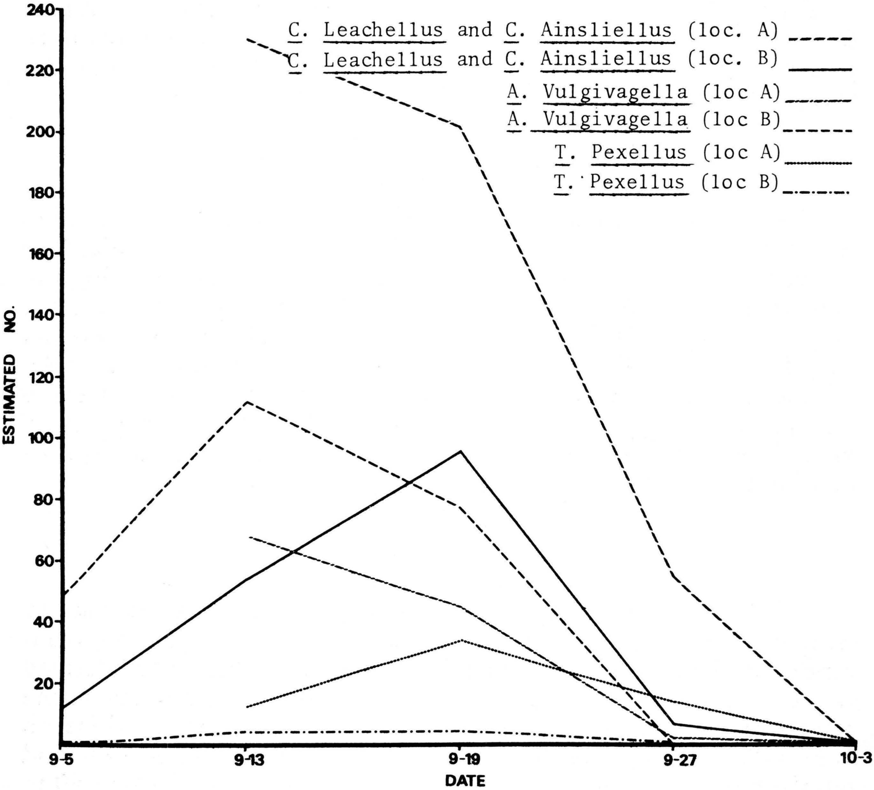

Figure 2. Estimated species composition of webworm moths observed along linear transects based on 50-moth samples taken at each locality during indicated five collection dates.

were randomly collected after each transect-count was completed, and the total number of each species present, expressed as a percentage of the sample, was multiplied by the total number of moths observed during the counting period. These data were used to estimate the species composition of the observed moth flights (Fig. 2).

Pitfall Trapping

Pitfall traps were used during 1972 and 1973 to capture adults of four common families of beetles, Carabidae, Scarabaeidae, Tenebrionidae and Elateridae. Although accurate measures of true population sizes could not be obtained from this approach, it helped identify periods of major insect activity as well as indicated comparative differences in beetle activity between habitats.

During 1972, 32 pitfall traps were arranged in the prairie at one location, and 20 traps each were placed in the cornfield and in the adjacent prairie at another.

During 1973, extensive pitfall trapping was conducted, with 27 traps employed at each of two locations. At one location, traps were placed in the adjacent prairie as well as the cornfield. At the other, the cornfield was divided into plots of slot- and till-planted corn.

Sweep Sampling

A sweep net 15 inches in diameter was used in collecting samples to estimate the effect of the presence of an irrigated cornfield on insect populations in the surrounding prairie. The first sampling was conducted in the prairie along a course immediately adjacent to the edge of the cornfield. A sampling consisted of 200 sweeps of the net at a given distance from, and parallel to, the edge of the cornfield. An additional 8 samples were similarly taken, each at 10 foot intervals further from the cornfield-prairie interface. Linear regression analysis was used to analyze the population trends of selected species at various distances from the edge of the cornfield.

Leafhopper Sampling

A DeVac® vacuum sampler fitted with a 72 sq. in. cone was used to sample leafhoppers (an insect species available for comparison) from randomized plots of slot- and till-planted corn which had received various rates of N/acre. These plots were sampled to determine the effects of fertility and tilling methods in various combinations on population levels of leafhoppers. Four replicates each of slot- and till-planted corn were used with the middle row of each 8 row x 20 ft. plot being sampled. The DeVac® cone was passed along the base of corn plants as the operator walked through the plots.

Transect Sampling

The north-to-south linear transect of selected cornfields was used during 1972 and 1973 to detect the occurrence of western corn rootworm, *D. virgifera* LeC.; European corn borer, *Ostrinia nubilalis* (Hübner); and other corn pests. Samples taken from 10 selected fields (Table 2) along the north-to-south linear transect, included: 1) soil particle size and organic matter analysis in attempts to determine if these edaphic factors influenced rootworm population, 2) western corn rootworm beetle samples obtained by counting beetles on alternate plants in a sample of 50 plants at two random locations in a field, 3) second brood European corn borer larvae counts obtained by dissecting all plants in a 1/1000 acre sample at three random locations in the field. Western corn rootworm counts were conducted between August 8–16 during 1972 and 1973, and European corn borers were counted October 6 and 7, 1972.

Table 2. Results of 2-year western corn rootworm survey conducted in the Nebraska Sandhills. Particle size and organic matter analysis conducted November 19, 1973.

Locality number	No. beetles per 50 plants (Aug. 8–16)		% sand	% organic matter
	1972	1973		
1	1	0	86	1.58
2	16	2	93	1.02
3	16	12	86	1.28
4	6	5	91	.80
5	43	14	89	1.21
6b	13	2	88	1.89
9	20	0	62	2.06
10a	58	35	78	.92
11	103	99	85	.78
12	123	153	90	1.06

RESULTS AND DISCUSSION

Webworms Encountered in the Nebraska Sandhills

Historically, webworm damage has been associated with corn and other crops planted in newly-tilled sod. When these crops were planted in these areas during succeeding years, damage by webworms was not commonly encountered (1, 4, 7, 12, 14, 29, 30). Above ground, larvae may defoliate plants, feed on leaf margins, or cut off plants near ground level. Larval tunneling in furled leaves results in straight rows of holes at right angles to the leaf margin. The most severe damage results when plants are cut off below ground, or when larvae chew holes into the sides of stalks damaging the meristem.

Webworms in this study represent the first report of webworm damage to corn in Nebraska, attributable to known species, since the work on *Thaumatopsis pectinifer* (Zeller) by Muma and Hill (27).

Webworm damage was first found in the study area on June 8, 1972, when plant height averaged 4 inches. Damage occurred in various locations throughout the field, but seemed to be more common in the higher areas. Individual larvae were found adjacent to underground stems and roots in chambers constructed of webbing and soil. These chambers opened to the surface and the larvae were principally nocturnal leaf feeders. Each chamber was attached to one side of a corn stalk. Entrances to chambers were open and the head capsules of larvae were often visible inside the entrances during the day. The slightest disturbance caused larvae to retreat further into their chambers. Examinations of corn plants showed larvae feeding on the lower leaf sheath at and/or below the soil surface (Fig. 3-E). Occasionally, larvae were found feeding on prairie sandreed *(Calamovilfa longifolia)* and Scribner's panicum *Panicum scribnerianum)* that had escaped tillage.

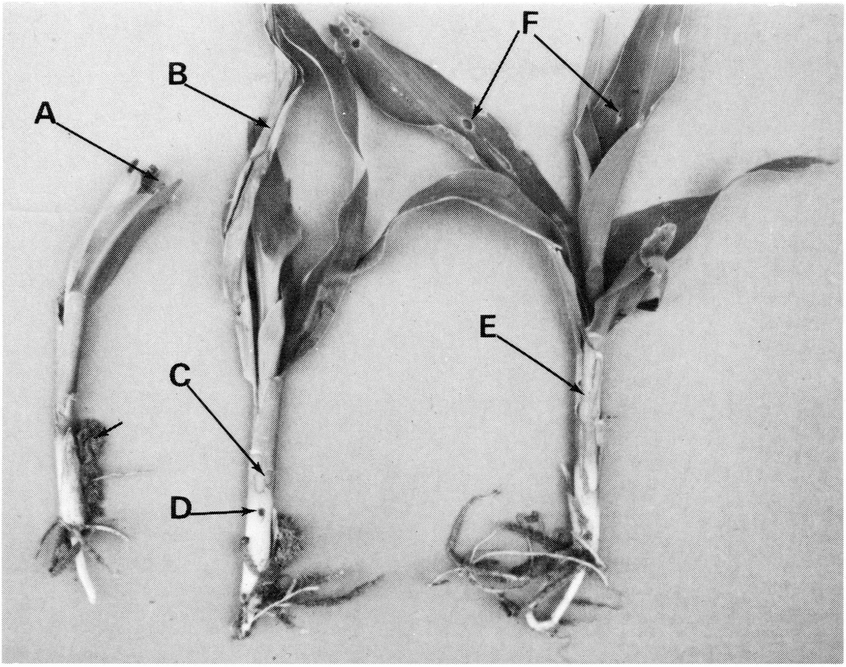

Figure 3. Types of feeding damage to corn by webworm larvae. Type I: Terminal leaf feeding (A) and associated larva and webbing (arrow). Type II: Girdling (C and E) and boring (D) resulting in dessicated leaves (B). Type III: Shothole effect of whorl feeding (F).

Silken chambers were also found along roots of corn plants, although no feeding damage to roots was observed. Because sandy soil is susceptible to rapid drying, it is believed that these webworm larvae were seeking a desirable soil moisture level. When searching for larvae in dry soil, many of those found were at the junction of the roots and stem. Rarely was there more than one larva per plant, although as many as four larvae were found close to a damaged plant.

Initially, an average of 11 larvae per 50 feet of row were found in one row each of three replicates. On June 8, 1972, 34% of the plants in the plots exhibited various degrees of feeding damage (Fig. 3). However, when subsequent observations were made on June 15 and 22, only 20% and 10%, respectively, of total plants remaining exhibited damage. The observed damage indicates that feeding activities of webworm larvae contributed to a 21% stand reduction (Table 1). However, the greater number of damaged plants observed on June 8 indicated that seedling corn was more susceptible than older plants, and that after the initial seedling stage the corn was able to withstand the damage. Once plants grew and masked earlier damage, the only indication of webworm feeding was occasional, profuse suckering on some plants. If larvae are still active on larger plants of 10–12 inches height, the only above-ground indication is leaf feeding damage to the suckers.

Three types of feeding damage were recognized (Fig. 3). Type I included terminal leaf feeding, Type II included plant girdling and boring, and Type III included the shot-hole effect caused by whorl feeding. Type II damage is potentially the most severe because if larval boring (Figs. 3-D & 4) reaches the meristematic region, plants usually become severely deformed and seldom outgrow the damage.

Of 200 plants examined on May 31, 1973, 11 larvae were taken from 48 webworm-damaged plants. The corn had been planted (and granular insecticides applied) the previous week. On June 5, 1973, 9 larvae were collected from 32 damaged plants in a 200-plant sample. Because of low larval numbers associated with the feeding damage observed, it was assumed that some larvae either escaped observation, migrated from plant to plant, or were killed by insecticides, pathogens or predators. Dead, flaccid larvae were occasionally encountered and on two occasions, carabid larvae of the genus *Calosoma* were observed feeding on webworms. Larvae apparently move around in the soil to

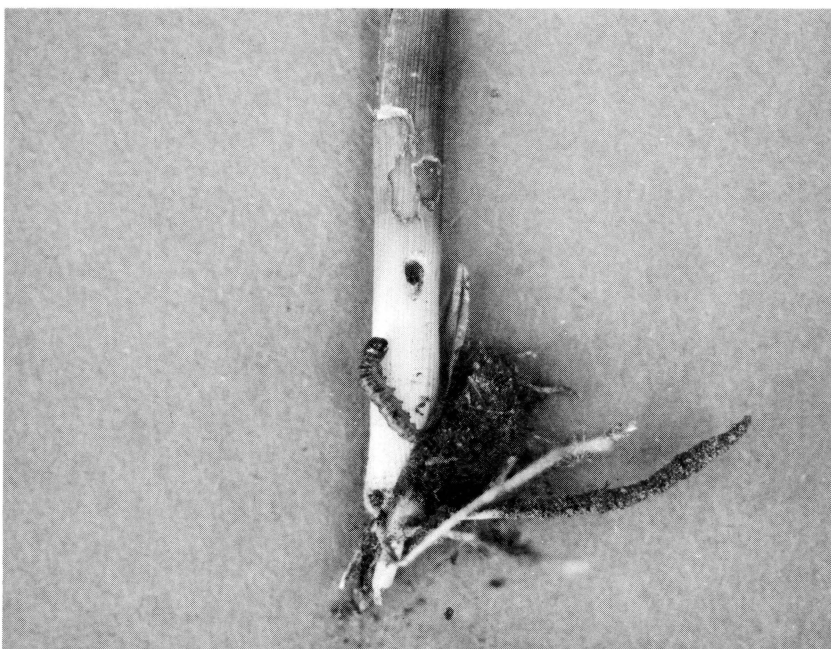

Figure 4. Enlargement of coleoptile region of center plant in Fig. 3 showing borer-type feeding injury, larva and webbing constructed of sand, silk and plant material (webbing pulled aside to show larva).

some extent because they were found in small tunnels in the soil as far as 2 inches away from a corn plant.

On June 8, 1973, webworm damage was evaluated in randomized plots of slot- and till-planted corn to evaluate effects of tillage practices, fertility and water on yield. Since the experiment was designed as a yield study, damaged plants could not be removed. In till-planted corn 4% of 400 plants examined were damaged, compared to 1% damage in the slot-planted corn.

Webworm Indentification, Larval Rearing and Life Histories

Failure to rear field-collected larvae during 1972 created the need for additional studies on the webworms in the Sandhills habitats and improvement of rearing techniques. Additional studies included observations of moth activity in the field, laboratory rearing of field-collected larvae, and rearing of larvae from laboratory-collected eggs with subsequent identification of moths.

A representative sample of moths collected on September 15, 1972, included *Agriphila vulgivagella* (Clemens), *Thaumatopsis pexellus* (Zeller), *Crambus ainsliellus* Klots and *C. leachellus* (Zincken). Of these, only *T. pexellus* and *C. ainsliellus* oviposited in the laboratory. Oviposition occurred on September 18, 1972. Eggs of *T. pexellus* were initially white, then became tan, and by October 2 exhibited a light- grayish-purple hue. Eclosion began October 4, and immediately after eclosion, *T. pexellus* larvae were grayish-brown except for the head capsule which was black. Larvae eventually became whitish and each abdominal segment had a dorsal, lightly pigmented band. The band became less evident as larvae matured, with mature larvae being much lighter in color (Fig. 5).

Of approximately 40 larvae, the one surviving larva pupated on January 24, 1973 and emerged as a moth on February 4. Larvae had been reared on corn leaves (Fig. 6), and the high larval mortality was apparently due to unsuitable food or accumulations of water in the cup caused by leaf tip respiration.

Eggs of *C. ainsliellus* were also white initially, then light brown, but turned bright pink before eclosion. Eclosion began September 26, but the larvae survived for only a few days. The abdomen and meso- and meta-thoraces of first-stage larvae were deep pink, whereas the head capsule and pronotal plate were black.

Webworm larvae collected on damaged corn plants from May 31–July 3, 1973, were reared in 1-oz. diet cups on Riddiford's modified diet. Pupation of these larvae occurred inside chambers constructed of the artificial diet, fecal pellets and silk, from September 6 through October 16, 1973. Moths were allowed to emerge in the cups, then mounted for future taxonomic determination.

The majority of these moths emerged September 18 to September

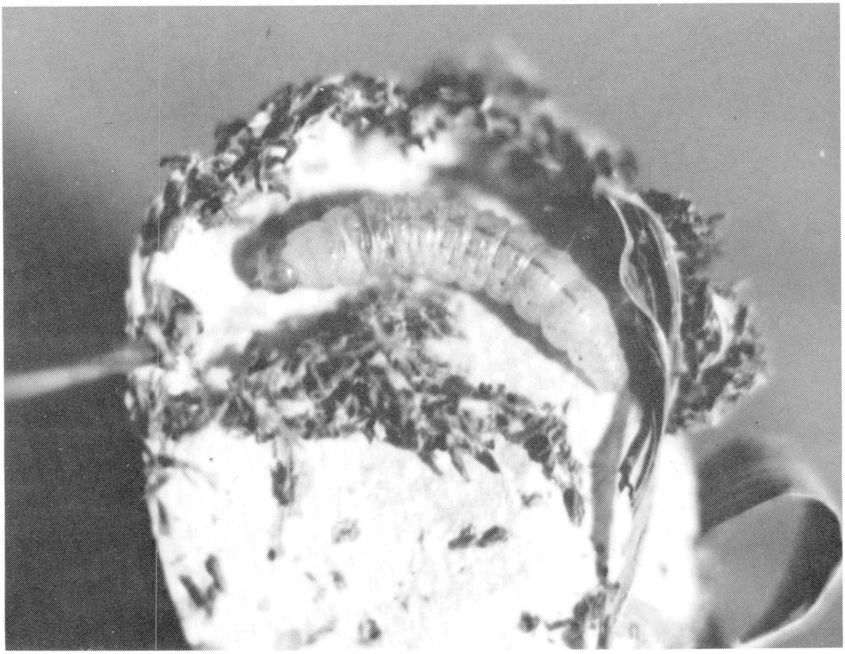

Figure 5. ***T. pexellus*** **full-grown larva reared on corn leaves during 1972.**

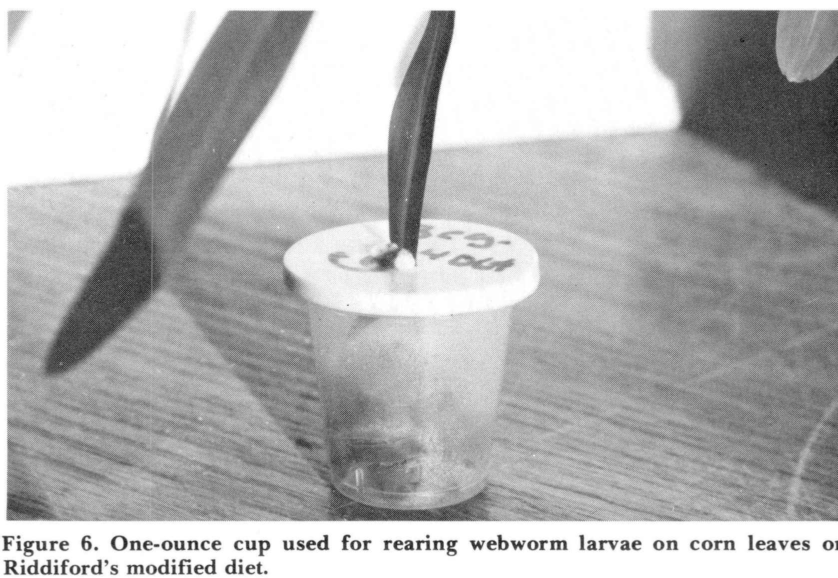

Figure 6. One-ounce cup used for rearing webworm larvae on corn leaves or Riddiford's modified diet.

30. According to Klots (personal communication), these moths included *T. pexellus*, which was the first species to emerge, *Pediasia trisecta* (Walker), *C. leachellus*, and *C. ainsliellus*, with *C. ainsliellus* being most numerous. Only one *P. trisecta* moth was reared from larvae collected in the Sandhills during 1973. However, several *P. trisecta* larvae and pupae were collected on June 22 and 27 from severely damaged corn in Dawson County, an area outside but close to the Sandhills, and successfully reared on the artificial diet. Forbes (14) found that *P. trisecta* was of great potential economic importance to corn production.

Parasites reared from field-collected larvae included the braconid, *Macrocentrus crambivorous* Viereck, and two tachinid species, *Lydina areos*[2] (Walker) and *Euphorocera* sp. These parasites emerged as adults from several *P. trisecta* larvae collected in Dawson County. *M. crambivorous* was the most common parasite encountered, with as many as 45 adults recovered from one *P. trisecta* larva. Parasitized larvae constructed normal pupal chambers, and when these chambers were opened the parasites were discovered.

Approximately 900 larvae were collected in Sandhills cornfields. However, parasites emerged from only two of these larvae. One was parasitized by *M. crambivorous*, the other by the ichneumonid, *Pristomerus spinator* (F.).

To provide larvae for future reference, webworm moths were collected in pastures adjacent to cornfields during September and October, 1973 and held for oviposition.[3]

C. ainsliellus eggs required 8–12 days to hatch and pupation began November 3. *A. vulgivagella* eggs required 8–12 days, *C. leachellus* 8–13 days and eggs from 1 *T. pexellus*, 14 days to hatch.

Linear transect counts of flying webworm moths were conducted in pastures adjacent to two fields during September and October of 1973 in attempts to determine periods of peak flight activity and to estimate the species composition of moths observed. Moths were not observed at either location on August 29, thus it was surmised that emergence began between this date and September 5. The total numbers of moths counted as pastures were sampled are given in Fig. 1 and estimated species composition, based upon the collection of 50 moths, is shown in Fig. 2. During identical transect samplings in cornfields at another location only three moths were counted in slot-planted corn and none in till-planted corn.

If the moths collected on each linear transect sampling date constituted valid representations of the species in the sampled localities, then *C. ainsliellus* and *C. leachellus* comprised the majority of the moth

[2]*Lydina areos* first instance of puparium collected with fly.

[3]Several life history stages of the four webworm species are preserved at the University of Nebraska Museum and the American Museum of Natural History.

population at one location and *A. vulgivagella* was more abundant at another during 1973 (Fig. 2). These data further indicate that peak flight activity for these three species, in addition to *T. pexellus*, occurred for an approximate 2-week period beginning the week following September 5. Although it is not confirmed from these data, Fig. 2 indicates that *A. vulgivagella* began emerging earlier than the other species. *C. leachellus* and *C. ainsliellus* moths can only be separated by detailed examination of the genitalia, making it impossible to recognize these two as different species in the field. However, a long series of moths collected during sampling, and subsequently determined, indicated the *C. leachellus* and *C. ainsliellus* population (Fig. 2) was composed principally of the latter species.

Forbes (14) reported that larvae of *A. vulgivagella* matured during late May on corn. If this was true in Nebraska, then it explains why *A. vulgivagella* was not reared from larvae collected on damaged corn plants during June–July 1973. Corn was planted during the first week of June and during late May and would have escaped the insect.

Adults of *A. vulgivagella* were collected during September and October of 1973. Eggs collected from these adults were held until eclosion began and then placed on Riddiford's modified diet. These insects were successfully reared to the adult stage.

It is concluded that *T. pexellus, P. trisecta, C. ainsliellus* and *C. leachellus* are potential pests of seedling corn in the Sandhills. *T. pexellus, C. ainsliellus* and *C. leachellus*, in addition to *A. vulgivagella*, are univoltine, oviposit from late August until late September and overwinter as partially grown larvae. In contrast, *P. trisecta* is bivoltine, with flights of the first brood occurring from mid-June to mid-July and those of the second brood from mid-August to mid-September (1, 4, 14). Because of the periods of activity, feeding habits, close proximity of the 1972 and 1973 infestations and similarity to the larvae of *C. ainsliellus* and *C. leachellus* found during 1973, it is also believed that most of the unidentified larvae collected during 1972 were *C. ainsliellus* and *C. leachellus*.

The literature contains numerous accounts of damage to seedling corn by webworm species not encountered during the Sandhills study. The species complex *C. luteolellus* Clemens-*C. caliginosellus* Clemens-*C. zellus* Fernald, commonly called the corn root webworm, is a widely known pest of corn in the United States (1, 10, 29). This is a difficult species complex, according to Klots (personal communication), and not established taxonomically. *P. mutabilis* (Clemens) and *C. praefectellus* Zincken have also been reported as being wide-spread and common economically important species (3, 6). According to Ainslie (2) *C. praefectellus* is often confused with *C. leachellus*, and the latter species was recovered during this study.

Pitfall Trap Studies

During the summers of 1972 and 1973 traps were placed in various Sandhills pastures and cornfields and used to compare differences in activity of selected beetle species. The beetle families Carabidae, Scarabaeidae, Tenebrionidae and Elateridae were selected as representative of insect fauna of the area. Although pitfall traps are of little value for direct estimation of populations (15, 31), they can yield useful guides to distribution, abundance, behavior and activity (25, 30). It was felt that these species might serve as indicators of effects of conversion of grazing land to irrigated cornfields on indigenous species.

Virgin grasslands may be vast reservoirs of potential pests of domestic crops and cultivation of these lands is often accompanied by a dramatic change in native fauna (36).

A modification of Shannon's formula as discussed by Wilhm (38, 39) was used to summarize information about numbers and kinds of species found in pastures and cornfields in the Sandhills.

Analysis showed that data, obtained when the triangular trap arrangements were used, were too variable to adequately test the hypothesis that traps in the larger triangles should capture more beetles. Therefore, the only comparisons that could be made involved differences between the pastures and cornfields (Tables 3, 4, 5, and 6).

Members of the family Carabidae were the most abundant both in total numbers and numbers of species (Tables 3, 7, and 8). They were commonly collected as a group, with certain species taken throughout the trapping period.

Pasimachus elongatus LeConte was frequently collected in pastures, but was rarely taken in cornfields, although relatively more abundant in slot-planted than till-planted corn (Table 3). This beetle is normally found in rangeland with a sandy-textured soil and is thought to prey on several species of rangeland insects (8). Although the trapping record indicates occasional peaks of activity, there was no seasonal synchrony to these peaks when corresponding dates at different locations were compared. This species was taken throughout the entire collection period at all prairie locations. These data also indicate *P. elongatus* is adversely affected when native pasture is replaced with irrigated corn (Tables 3, 7, and 8) despite Kirk's (20) report that this beetle is one of the most commonly collected cropland species.

Discoderus parallelus Haldeman and *Selenophorus planipennis* LeConte were more commonly collected in prairie than in corn (Tables 7 and 8). This situation is also true for *D. parallelus* in till-planted corn (Table 3). However, during 1973 the numbers of *D. parallelus* and *S. planipennis* were greater in slot-planted corn than in prairie or till-planted corn (Table 3). The till-plant system destroys most of the

Table 3. Seasonal total of carabids collected in pitfall traps at McPherson County site from June 14 – September 1, 1972 and June 27 – October 3, 1973 (based on average number of beetles per trap).

Species	Prairie 1972	Prairie 1973	Slot-planted corn 1973	Till-planted corn 1973
Discoderus parallelus	7.19	2.78	5.21	2.09
Selenophorus planipennis	6.90	2.63	7.36	5.33
Chlaenius tomentosus	2.56	2.63	.21	.21
Harpalus pennsylvanicus	3.50	2.56	109.41	53.42
Euryderus grossus	15.10	2.29	1.43	3.19
Pasimachus elongatus	9.00	2.07	1.13	.19
Anisodactylus merula	1.09	1.85	.71	1.14
Harpalus paratus	1.28	.85	7.00	1.52
Amara convexa	0	.48	.21	.14
Stenolophus conjunctus	0	.29	0	.18
Cratacanthus dubius	.06	.19	.14	0
Bembidion nitidum	0	.19	0	0
Cymindis interior	0	.19	0	0
Harpalus indigens	0	.15	0	0
Bembidion rapidum	0	.15	0	0
Agonum placidum	0	.11	2.35	1.62
Harpalus caliginosis	.31	.11	.07	.05
Amara pennsylvanica	0	.07	.21	.19
Agonoderus comma	0	.07	0	.14
Amara obesa	.03	.07	0	0
Calosoma affine	0	.07	0	0
Chlaenius nebraskensis	0	.04	.07	.05
Cymindis planipennis	.03	.04	0	.10
Chlaenius sericeus	0	0	.14	.09
Harpalus ellipsis	0	0	.07	.09
Bembidion rupicola	0	0	0	.05
Chlaenius nemoralis	0	0	0	.05
Anisotarsus piceus	0	0	.07	0
Agonum cupripenne	0	0	.07	0
Anisodactylus sanctaecrusis	0	0	.07	0
Calosoma obsoletum	.06	0	0	0
Harpalus erraticus	.03	0	0	0
Pasimachus obsoletum	.03	0	0	0
Total number collected	1504	537	1904	1466
Number of pitfall traps	32	27	14	21
Coefficient of diversity	2.67	3.49	1.24	1.48

native vegetation whereas slot-planting results in a minimum of soil disturbance. Availability of grass cover may be an important factor in the distribution of these insects. *Chlaenius tomentosus* Say, *Anisodactylus merula* Chaudoir and *Euryderus grossus* Say tended to be more common in the prairie than in cornfields with the exception of *E. grossus* at one site and *A. merula* at another. Kirk (20) reported only rare collections of these three species in South Dakota cropland.

The cornfields studied during 1972–73 had fewer numerically dominant species of carabids in comparison to prairie, but had a greater total population density (Tables 3, 7, and 8). Of the 34 species collected at one location during 1973, *Harpalus pennsylvanicus* DeGeer and *H. paratus* Casey comprised 46.5% and 39.5%, respectively, of the total carabids collected in cornfields (Table 8). These species were also among the numerically dominant carabids collected in prairie, but accounted for only 16.6% and 8.9%, respectively, indicating a greater numerical balance among species in the prairie. Greater numerical balance resulted in the higher diversity coefficients of the prairie at three sites (Tables 3, 7, and 8), although a greater number of species was found in the corn than in the prairie at another. These data correspond to the findings of Bey-Bienko (5) and Uvarov (35).

H. pennsylvanicus and *H. paratus* are rather cosmopolitan species and Kirk (20) estimated an average of 4000 *H. pennsylvanicus* per acre in cornfields included in his studies. Greater numbers of these two

Table 4. Seasonal totals of scarabs collected in pitfall traps at McPherson County site from June 14 – September 1, 1972 and June 27 – October 3, 1973 (based on average number of beetles per trap).

Species	Prairie 1972	Prairie 1973	Slot-planted corn 1973	Till-planted corn 1973
Diplotaxis rudis	6.31	37.00	.33	.33
Geotrupes opacus	.22	1.07	.14	.29
Canthon nigricornis	.25	.81	.07	.24
Cremastocheilus knochi	.28	.29	.14	.09
Euphoria inda	.19	.22	0	0
Psammodius interruptus	0	.15	0	0
Cremastocheilus variolosus	.03	.11	.07	0
Serica curvata	0	.07	0	0
Anomala ludoyiciana	0	.07	0	0
Pleurophorus atlanticus	0	.04	.07	.19
Eucanthus impressus	.16	.04	.07	.05
Hoplia laticollis	0	.04	.14	.05
Onthophagus orpheus pseudorphis	0	.04	.07	0
Ochadeus muscalus	0	.04	0	0
Aphodius concavus	0	0	.07	0
Corpris fricator	0	0	.07	0
Polyphylla decemlineata	0	0	.07	0
Onthophagus knausi	0	0	.07	0
Aphodius ruricola	0	0	.07	0
Onthophagus hecate hecate	0	0	.07	0
Stephanucha pilipennis	0	0	.07	0
Strigoderma arboricola	0	0	0	.05
Aphodius fimentarius	0	0	0	.05
Canthon ebenus	.59	0	0	0
Eucanthus lazarus	.22	0	0	0
Aphodius coloradensus	.03	0	0	0
Total number collected	265	1086	36	30
Number of pitfall traps	32	27	14	21
Coefficient of diversity	1.46	.95	3.78	2.78

Table 5. Seasonal totals of tenerionids collected in pitfall traps at McPherson County site from June 14 – September 1, 1972 and June 27 – October 3, 1973 (based on average number of beetles per trap).

Species	Prairie 1972	Prairie 1973	Slot-planted corn 1973	Till-planted corn 1973
Eleodes tricostata	2.78	3.89	1.28	.66
Blapstinus pratensis	3.50	3.52	2.21	0
Eleodes suturalis	.56	.11	0	.14
Eleodes opaca	.31	.04	.07	.05
Eleodes fusiformis	.25	.04	0	.05
Bothrotes plumbeus	.03	.04	0	0
Embaphion muricatum	.09	.04	0	0
Eleodes obsoleta	.06	0	0	0
Asidopsis opaca	.06	0	0	0
Total number collected	245	207	37	21
Number of pitfall traps	32	27	14	21
Coefficient of diversity	1.52	1.26	1.08	1.21

species were captured in slot-planted corn than in till-planted corn during 1973 (Table 3). Two important factors affecting ground beetle populations are soil moisture and surface cover, both of which are greater in the slot-planted corn due to the presence of thatch and living grasses.

Agonum placidum Say, *Amara pennsylvanica* Hayward and *Harpalus caliginosus* Fabricius were commonly collected at one location (Table 8), although the two latter species were less evident at other localities. *A. placidum* was collected in greater numbers in slot-planted than in till-planted corn or prairie during 1973.

Several of the carabids rarely taken in cornfields during this study have been reported elsewhere (20, 28) as being commonly collected in pitfall traps placed in cropland. This group included *Stenolophus conjunctus* Say, *H. erraticus* Say, *Agonoderus comma* Fabricius, *Pterostichus chalcites* Say, and *A. obesa* Say. The low number collected may be a

Table 6. Seasonal totals of elaterids collected in pitfall traps at McPherson County site from June 14–September 1, 1972 and June 27–October 3, 1973 (based on average number of beetles per trap).

Species	Prairie 1972	Prairie 1973	Slot-planted corn 1973	Till-planted corn 1973
Conoderus auritus	2.03	2.52	.78	1.71
Colaulon rectangularis	1.25	.70	.29	.09
Hemicrepidius memnonius	.03	0	0	0
Melanotus decumans	0	0	0	.05
Total number collected	106	87	15	39
Number of pitfall traps	32	27	14	21
Coefficient of diversity	1.18	.76	.84	.45

Table 7. Seasonal totals of carabids collected in pitfall traps at Logan County site from August 3–August 24, 1972.

Species	Prairie	Cornfield
Harpalus pennsylvanicus	67	234
Anisodactylus merula	43	17
Euryderus grossus	29	1
Discoderus parallelus	26	5
Harpalus paratus	25	87
Harpalus caliginosus	25	4
Selenophorus planipennis	24	4
Pasimachus elongatus	15	0
Chlaenius tomentosus	9	1
Agonum placidum	4	6
Chlaenius sericeus	2	0
Cymindis interior	2	0
Agonum cupripenne	1	0
Agonoderus comma	1	1
Chlaenius nebraskensis	0	3
Hellumorphoides praeustus bicolor	1	0
Cymindis planipennis	1	0
Brachinus quadripennis	1	0
Pasimachus obsoletum	1	0
Agonum obsoletum	0	1
Total number collected	277	364
Coefficient of diversity	3.09	1.58

result of surveying relatively isolated, first-year cornfields. These carabids were also rarely collected in pastures, thus if their populations are capable of increasing in cornfields over several seasons, surveys of established fields may show greater numbers of these species. *A. comma* is probably the only carabid collected that is of potential economic importance. This species is often confused with the seed-corn beetle, *A. lecontei* Chaudoir, and has been reported as being economically injurious to germinating corn seeds (17) as well as being a predator on certain root maggots (18).

Diplotaxis rudis LeConte and *Geotrupes opacus* Haldeman were the numerically dominant scarabs taken during 1972 and 1973 (Table 9). *D. rudis* was active from June 27 until July 25 with periods of peak activity occurring between July 11–25. *G. opacus* was not taken before August 29 and was active until October 3. Periods of peak activity for this species occurred between August 29 and September 12.

There was little difference between diversity coefficients for corn and prairie at one location (Table 10). However, the diversity coefficients and total number of individuals for another, two miles away (Table 4) are unusual in that the coefficients for slot- and till-planted corn, as opposed to expectation, were greater than the coefficient for prairie. According to Uvarov (36), greater diversity and lower population density is usually expected in grassland than in cropland. A factor which may have contributed to this situation is the fact that the average number of *D. rudis* per trap is almost 37 times greater than

Table 8. Seasonal totals of carabids captured in pitfall traps at second McPherson County site from June 13–October 3, 1973.

Species	Prairie	Cornfield
Harpalus pennsylvanicus	150	4638
Discoderus parallelus	130	8
Pasimachus elongatus	125	6
Amara convexa	105	22
Chlaenius tomentosus	105	7
Harpalus paratus	100	3983
Selenophorus planipennis	41	5
Harpalus caliginosus	37	462
Amara quenselli	22	23
Cymindis planipennis	13	0
Amara pennsylvanica	9	354
Agonum placidum	9	313
Euryderus grossus	9	6
Cymindis interior	8	2
Anisodactylus merula	6	16
Cymindis pilosa	5	0
Harpalus funerarius	4	57
Harpalus erraticus	4	11
Amara rubrica	4	10
Agonoderus comma	3	7
Hellumorphoides praeustus bicolor	3	1
Agonum cupripenne	1	1
Amara obesa	1	0
Harpalus desertus	1	0
Cratacanthus dubius	1	0
Pterostichus chalcites	1	0
Calosoma luxatum	1	0
Amara littoralis	1	0
Chlaenius nebraskensis	0	13
Stenolophus conjunctus	0	7
Brachinus quadripennis	0	4
Harpalus indigens	0	2
Bembidion nitidum	0	2
Anisodactylus sanctaecrusis	0	2
Geopinus incrassatus	0	1
Anisodactylus sericeus	0	1
Harpalus indianae	0	1
Chlaenius sericeus	1	1
Anisotarsus terminatus	0	1
Calosoma obsoletum	0	1
Agonum decorum	1	1
Bembidion rupicola	0	1
Total number collected	899	9970
Coefficient of diversity	3.67	1.78

the next most abundant species in prairie during 1973. High numbers of a few species greatly decrease a diversity coefficient calculated by Shannon's formula. The low number of *D. rudis* and other species collected in cornfields may indicate that irrigation and soil disturbance either created an undesirable habitat for these beetles or may

Table 9. Seasonal totals of scarabs collected in pitfall traps at Logan County site from August 3–August 24, 1972.

Species	Prairie	Cornfield
Diplotaxis rudis	2	14
Geotrupes opacus	0	2
Eucanthus lazarus	1	0
Aphodius coloradensis	1	0
Cremastocheilus variolosus	1	0
Ataenius imbricatus	1	0
Estephanucha pilipennis	1	0
Cremastocheilus knochi	0	1
Total number collected	7	17
Coefficient of diversity	2.52	.83

Table 10 Seasonal totals of scarabs captured in pitfall traps at second McPherson County site from June 13–October 3, 1973.

Species	Prairie	Cornfield
Geotrupes opacus	42	13
Pleurophorus atlanticus	26	6
Cremastocheilus knochi	13	21
Anomala ludoyiciana	9	6
Euphoria inda	8	0
Diplotaxis rudis	4	0
Phyllophaga sylvatica	3	3
Eucanthus greeni	3	2
Hoplia laticollis	2	1
Aphodius ruricola	2	0
Phyllophaga lanceolata	2	0
Onthophagus orpheus	1	5
Eucanthus impressus	1	2
Canthon nigricornis	1	2
Onthophagus hecate hecate	1	2
Aphodius walshi	1	1
Corpris fricator	1	1
Eucanthus lazarus	1	0
Aphodius concavus	1	0
Corpris fricator fricator	1	0
Psammodius interruptus	0	3
Aphodius fimentarius	0	2
Glaresis inducta	0	1
Serica curvata	0	1
Cremastocheilus variolosus	0	1
Anomala binotata	0	1
Phyllophaga mucoria	0	1
Aphodius distinctus	0	1
Total number collected	123	76
Coefficient of diversity	3.09	3.58

Table 11. Seasonal totals of tenebrionids collected in pitfall traps at Logan County site from August 3–August 24, 1972.

Species	Prairie	Cornfield
Blapstinus pratensis	29	3
Eleodes tricostata	6	0
Bothrotes plumbeus	2	0
Total number collected	37	3
Coefficient of diversity	.93	0

have resulted in high mortality of immature forms. Occurrence of greater numbers of individuals and species in slot-planted than in till-planted corn further indicates the disruptive influence on indigenous species due to tillage of native prairie and subsequent replacement with corn.

Tenebrionids of the genera *Eleodes* and *Embaphion* are often referred to as false wireworms and are known to be associated with damage to irrigated and non-irrigated crops when grazing land is brought under cultivation. Although damage has most often been associated with wheat and other small grains (16, 37), it is possible that false wireworms could be of concern to cornfields that follow grazing land because they are known to feed on corn (23, 32).

E. opaca, E. tricostata and *Blapstinus pratensis* LeConte were the most commonly occurring tenebrionids during 1972 and 1973 (Tables 5, 11, 12). These beetles were taken throughout the summer with peak periods of activity from mid- to late July. More tenebrionids were taken in the prairie than in cornfields and calculated diversity coefficients were also higher for the prairie, as expected. Tenebrionids of the genus *Eleodes* are generally found in greater abundance in areas of low rainfall and humidity (23). In oviposition studies with *E. tricostata*, McColloch found that females preferred to oviposit in dry soil. The moist and humid conditions in cornfields probably account for the low numbers of these beetles collected in Sandhills cornfields.

Elaterids were the least commonly collected of the families studied (Tables 6, 13, 14,). Wireworms are normally associated with soils high in organic matter (21, 22) and since the highest organic matter con-

Table 12. Seasonal totals of tenebrionids captured in pitfall traps at second McPherson County site from June 13–October 3, 1973.

Species	Prairie	Cornfield
Eleodes opaca	225	55
Eleodes tricostata	154	6
Blapstinus pratensis	61	12
Eleodes fusiformis	13	17
Eleodes suturalis	13	4
Embaphion muricatum	4	0
Total number collected	470	94
Coefficient of diversity	1.78	1.72

Table 13. Seasonal totals of elaterids collected in pitfall traps at Logan County site from August 3–August 24, 1972.

Species	Prairie	Cornfield
Colaulon rectangularis	2	0
Conoderus auritus	1	0
Hemicrepidius memnonius	1	0
Total number collected	4	0
Coefficient of diversity	1.5	0

tent of soils sampled in Sandhills cornfields during 1972–1973 was 1.89% (Table 2), wireworms may not be economically important to corn production in the Sandhills. Two years of clean cultivation of fields in Quebec resulted in a decline in numbers of elaterid beetles (21). Cultivation decreased the amount of root material available for young larvae and destroyed pupal cells, larvae and adults as well as reducing suitable plant cover for oviposition sites. This should also be true for elaterids in the Sandhills, particularly in a till-planted system.

Conoderus auritus (Herbst), and *Colaulon rectangularis* Say were the most commonly collected elaterids with numbers taken in prairie being much higher than those taken in cornfields. In studies of cover selection by adult elaterids, Doane (9) reported that adults avoided high soil moisture sites (20% moisture), and this behavior may partially explain the lower level of activity of elaterid adults in Sandhills cornfields.

During 1972 and 1973 adults were collected throughout the season. Collection records indicate that activity was greatest during June. The only elaterid collected after August 29 was *C. vespertinus*, two specimens of which were collected on September 26, 1973.

Sweep Samples

Sweep-net samples were taken as a means to compare relative numbers of 11 selected species found in prairie adjacent to an irrigated, first-year cornfield on August 11, 1972. Analysis of these data indicated that the numbers of individuals collected depended upon distance from the cornfield (Fig. 7 and 8).

Tillage operations involved with planting and cultivation of the

Table 14. Seasonal totals of elaterids captured in pitfall traps at second McPherson County site from June 13–October 3, 1973.

Species	Prairie	Cornfield
Conoderus auritus	125	91
Colaulon rectangularis	13	20
Melanotus decumans	11	10
Conoderus verspertinus	0	4
Total number collected	149	125
Coefficient of diversity	.60	1.22

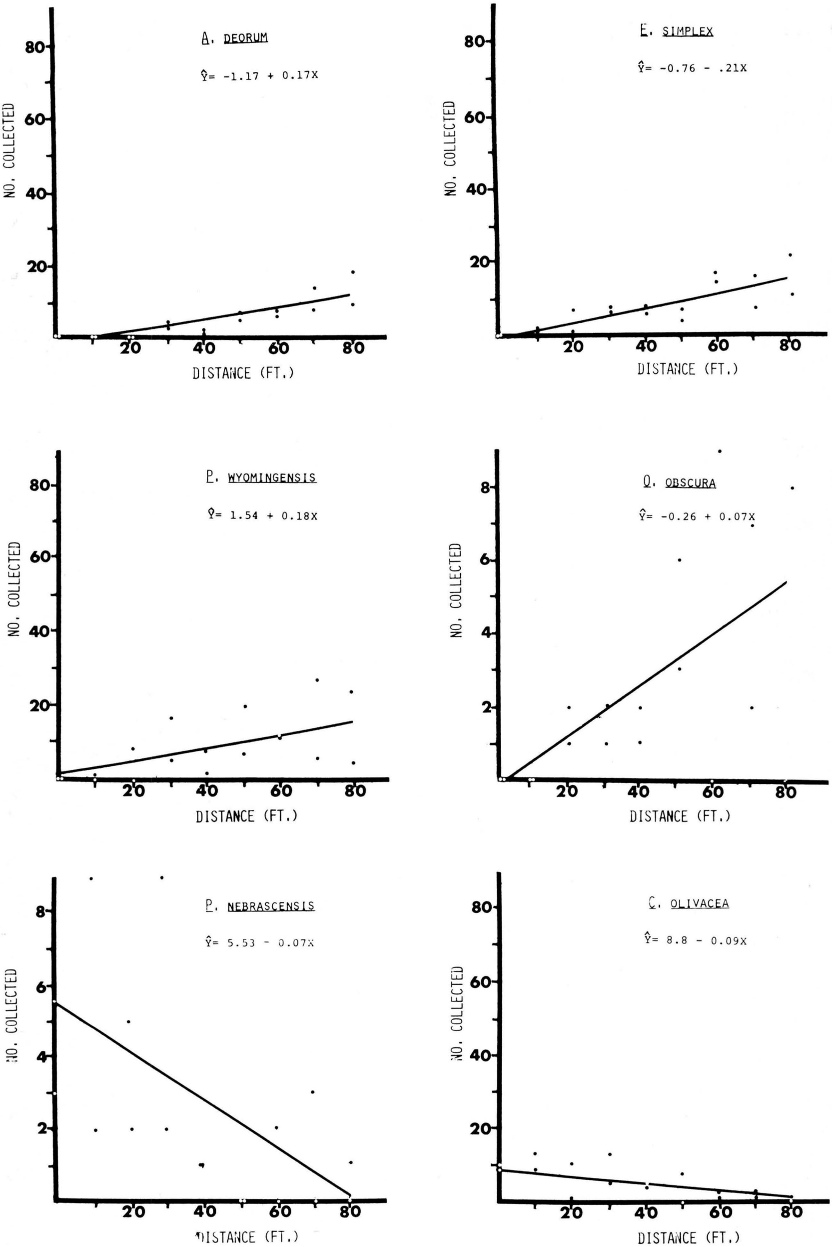

Figure 7. Linear relationships of distance from a cornfield and numbers of *Ageneotettix deorum, Eritettix simplex, Parapomola wyomingensis, Opeia obscura, Phoetaliotes nebrascensis* and *Campylacantha olivacea* collected in sweep samples.

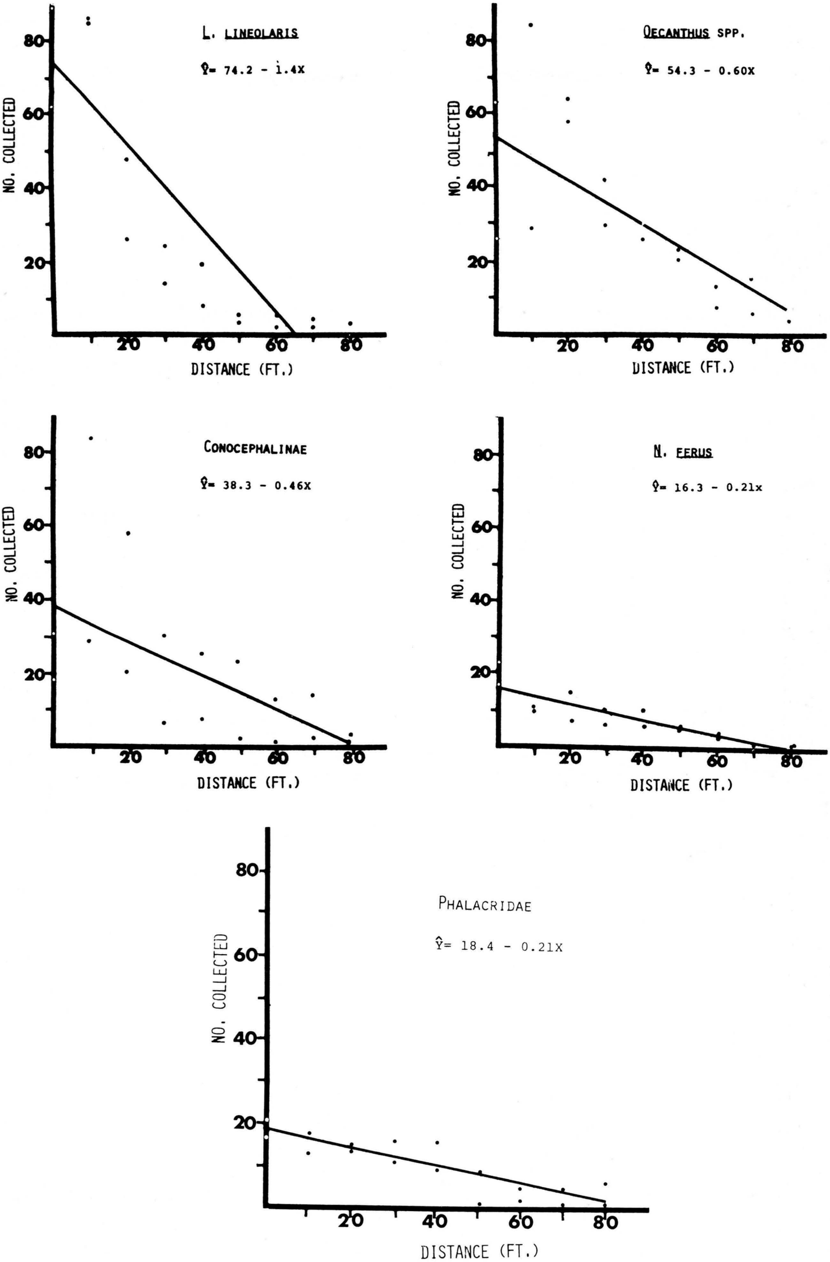

Figure 8. Linear relationships of distance from a cornfield and number of *Lygus lineolaris, Oecanthus* spp., Conocephalinae, *Nabis ferus* and Phalacridae collected in sweep samples.

cornfield resulted in destruction of some of the native plants immediately adjacent to the field. Native grasses in these disturbed areas were usually replaced by grassy and broadleafed weeds. Irrigation systems often irrigated a small strip of prairie surrounding the cornfield. This application of water, in conjunction with the fertilizer injected into the irrigation system, resulted in a lush growth of mixed vegetation at the edge of the cornfield. These factors, in conjunction with undefined microclimatic effects, may be responsible for higher numbers of certain species bordering a cornfield.

For example, the greater frequency of *Campylacantha olivacea* (Scudder) near the cornfield (Fig. 7) was probably due to the presence of certain broadleafed weeds. Western ragweed *(Ambrosia psilostachya)*, a primary food plant for *C. olivacea* (26), is normally associated with overgrazed rangeland and disturbed areas of prairie. The occurrence of these weeds may also influence other insects such as shining flower beetles, Phalacridae (Fig. 8). Similarly, the concentration of western ragweed may have been the key factor causing high numbers of tarnished plant bugs, *Lygus lineolaris* (Say), to be collected at the edge of the cornfield (Fig. 8). *L. lineolaris* has been reported to occur in such numbers on ragweed as to constitute a check in development of the weed (24).

Fewer conocephaline or meadow grasshoppers were taken in samples collected at increasingly greater distances from the cornfield (Fig. 8). These tettigoniids are commonly found in wet meadows or grassy areas near ponds and streams. The inadvertent irrigation of grasses and weeds bordering cornfields probably contributed to the relatively greater numbers of these grasshoppers as well as the grass feeding acridid, *Phoetaliotes nebrascensis* (Thos.) in samples taken near the cornfield. Similarly, some tree crickets, *Oecanthus*, are known to occur in tall grasses and weeds.

Although lower numbers of the predator, *Nabis ferus L.*, were taken in contrast to the numbers of insects with other feeding habits, significantly more *N. ferus* occurred near the edge of the corn field. Perhaps this indicates a greater availability of prey.

The number of species of rangeland grasshoppers increased as the distance from the cornfield increased (Fig. 7). The collections included *Eritettix simplex* (Scudder), *Opeia obscura* (Thomas), *Ageneotettix deorum* (Scudder) and *Parapomola wyomingensis* (Thomas). Destruction of native habitat and moist conditions created by irrigation are plausible explanations for lower numbers of these grasshoppers at the edge of the cornfield.

Vacuum Sampling of Leafhoppers

Indria inimica (Say) and *Macrosteles fascifrons* (Stal) (Homoptera: Cicadellidae) were found to be the most abundant leafhoppers on corn when fields were sampled with a vacuum sampler on July 25, 1973.

There were no significant effects due to fertilizer rates; however, a t-test comparison showed significantly more *I. inimica* in slot-planted corn than in till-planted corn. A total of 372 *I. inimica* were found in four 20-linear-ft. samples of slot-planted corn, compared to 178 for the till-planted corn. No significant differences were detected in the numbers of *M. fascifrons* collected in the two tillage systems. A total of 455 *M. fascifrons* were collected in slot-planted corn whereas 408 were collected in till-planted corn.

Transect Samples of Cornfields

Because little is known about populations of western corn rootworm (WCR) and European corn borer (ECB) in the Sandhills, linear transect sampling of Sandhills cornfields that had been cultivated for various periods of time were conducted during the study period to detect the occurrence of these and other corn pests (Tables 2 and 15). WCR beetle samples were taken between August 8 and August 16 during both years. Second brood ECB were surveyed on October 6 and 7 during 1972.

It is believed that high sand content of soils, and its probable physical abrasion to larval cuticle, may be a significant factor causing low populations of WCR to occur in the Sandhills. Laboratory studies on WCR larvae conducted by Turpin and Peters (33) support this concept.

Another factor that may account for the relatively low incidence of WCR in the Sandhills is lack of suitable oviposition sites. Kirk (19) found that WCR females preferred oviposition sites composed of relatively large soil particles, soil cracks to large soil aggregates, and preferred moist soil. Few such sites are available in the Sandhills.

The fact that WCR beetles were observed in relatively isolated fields in the central area of the Sandhills (Table 2), indicates that at least a few WCR larvae are capable of surviving in sandy soil. The required provision of irrigation water for profitable corn production may aid rootworm survival by lowering the levels of larval mortality through dessication. However, no research was conducted during the

Table 15. Results of European corn borer survey conducted October 6–7, 1972. Three samples, each consisting of 1/1000 acre, taken at each locality.

Locality number	Avg. no. plants per sample	Avg. no. cavities per plant	Avg. no. larvae per plant
1	33	0	0
2	25	.11	.10
4	22	.29	.11
6b	34	0	0
9	22	.81	.41
10a	23	.12	.03

present study to determine this possible explanation. WCR populations were relatively low at all Sandhills locations and the number of years in corn cultivation apparently had no effect on numbers of beetles observed during samplings. For example, one locality had been in corn production for at least 13 years and only two beetles were found in a 50-plant sample (Table 2), whereas at another which had been in corn production for only four years, 14 beetles were observed in a 50-plant sample.

Soil tests at two localities not in the Sandhills showed that the sand content in these fields was comparable to that in Sandhills fields (Table 2). Their close proximity to the Platte River Valley, an area of intensive corn production and large WCR populations, may have influenced the beetle counts obtained at these two localities. It is plausible that many of the beetles observed were migrants from the valley fields. The probability of sampling migrant beetles should have been greater there than at a site which is, for example, at least 25 miles from other cornfields. The relatively high beetle counts may also have been a result of the close proximity of a field to the Platte River Valley.

ECB populations were relatively low throughout Nebraska during 1972 (D. L. Keith, personal communication), and this may partly explain the low incidence of infestation encountered in the Sandhills survey (Table 15). The Sandhills are on the western edge of the ECB distribution and, although only one of the cooperators interviewed had observed high ECB damage, the present studies showed that the insect was present in low numbers in Sandhills cornfields.

Other potential corn pests observed during this study include the western bean cutworm, *Loxagrotis albicosta* (Smith); corn earworm, *Heliothis zea* (Boddie); corn leaf aphid, *Rhopalosiphum maidis* (Fitch); fall armyworm, *Spodoptera frugiperda* (Smith); and, armyworm, *Pseudaletia unipuncta* (Haworth). Potential pests of seedling corn in new fields include true and false wireworms, white grubs and cutworms. These insects were only found occasionally, with the armyworm more common than others. Armyworms were found on corn plants in fields that had infestations of field sandbur *(Cenchrus pauciflorus)*. Females probably oviposited in the weedy areas, with larvae eventually moving onto corn plants during July and August.

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