EFFECTS OF ARMY CUTWORM DAMAGE (*EUXOA AUXILIARIS* [GROTE]) ON THE GROWTH AND YIELD OF WINTER WHEAT

By

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PREFACE

The following pages describe the relationship between army cutworm defoliation and the growth and yield of winter wheat. The research that went into this manuscript resulted in the development of a scale for rating army cutworm damage. The result is a good example of the efficiency of visual damage ratings versus actual damage measurements. In addition, a new method of rearing army cutworms was developed which greatly increased survival of the first instar larvae. This method may be helpful in other cutworm rearing programs. Finally, the results indicate that a damage rating of 6 and above (approximately 40 to 50% defoliation per plant) in a greenhouse does result in decreased yield. Such damage is equated with a level of about 4 to 6 fifth-instar cutworms per plant. This level of infestation is not meant to be an economic injury level for army cutworms on winter wheat, for, the greenhouse conditions under which these tests were run are different than those in the field.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

For approximately 90 years, the larvae of the army cutworm (Euxoa auxiliaris Grote) have been recognized as pests of many crops grown in the Great Plains of the United States and southern Canada. Though it is a polyphagous feeder capable of using over sixty plants as hosts (Burton et. al., 1980), its major host is wheat, the most commonly grown crop in this area. To most farmers in this region, the army cutworm is a sporadic pest, rarely if ever present in numbers large enough to be considered an economic threat to an already low-priced crop. Nonetheless, nearly every year somewhere in the Great Plains an infestation of army cutworms does reach economically damaging proportions, often with devastating results. As recently as 1976, 2,500,000 acres of crop land were treated to control army cutworm in Oklahoma. Kansas, Texas, Nebraska, and South Dakota were hit hard that year as well. Montana has also been plagued by this insect pest, suffering hundreds of thousands of dollars in damage and requiring treatment of several hundred thousand acres. Despite the damage potential of this insect, it still is considered of minor importance as a wheat pest due to its sporadic occurrence and the fact that its damage results only in defoliation.

Wheat, as a grass, is more capable than other plants of regrowth after defoliation. Its common use as winter and spring forage for cattle and sheep before it is harvested as a grain crop is a testimony to its regrowth potential. While most researchers agree that defoliation after stem extension, or "jointing", retards growth and decreases yield, there is more controversy about whether defoliation before jointing is detrimental to wheat growth and results in lower yields at harvest. While many forage specialists have noted increased growth in wheat due to defoliation, cattle grazing and army cutworm grazing are not equivalent. Army cutworms feed mostly on leaves, but cattle grazing includes the stems of wheat plants as well. In addition, defoliation at different stages of a plants growth cycle can cause growth and yield to increase or decrease accordingly. The amount of damage occurring to a plant can also make a difference, since a small amount of leaf-feeding may actually be beneficial, stimulating plant growth through a compensatory mechanism within the plant which increases its efficiency (Southwood and Norton, 1973). Therefore, variation in the effects of defoliation makes determining the influence of army cutworm damage on the plant much more difficult. This, coupled with the wheat plant's long-term relationship with the army cutworm (which may spend up to six months in the larval stage) makes determining the economic threshold of this insect difficult.

The economic thresholds currently used for this insect do not take into account the phenological stages of the plant which can be affected or the size and instar of larvae attacking the wheat. Consequently the precise effect that army cutworm defoliation has on wheat has not been well explored. The following study was conducted to quantify army cutworm damage, and determine the effects this damage has on the growth and yield of the winter wheat variety, TAM W-101.

CHAPTER II

LITERATURE REVIEW

The army cutworm (Euxoa auxiliaris [Grote]) is one of the most destructive cutworms in the Great Plains of Canada and the United States (Walkden, 1950; Cook, 1927; Burton et. al., 1980). It belongs to the family Noctuidae in the order Lepidoptera. This family is a well-known source of some of the most notorious lepidopterous pests including the corn earworm (Heliothis zea [Boddie]) and the fall armyworm (Spodoptera frugiperda [J. E. Smith]). Within this family, the genus Euxoa is unique in that it consists exclusively of surface-feeding, or climbing cutworms. A number of these cutworms are considered to be serious pests. For example, E. orchrogaster Guenee, the red-backed cutworm, is of particular importance on the prairie where it attacks mustard, wheat, oats, and flax. The dark-sided cutworm (E. messoria Harris) is an important pest of tobacco in Canada, while the white cutworm, E. scandens, often intensifies its climbing habit and causes serious damage to fruit trees and nursery stock (Hudson, 1973). Though each of these insects can be devastating to agricultural and horticultural crops in localized areas, none have the destructive potential of the army cutworm. This is partly due to this insect's wide distribution both in the terms of host plants and geography.

Host Plants

Army cutworms feed on a wide variety of plants. Burton et. al. (1980) list over 60 species of known hosts, mostly crop plants. Crops affected include winter wheat, spring wheat, barley, corn, alfalfa, sweetclover, crown vetch, broccoli, cauliflower, turnips, sugar beets, mustards, lettuce, tomatoes, apple, blackberry, and most other vegetable and orchard crops not mentioned. In addition, the army cutworm feeds on a number of range and weed species including bromegrass, bluegrass, and tansy mustard. Doubtless, there are a number of plant species army cutworm uses for food that are not as yet recorded.

Distribution

The distribution of the army cutworm was mapped by Burton et. al. (1980), who described the maximum range of this insect as a roughly elliptical area bounded on the north by the Canadian provinces Alberta and Saskatchewan, and on the south by Mexico. Army cutworms have been found in every state west of the Mississippi River except Louisiana, and even in some states east of the Mississippi River including Michigan, Wisconsin, and Illinois. The region most affected by the army cutworm, however, seems to be the semi-arid regions of the Great Plains, especially those areas that lie adjacent to the Rocky Mountains (Crumb, 1929). Larvae have been reported in destructive numbers in Minnesota (Knutson, 1944), Texas, Oklahoma, Kansas, Nebraska, South Dakota, North Dakota, Montana, Wyoming, Colorado, New Mexico, Utah, Idaho, and Oregon in the United States (Walkden, 1950) and Alberta and Saskatchewan in Canada (Beirne, 1971).

Life Cycle

The publication by Burton et. al. (1980) reviews the life cycle of this insect. The information in this section has been taken from this publication except where otherwise referenced.

Adult females oviposit in late summer or fall throughout their range, depending on temperature and perhaps on distance from their summer habitat in the Rocky Mountains. As a rule, the period of oviposition begins earlier in the North. For example, adults begin laying their eggs in late August in Canada (Strickland, 1916), whereas oviposition does not begin until late September in Texas (Crumb, 1929). Though oviposition usually occurs from late September to the middle of October, the subsequent size of an outbreak may depend to some extent on the length of the oviposition period.

Each female usually lays from 1000 to 3000 yellowish-white eggs. Only one or two eggs are laid at a time, usually beneath clods of soil, or just below the soil surface. Vegetation is not a requirement for oviposition, however, though weed and volunteer growth in an otherwise clean field may stimulate egg laying (Strickland, 1916). Pruess (1961) showed that army cutworm adult females preferred sand to soil and ideally required a solid surface below a loose substrate or small clods with loose soil as an oviposition medium. In addition, straw on the surface increased egg production in soil but did not affect egg production on sand, indicating that the reflectance of an oviposition medium is important in stimulating egg production. This may explain why more larvae are found in barley fields which reflect more light than adjacent wheat fields (Pruess, 1961).

Eggs hatch in the field after ten to fifteen days. High temperatures and presence of adequate soil moisture shorten the incubation time, whereas, low temperatures and absence of soil moisture increase incubation time. When reared at 25°C with adequate moisture, eggs hatch in five days time.

After hatch, larvae immediately begin feeding on whatever plant material is available. Because army cutworms are polyphagous feeders, the chances of them finding a suitable host are good. Larval feeding occurs mainly from late afternoon to dark, after which young larvae will burrow beneath the ground to a depth of two to three centimeters.

Very young larvae may hide in the crown of wheat plants instead of in the soil (Cooley, 1908). Though army cutworms are exclusively surface feeders, larvae may follow the stem of a seedling down to the root area if food is not plentiful, thus destroying the plant and reducing the stand.

Larvae continue to feed in the fall until temperatures become low, at which time, larvae will burrow three to seven centimeters below the surface of the soil and pass the winter in a state of quiescence. If temperatures rise during the winter period, larvae will again resume feeding. Though a low temperature feeding threshold has not yet been determined for the army cutworm, larvae have been seen feeding at temperatures close to freezing. (Painter et. al., 1954).

Nearly every instar of the army cutworm is capable of overwintering. Small third-instar larvae ranging up to larvae nearly fully grown have been found below the ground. The period of quiescence usually lasts only as long as the period of cold weather. In the northern states, larvae may spend the entire winter below ground, whereas, farther south where winters are milder, larvae may emerge to feed between cold periods. When temperatures rise sufficiently in late winter or early spring, the larvae will resume their regular pattern of feeding until fully developed. As food gets scarce, the larvae generally tend to migrate *en masse* in a northwest direction consuming most vegetation in their path, hence, the name army cutworm. It is usually in this early spring period that greatest damage occurs.

As in the case of egg incubation, the period of larval development most likely depends on temperature, though other environmental cues may also be involved. In the laboratory, the period of larval development when reared at 27°C is six weeks. Pupation occurs on the average from May to early June. There is some evidence that actual pupation may be delayed as much as two weeks after the larvae have entered the soil (Strickland, 1916). To prepare for pupation, the larva burrows vertically into the soil to a depth of as much as eight centimeters depending on the soil type. There the larva constructs a vertical earthen cell. One to two months later, depending on the temperature, the adult moth will emerge. Pupation under a laboratory setting lasts only 10 to 14 days.

Adult emergence marks the first of two great flights characteristic of this species. At one time it was believed that this first flight occurring in May and June marked the beginning of adult aestivation, a period of inactivity that was spent avoiding the heat of the summer months by hiding beneath rocks or taking shelter in buildings. Pruess (1967) proved that this flight actually marked the beginning of an annual migration of this moth from the Great Plains to the higher elevations of the Rocky Mountains. Not only do moths avoid high potentially lethal summer temperatures, but the time spent under the cold mountain temperatures seems to be necessary to break the reproductive diapause characteristic of newly-emerged adults (Diapause can be artificially broken by keeping adult moths at 4°C for 30 days [Burton et. al., 1980]). The second flight marks the return of the adult moths from the mountains to the Great Plains. It is not known if adults mate after reaching the Great Plains or somewhere along the away, but it is only on the return flight that females have been found with fully developed ova.

Economic Importance

As stated earlier, the army cutworm attacks a wide range of crop plants. Winter wheat, however, has probably suffered from army cutworm damage most since it is the preferred crop of most farmers in the Great Plains area.

Characterization of Damage to Winter Wheat

Army cutworm damage consists of defoliation of plant shoots. Usually feeding is confined to the blade (Strickland, 1948), and tender shoots (Dean and Smith, 1935), with no damage occurring to the growing point (Strickland, 1916). Consequently, infested plants are usually not completely destroyed by army cutworm feeding in winter wheat. The first traces of cutworm injury appear as more or less semicircular areas nibbled from the edge of the leaf or as holes eaten through it (Cooley and Parker, 1916). New tillers and leaves are usually cut off at slightly below or above the soil surface, often below the accumulation of leaves killed by winter (Painter et. al. 1954).

Damage in a field is usually first noticed in the spring in the form of bare areas where the plants have been damaged by these pests eating into the crowns. (Fenton and Whitehead, 1944). Since larvae move to the northwest when they migrate, these bare areas will often arise on the southern side of fields not infested with army cutworms (Daniels, 1964).

Some fields seem more prone to army cutworm attacks than others. For instance, Coppock (1979) and Kantack et. al. (1979) observed that fields which had been stubble-mulched or had more vegetation on them had higher populations than clean-tilled fields. Similarly, summer-fallowing of fields was reported as preventing large infestations of army cutworms when such fields were completely free from weeds (Strickland, 1948). On the other hand, winter wheat in South Dakota planted in early fall in summer-fallowed fields was more likely to be infested with army cutworms possibly due to early wheat growth acting as an oviposition stimulant (Kantack et. al., 1979). Gillette (1904) reported that fields adjoining grassland, rangeland, or uncultivated land had heavier infestations of army cutworms than surrounding fields. Knowlton (1942) actually observed army cutworms moving into crops from adjacent rangeland. Daniels (1964) and Gillette (1904) also reported that fields plowed in the fall had fewer army cutworms the following spring than unplowed fields. DePew (1965) and Daniels (1964) both found that in Kansas and Texas respectively, fields hardest hit by army cutworm had already suffered some damage from drought and winterkill. Lighter soils and shale areas also seem to be more heavily infested than other areas in a field (Coppock, 1979).

Weather conditions also have a lot to do with the severity of an infestation. Strickland (1948) and Beirne (1971) observed that a wet fall promotes army cutworm infestations. Painter et. al. (1954) reported that cold, late springs prolonged the feeding period of the larvae and also prevented rapid growth of the wheat plants, causing them considerable injury.

Economic History

The first economically important army cutworm infestation recorded occurred in the Bitter Root Valley of Montana in 1898 (Wilcox, 1898). About 15 to 40 larvae per sq. ft. of wheat field was common throughout this area. Colorado suffered its first major outbreak of army cutworms in the spring of 1903, causing Johnson (1905) to call the army cutworm the most common and injurious cutworm in the state. Kansas, in 1909, was the next state to suffer a major outbreak (Dean and Smith, 1935). The first occurrence of the army cutworm as a field pest in Canada was an outbreak in Alberta in 1915. Strickland (1916) reported that this outbreak covered an area of 3000 sq. mi., with as many as 100-150 larvae per sq. ft. in some areas. Montana was similarly affected that same year with a near state-wide infestation of army cutworm that destroyed 100,000 acres of crops, mostly winter wheat. Cooley and Parker (1916) estimated that this infestation cost the state of Montana $925,000.

There have been other important outbreaks since the army cutworm made its first appearance. For instance, 30,000 acres of alfalfa, wheat and other small grains, pasture, and rangeland in Utah were moderately to heavily infested with army cutworm larvae in the spring of 1941 (Knowlton, 1942). In the spring of 1945, Montana suffered an extensive infestation which affected 300,000 acres, destroying 1000 acres completely (Mills et. al., 1947). Nearly 750,000 acres in western Kansas were treated in 1963 for army cutworm to combat an infestation that reached 18 larvae per ft. of row (DePew, 1965). That same year, Daniels (1964) reported an infestation in the northeast Texas Panhandle. Beirne (1971) noted that out of 40 years, three infestations in Alberta were severe, nine important, and thirteen were locally important. The late winter and spring of 1976 proved to be a good year for the cutworm but a bad year for wheat farmers as an extensive outbreak of army cutworm affected Texas, Nebraska, Oklahoma, Kansas and South Dakota. Nearly 10,000 acres of wheat were treated for army cutworm control in South Dakota, while 2,500,000 acres were treated in western Oklahoma to combat an infestation that often exceeded 15 larvae per sq. ft. (Burton et. al., 1980).

What causes such extensive army cutworm outbreaks is not known. This is unfortunate, since the army cutworm is of greater economic importance than most other cutworms for a number of reasons. Outbreaks of army cutworms generally develop far more rapidly than do those of other cutworms (Strickland, 1948; Beirne, 1971). In addition, its wide distribution, polyphagous diet, high population in infested areas, prolonged season of destruction from late winter through spring, and the mass migratory habit that larvae attain while searching for food, all increase the potential destruction of this pest (Cooley, 1910).

In the past, a few studies have attempted to quantify army cutworm damage in terms of wheat growth and yield. Burton et. al. (1980) conducted a field study on winter wheat during the 1976-1977 growing season. They infested plants at levels of 0, 3, 6, and 12 larvae per ft. of row. Though the level of 3 per ft. did not cause significant damage, both of the higher rates reduced stand and yield. The rate of 12 larvae per row ft. caused a loss of over 7 bushels per acre. Burton et. al. (1980) also cited some unpublished data showing a reduction in yield of 0.6 bushels per acre for each larva per sq. ft.

Despite the lack of information, economic thresholds have been recommended for this insect. Jacobsen (1962) stated that wheat could withstand up to five larvae per sq. ft. without suffering a loss in yield. Kantack et. al. (1979) and Coppock (1979) suggested that wheat plants less than four inches tall should be treated if as many as two larvae were found per linear ft. This is especially true if the wheat has already suffered damage from drought stress, or if feeding is evident. Wheat plants five to six inches high can tolerate three to four larvae per linear ft. of row. Though such economic thresholds provide a good benchmark for timing control measures, they do not take into account larval size, or the growth stage of the plant at time of infestation. No studies, so far, have attempted to quantify the damage done by army cutworm larvae at differing stages of plant growth. Consequently, the results of other studies dealing with defoliation in winter wheat can be helpful in understanding the potential consequences of army cutworm damage.

Effects of Defoliation on Winter Wheat

The effect of defoliation on winter wheat is a highly complex situation. Defoliation not only affects different parameters of plant growth and yield in different ways, but also may affect each parameter differently at differing stages of growth. Also, short periods of defoliation (acute) do not affect the plant in the same way as longer periods of defoliation (chronic). In addition, different methods of defoliation produce surprisingly different results. To lessen confusion, some commonly measured parameters of wheat growth and yield as affected by defoliation are presented below.

Growth Determinants

Plant Height

Plant height has often been used to measure the effect of environmental stress on wheat. Capinera and Roltsch (1980) worked with young wheat plants 3, 12, and 15 cm in height grown in a growth chamber, a greenhouse, and in the field respectively. Defoliation levels consisted of 1/3 to all of the leaf area removed, either by hand or by grasshopper defoliation. Results indicated that very small plants (3 cm) lost height but regained it after about ten days, whereas, older plants remained shorter than controls even 48 days after defoliation. In another study, Lucas and Asana (1968) also found that undefoliated spring wheat plants were taller than defoliated plants at flag leaf emergence, but were equivalent in height at anthesis. This was attributed to an increase in stem growth rate of defoliated plants, resulting in an increased distance from flag leaf to head.

At harvest, Mukerji et. al. (1976) showed that spring wheat plants defoliated 570 to 880 degree days after planting were 10 centimeters shorter than undefoliated plants. Interestingly, plants defoliated after 880 degree days were taller than plants defoliated earlier. Davidson (1965) also found that spring wheat plants maintained at a leaf area index (total green leaf area per unit area of land) of three or one were 30 centimeters shorter at harvest than their undefoliated counterparts with a leaf area index of twelve. Similarly, Aase and Siddoway (1975) discovered that plots of winter wheat clipped at ground level successively throughout the growing season were shorter than their unclipped counterparts. In addition, the later a plot was clipped up until the ligule of the last leaf emerged, the greater the decrease in height when compared to controls at harvest. Based on this information, defoliation stress both before and after jointing (at least up to the boot stage) results in a decrease in plant height.

Leaf Area

Though it is obvious that defoliation decreases leaf area, the ability of the plant to make up for this loss is important in determining its actual effect on the plant. The stage of growth of the wheat plant at the time of the defoliation greatly affects the ability of the plant to rejuvenate lost leaf area. In looking at the effects of simulated and actual grasshopper feeding on wheat, Olfert and Mukerji (1983) discovered that the ground-level cutting of spring wheat at early tillering had no lasting effect on leaf area, however, cutting after this stage did result in a lower leaf area in defoliated as compared to undefoliated plants at harvest. Lucas and Asana (1968) found that the area of the eighth and ninth leaves of spring wheat plants were reduced when leaves five, six, and seven were removed, however, the size of the flag leaf was not affected.

Removal of these same three leaves resulted in significantly lower leaf areas than undefoliated plants after anthesis.

Cultivar also plays an important part in the way in which the wheat plant reacts to defoliation. Rahman and Wilson (1977) found that the rate of increase in leaf area of defoliated spring wheat plants was greater than that of undefoliated plants in the wheat cultivar '8-23'. In the cultivar Sunset, however, defoliated plants had a lower rate of increase in leaf area than undefoliated controls. On the average, however, defoliation tends to result in a permanent loss in leaf area, especially after jointing.

Dry Matter

Defoliation also seems to result in decreased plant dry weight (Aase and Siddoway, 1975; Armbrust et. al. (1974); Capinera and Roltsch, 1980; Lucas and Asana, 1968; Mukerji et. al. (1976); and Olfert and Mukerji, 1983). Armbrust et. al. (1974) found that removing even the distal quarter of each leaf of winter wheat plants reduced dry weight production when compared to controls. Lucas and Asana (1968) reported that dry weight of remaining leaves of spring wheat plants decreased consistently at harvest as leaf removal increased from one leaf to three. Removal of two to three leaves also significantly reduced stem weight. Two weeks after anthesis, however, these differences were not apparent. They attributed this to events after the emergence of the flag leaf, when subsequent rate of increase in stem weight was greatest in plants whose leaves had been removed resulting in equivalent dry weights at anthesis.

Among other factors, the stage of wheat growth at which defoliation occurs greatly affects the extent of dry matter reduction. Though Aase and Siddoway (1975) found that ground-level clipping from the one-shoot stage to flowering reduced dry matter yields of winter wheat when compared to the control, clippings after tillers had formed and begun to lengthen reduced dry matter yield the most. The greatest reduction occurred in plants clipped at the boot stage. Mukerji et. al. (1976) found that the earlier the onset of artificial defoliation of spring wheat, the lower the above-ground biomass at harvest, while, Olfert and Mukerji (1983) found that the later defoliation was inflicted in the spring wheat, the greater the reduction in total biomass. In the first case, however, defoliation occurred over a six-week period, while in the second case, plants were defoliated quickly, and then allowed to recover undisturbed. This explains the contradictory findings of these two tests.

Root Growth

Just as defoliation affects the subsequent growth of the shoot, so it also affects the growth of the root. Langer et. al. (1973) showed that defoliation of 60% of each leaf on isolated main tillers of spring wheat decreased the growth of nodal roots. Interestingly, the application of kinetin to the growth solution also decreased root growth. Uprety et. al., (1983) studied the differential effect of photosynthates from mother shoot and tillers for the growth of seminal and nodal roots of spring wheat varieties. At 46 and 56 days after sowing, mother shoot defoliation significantly lowered nodal root production in three of four varieties. Tiller defoliation in the four varieties, on the other hand, had little effect on nodal root production at any stage. Elongation of nodal roots was significantly lowered by defoliation of the mother shoot and, surprisingly, by tiller defoliation in all varieties 46 and 56 days after sowing. Dry weight of nodal roots was significantly depressed by defoliation of the mother shoot in three of four varieties, but tiller defoliation did not affect the dry weight of nodal roots significantly.

The seminal roots of spring wheat plants were also found to be affected by defoliation. Uprety et. al. (1983) discovered that defoliating the mother shoot 36, 46, 56, and 66 days after sowing significantly reduced the number of seminal roots in all of the four varieties used except in one variety that was defoliated on the 36th day. Tiller defoliation also resulted in a reduction in seminal root number, though this reduction was only significant in two of the four varieties. Mother shoot defoliation also resulted in a significant reduction in the dry weight of seminal roots in all the varieties, however, the the defoliation of tillers did not significantly affect the dry matter production of seminal roots. In general, the adverse effect of defoliation was more pronounced in the nodal root characters (length and weight) than in those of seminal roots, with mother shoot defoliation reducing root growth more than tiller defoliation.

Yield Determinants

Tillers and Heads

The results of studies exploring the effects of defoliation on tiller and head number in the wheat plant are not nearly as consistent as the results of research on the previously discussed variables. In some cases, defoliation was found to reduce the number of fertile heads or tillers. For instance, Romaschenko (1956) as cited by Davidson (1965), attributed a reduction in head number to leaf removal. Aase and Siddoway (1975) found that spring clipping of winter wheat at all stages decreased the head population, but not appreciably until the ligule of last leaf became visible. Thereafter, it was drastically reduced. On the other hand, Mukerji et. al. (1976) found that defoliation of spring wheat between 570 and 880 degree days (late tillering) reduced the number of heads more than defoliation at any other time. After 880 degree days, a gradual increase in head number was obtained relative to earlier defoliation. White (1946) as cited by Mukerji et.

al. (1976), also noted serious reductions in number of heads per plant when defoliation occurred 2 to 5 weeks from seeding or about 370 to 880 degree days.

Some studies showed that defoliation increased the tiller and head number or at least had no effect on these variables. For example, Davidson (1965) discovered that decreasing the leaf area index in spring wheat from as much as twelve to three (a decrease of 75% at late tillering) resulted in no change in number of tillers per plant but did increase the number of heads per unit area through an increase in the number of fertile tillers. Similarly, Lucas and Asana (1968) determined that defoliation of the fifth, sixth, and seventh leaves as the stem extended had no adverse effect on tillering or final head number of spring wheat plants.

The contradictions in these findings result in part from the complicated mechanism by which tiller initiation is controlled. Tiller initiation is related to lateral bud control. There are two phases of lateral bud control as described by Langer et. al. (1973). One is bud inhibition due to apical dominance after floral initiation and stem elongation. The other is the release of buds from inhibition around head emergence. Unlike dicots, bud inhibition in grasses is at its height during the reproductive phase, especially at stem elongation.

In studying the effects of kinetin application on lateral bud elongation in spring wheat, Langer et. al. (1973) found that defoliation significantly depressed bud growth with the appearance of spikelet primordia early in tillering (5.5 leaves emerged); had no effect on lateral bud elongation ten (7.5 leaves emerged) or twenty (9.5 leaves emerged) days after appearance of primordia; but promoted bud growth at flag leaf emergence (10.5 leaves). Langer et. al. (1973) explained these results by theorizing that early in the development of the plant, it is auxin from the apical meristem which inhibits lateral bud development. The presence of assimilate can to some extent override the effect of auxin (Youngner, 1972). Defoliation, therefore, decreases lateral bud development by reducing the assimilate supply. As plants mature, they produce more leaf area and consequently more assimilate than they need. Defoliation, therefore, has less effect on lateral bud growth. With the emergence of the head, lateral buds are still inhibited, but this inhibition is not caused by auxin. Application of TIBA, a chemical which inhibits auxin transport, failed to increase elongation in undefoliated plants. Similarly, application of DCMU, a chemical which inhibits photosynthesis, to undefoliated plants did not affect tillering, indicating that the assimilate supply is not involved. Defoliation of plants at this time, however, did cause an elongation nearly three times that of undefoliated plants. Langer et. al. (1973) concluded that leaves at head emergence inhibited lateral bud growth in some manner that was apparently not connected with auxin or movement of assimilates.

In a follow-up study, Laude (1975) confirmed Langer's results. Laude found that removal of all leaf laminae on the main culm of spring wheat plants beginning at jointing and continuing through head emergence caused a two-week delay in tiller senescence, retention of some living tillers during the heading stage, as well as resumption of tillering after heading. As more of the younger leaf blades were retained, tillers senesced sooner and tillering did not resume. On culms with all leaf laminae removed, average elongation of measured lateral buds was greater than for buds on culms retaining only laminae of flag leaves. This led Laude (1975) to conclude that foliage leaves while young and growing repress the elongation of exposed buds on uprooted culms during and after jointing.

In summary, the effects of defoliation on tiller and head number is very dependent on the type of leaf material removed, and the growth stage of the plant at the time of leaf removal. On the average, clipping of plants increases tillering while leaf removal decreases tillering (Youngner, 1972). Early defoliation may decrease tillering more than leaf removal later. Defoliation of new leaves, in particularly at jointing, may actually promote tillering. Defoliation under a field situation may decrease shading and competition between plants and consequently promote tillering, whereas, defoliation in a greenhouse or growth chamber might be more likely to decrease tiller number.

Kernel Number

The number of kernels per head is also affected by defoliation. Davidson (1965) found that leaf area control at indices of three and one greatly affected grain yield of spring wheat by reducing the number of grains in each spikelet. Since grain numbers per spikelet were markedly reduced by leaf area reduction before head emergence, grain number per head may be largely determined before head emergence. Romaschenko (1956, as cited by Davidson (1965), attributed reduction in grains per head to leaf removal. Aase and Siddoway (1975) also found that clipping reduced kernels per head in winter wheat, mainly after the ligule of the last leaf became visible. Lucas and Asana (1968) also showed that the yield decrease in spring wheat plants in which two leaves were removed after jointing resulted partly from reduction in grain number per head. Olfert and Mukerji (1983), on the other hand, noticed no difference in number of kernels per head due to defoliation. Richards (1983) found that kernel number was influenced most by pre-anthesis events in spring wheat.

Kernel Weight

Kernel weight is also an important determinant of yield, and is usually lowered by defoliation. Aase and Siddoway (1975) found that the first three clippings of winter wheat at the one-shoot stage, when tillering begins, and when tillers are formed increased kernel weight. The last three clippings at boot, flowering, and when flowering was over decreased kernel weight. Davidson (1965) found that defoliating spring wheat plants to maintain a leaf area index of 3 or 1 greatly affected grain yield through reduction in grain size. Removal of all leaves at head emergence also reduced mean size of grain. Romaschenko (1956), as cited by Davidson (1965), also attributed reduction in grain weight to leaf removal. Lucas and Asana (1968) found that yield was less than controls in spring wheat plants in which the three leaves had been removed after jointing partly due to a decrease in 1000-grain weight. The yield decrease in plants in which two leaves were removed was also attributed in part to 1000-grain weight. Olfert and Mukerji (1983) noted that reduction in kernel weight was partly responsible for the yield decrease due to defoliation in spring wheat. Pickford and Mukerji (1974) discovered that loss in yield of spring wheat due to grasshopper feeding was mainly due to reduced kernel weight, especially in the early infestations. In addition, kernel weight decreased greatly as infestation level increased. They also noted that a loss in kernel weight results both in a loss in yield and a loss in quality of the grain crop. Contrarily, Richards (1983) reported that kernel weight of spring wheat was influenced most by events after anthesis.

Grain Yield

Though the effects of defoliation on growth of the wheat plant is important, especially where it is grazed, grain yield is still the product of primary importance economically. Unfortunately, the effects of defoliation on grain yield have been extremely difficult to discern, since direct damage to the head is not usually involved. Pickford and Mukerji (1974) mentioned this as a difficulty in assessing grasshopper damage in wheat. Not only does defoliation reduce yield, but destruction of leaves also tends to reduce seed quality, a variable that is not easily measured. In addition, Pickford and Mukerji (1974) discovered that grasshopper feeding early in the season caused greater yield loss in spring wheat than when initiation of feeding occurred later. For instance, an infestation of 20 grasshoppers per cage initiated on May 23 reduced plot yield by 42.7 % in comparison with a reduction of 26.9 % when feeding was initiated ten days later. Similarly, an infestation of 40 grasshoppers initiated on May 23 decreased yield by 98.3%, while causing a decrease of only 50.2% ten days later. Overall, the reduction in yield in the early treatment was almost double the late one. Aase and Siddoway (1975), on the other hand, found that yield of winter wheat was not appreciably reduced by clipping until the beginning of stem extension. In the study done by Davidson (1965), leaf area indices maintained at three and one in spring wheat led to a reduction in yield of about 50 to 80%. Removal of all leaves at head emergence also lowered yield by 20%, though this failed to be significantly different than controls at the 5% level.

Lucas and Asana (1968) found that defoliation decreased grain yield of main tillers more than that of primary and secondary tillers of spring wheat. They reported that yield of the main shoot was reduced 7% with removal of leaves five and six, and 15% with removal of leaves five, six, and seven. Grain yield of primary tillers was not affected by defoliation, though yield of secondary tillers was significantly reduced in plants in which three leaves were removed. Grain yield per plant was depressed by 5% with removal of one or two leaves, and 11% with removal of three leaves.

Olfert and Mukerji (1983) noted that as damage was inflicted to spring wheat at later stages of development, total seed yield decreased. Where available soil moisture was high, however, yield of plants damaged early in development were not significantly lower than control plants. The interaction of other environmental stresses with defoliation can also affect a wheat plant's response. Often leaf weight and leaf area in drought-stressed wheat are in excess of that required to produce maximum yield at that moisture level. Richards (1983) found that with 100 plants per meter squared, defoliation, especially around the middle of the vegetative period, slowed water use and as a result increased yield of spring wheat.

In summary, the wheat plant is progressively more stressed by defoliation as it approaches boot stage. The parameters mentioned, namely plant height, leaf area, dry matter, root growth, tiller number, head number, kernels per head, kernel weight, and overall grain yield are all decreased with increasing intensity of defoliation. As components of grain yield, the number of kernels per head seems to be less affected by defoliation than kernel weight and number of heads. Tiller and head number in some cases were more greatly affected by defoliation at early tillering rather than at late tillering or stem extension. In plants fed upon by grasshoppers, this trend was very evident.

The following experiments were conducted to discern the effects of army cutworm defoliation on the winter wheat variety TAM W-101 when inflicted at two different plant stages - late tillering (before jointing) and stem extension (after jointing; to quantify the amount of damage different levels of larvae are capable of inflicting; and to determine difference in the response of the winter wheat variety TAM W-101 and the more drought and insect-susceptible variety Sturdy to army cutworm feeding.

CHAPTER III

MATERIALS AND METHODS

Rearing the Army Cutworm

The army cutworm was reared using the method described by Burton et. al. (1980) with a few minor changes. Eggs were collected from fine white sand using a 30-mesh screen. They were then placed on moistened filter paper in petri dishes that were sealed with Parafilm to prevent eggs from dehydrating. After five days, eggs hatched, and new larvae began feeding on surface-sterilized lettuce leaves placed in the dishes a day or two before eclosion.

Shortly after hatching, first-instar larvae were added to a pre-measured amount of corn grits and dispensed using a bazooka (Davis and Oswalt, 1979) into plastic cups containing fresh lettuce leaves. Leaves were changed every other day. After about ten days, third-instar or older larvae were transferred to 30 ml diet cups at a density of three larvae per cup. Each cup contained 15 ml of a modified bean diet developed by Burton et. al. (1980). To prevent fungal growth on the diet, 1 g of a benomyl powder with 50% active ingredient was added to the diet. The surface of the diet was cut in each cup to provide a groove in which larvae could feed. In most cases, transfer of larvae to new diet before pupation was not necessary except when conditions allowed the diet to dry too quickly.

Larvae pupated after about six weeks, at which time, pupae were removed from the cups and sexed. They were then placed into plastic cups containing moistened cotton. About two weeks later, adult moths emerged. They were transferred to freezer boxes containing a solution of 10% honey and water and kept in darkness for thirty days at 5°C to break reproductive diapause. Oviposition cages, 32 cm high and 28 cm in dia., were made from 12-mesh wire gauze. Fifteen cold-treated males and females were added to each cage. They were fed a solution of 10% honey and water and provided white sand in petri dishes for egg laying. The oviposition cages were kept in a growth chamber at 15°C and a twelve hour photoperiod. Egg laying began approximately one week after adults were caged.

Conducting the Greenhouse Experiments

A total of three experiments were performed in the greenhouse in order to discern the effects of army cutworm feeding on plant growth and yield. The experimental conditions under which these tests were run are summarized in Table I. In most cases, seeds of the hard red winter wheat variety, TAM W-101, were aerated in water until the root tip of the developing plant became visible. This took about 24 to 48 hours. These germinated seeds were then

TABLE I

EXPERIMENTAL CONDITIONS

Experimental Conditions	Experiment 1	 2	 3
Date Planted	1/06/84	1/10/84	5/21/84
Stage at Planting	vernalized plants	germinated seed	germinated seed
Experimental Design	9X6 Ran. Block	10x10 Latin Square	10X10 Latin Square
Variety	TAM W-101	TAM W-101	TAM W-101 Sturdy
Infestation Level	0, 2, 4	0,1,2,3,& clipping	0, 2, 4, 6
Plant Stage at Infestation	before and after jointing	before and after jointing	early tillering before jointing
Procedure Used to Vernalize	Vernalized transplants in field	Vernalized seedlings in cold frame	Not vernalized
Container Used	15 cm dia. pot	15 cm dia. pot	4 cm dia. conetainer
Potting Medium	Equal parts sand, soil, peat.	Equal parts sand, soil peat.	fritted clay
Date of Infestation	BJ 3/14/84 AJ 4/03/84	BJ 3/16/84 AJ 4/05/84	6/22/84
Length of Infestation	20 days	12 days	10 days
Larval Instar	Fourth	Fifth	Fifth
Greenhouse Conditions	Cool 65-70°C Dry	Cool 65-70°C Dry	Hot 75-80°C Dry

planted three centimeters below the soil surface in pots 15 cm in ht. and dia. Two seeds were planted per pot. Three to four days after seedling emergence, the plants were thinned to one per pot.

Plants were arranged in the greenhouse to conform to the experimental design used. Every test was surrounded by a border row. All plants were watered daily and fertilized twice a week with 120 ml of a solution of 1.3 g of Peters Peat-Lite Special (15-16-17) soluble fertilizer per liter of water. In addition, plants were monitored weekly for the occurrence of powdery mildew and aphids. Outbreaks of powdery mildew were usually controlled by burning sulfur in the greenhouse. Infected plants that were not infested with army cutworm larvae were isolated and the contaminated leaves removed. Before and during larval infestation, any aphids discovered were removed from the plants by hand. After the removal of army cutworms, a spray of malathion was used to control aphids on plants.

Army cutworm larvae targeted for infestation were reared as described earlier. Fourth or fifth instar army cutworms were used in most tests since such insects were readily visible to the naked eye and still 10-14 days from pupation. Also a number of consumption studies with range-feeding lepidoptera have shown that fifth instar larvae were among the most efficient feeders (Bellows et. al., 1983; Garner and Lynch, 1981).

Cages used to contain the larvae were made from sheets of thin Lexan rolled and glued into a cylinder 30 cm high and 13 cm in dia.. Each cage had two circular areas 8 cm in dia. cut in two sides. These areas and the top were covered with cotton muslin to allow adequate air flow through the cage.

About midway through the infestation period, each infested plant was checked for larvae by digging gently through the planting medium to a depth of three to four cm. If necessary, additional larvae were added to maintain the starting infestation level. At the end of the infestation period, plants were checked for larvae in the same manner as before and all larvae found were weighed. In addition to determining larval weight and counting the number of larvae found, each plant was rated for damage on a scale from 0 to 9, where 0 = no damage, 1-3 = light damage, 4-6 = moderate damage, and 7-8 = heavy damage, and 9 = plant death.

The response variables for each test were divided into three groups - those measuring larval survival and growth on the plants; those measuring direct damage to the wheat plants as caused by army cutworm larvae; and those measuring indirect damage to the plant. Variables describing larvae and direct damage were taken before or immediately after the period of infestation. Parameters measuring indirect damage were taken at the time of harvest. Weights of plant parts were taken immediately after being dried for 24 hours at 70°C.

The data from each test were subjected to an analysis of variance, and linear regression. Means were separated by using Duncan's New Multiple Range Test (Duncan, 1955). The statistical analyses software packages used to analyze these data were the Statistical Analysis System (SAS) (Ray, 1982) and Energraphics (Enertronics, 1984).

Though all tests were conducted under most of the conditions described above, there were some experimental parameters that were peculiar to each test. In following chapters, the materials and methods section describes these exceptions. In addition, these chapters present the results of the data analyses and a discussion of those findings for each experiment.

CHAPTER IV

EXPERIMENT 1: THE EFFECT OF TIME AND LEVEL OF INFESTATION OF FOURTH INSTAR ARMY CUTWORMS ON THE GROWTH AND YIELD OF THE WINTER WHEAT VARIETY TAM W-101

In general, the effect of army cutworm damage on the wheat plant is dependent upon two factors - plant growth stage, and the extent of defoliation. In turn, the extent of defoliation is dependent upon the size of larvae, their number, and the length of the infestation period. In this experiment, relatively small larvae, third and fourth instar, were used to infest wheat plants in the greenhouse at two stages of plant growth - before jointing (late tillering) and after jointing (stem extension) - in order to ascertain the effect of defoliation on plant growth and yield.

Materials and Methods

Vernalized plants of the wheat variety TAM W-101 were taken from a field plot in January of 1984 and transplanted into pots filled with a planting mixture of equal parts soil, peat, and sand. Plants were arranged in a randomized block design, with treatments consisting of nine replications of six treatments. Treatments were a factorial of two infestation periods - before jointing and after jointing; and three levels of larvae - 0, 2, and 4.

Half of the 54 plants used were infested before jointing and the other half were infested after jointing, when the first node of the plant emerged from below the soil. All larvae used were fourth instars weighing between 100 and 300 mg. Larvae were left on the plants for a total period of 20 days. After 10 days, plants were checked for larvae, and if necessary, new larvae were added to maintain the infestation level. At the end of the twenty day period, plants were rated for damage, and larvae were counted and weighed.

Plants were harvested when grain was at the hard dough stage. All other response variables so far not mentioned were taken at the time of harvest. Table II describes all these parameters, and gives the abbreviated names.

Results and Discussion

Survival and Growth of the Army Cutworm

Army cutworm survival and growth on the wheat plant is important in determining the effectiveness of the infestation procedures, as well as what outside factors might be important in promoting an infestation in the field. The parameter used to describe larval survival was the number of larvae found after twenty days. The parameters used to describe larval growth were total larval weight and average larval weight.

TABLE II

EXPERIMENT 1: RESPONSE VARIABLES

VARIABLE	ABBREVIATION	DESCRIPTION
Number of larvae found	LARFND	Number of larvae found after infestation
Total larval weight	TTLLWT	Total weight of larvae per plant (mg)
Average larval weight	AVGLWT	Average weight of larvae per plant (mg)
Damage rating	DMGRTG	A visual rating of defoliation on a scale of 0 to 9 where 0 = no defoliation and 9 = 100% defoliation
Plant height	PLNTHT	Height of plant measured at time of harvest (cm)
Weight of dry matter	DRYMTR	Total weight of above ground plant parts (g)
Number of tillers	TLRS	Number of tillers measured at harvest
Number of heads	HDS	Number of heads per plant at harvest
Number of kernels per head	KRNLHD	Number of kernels per head per plant
Total seed weight per plant	TTLSDWT	Total weight of seed per plant (g)
Seed weight per 1000 seed	SDWT1000	The thousand seed equivalent of total seed weight per plant (g)

Larval Survival

The effect of time of infestation on larval survival could not be determined in this test due to absence of data after jointing.

Level of infestation, either 0, 2, or 4 larvae per plant, had a significant effect ($\underline{P} < 0.0001$) on the number of larvae found at the end of the twenty-day infestation period (Table XI, Appendix). Mean numbers of larvae found for each level were different from one another ($\underline{P} < 0.05$) according to a Duncan's New Multiple Range Test (Duncan, 1955) (Table III). Though a difference in larvae found is expected between infested and noninfested plants, the number of larvae found on plants infested with two larvae ($\bar{Y}_2 = 1.44$) is statistically different from the number of larvae found on plants infested with four larvae ($\bar{Y}_4 = 2.11$), even though both means are close to one another. This indicates that there was little variability in the number of larvae at each level.

The percent survival (number of larvae found / level of infestation) was 72% at a level of two, and 53% at an infestation level of four. This may indicate that survival is dependent on the number of larvae on the plant. Hinks and Byers (1976) found that many species of _Euxoa_ larvae turn cannabalistic at fourth instar. Wilcox (1898) also reported that army cutworm larvae will readily feed on one another in absence of an adequate food source, consequently

TABLE III

EXPERIMENT 1: MEAN SEPARATION BY LEVEL OF INFESTATION

LEVEL	LARFND (#)	DMGRTG (#)	TTLLWT (mg)	AVGLWT (mg)	PLNTHT (cm)
0	0.00 a	0.00 a	-------	-------	57.9 a
2	1.44 b	2.33 b	140.0 a	102.2 a	55.2 a
4	2.11 c	4.11 c	140.0 a	58.2 a	56.6 a

LEVEL	DRYMTR (g)	TLRS (#)	HDS (#)	KRNLHD (#)	TTLSDWT (g)	SDWT1000 (g)
0	3.24 a	1.78 a	1.56 a	15.7 a	0.96 a	36.9 a
2	3.03 a	1.94 a	1.31 a	15.6 a	0.86 ab	33.7 a
4	3.15 a	1.93 a	1.60 a	13.8 a	0.79 b	34.4 a

Means in the same column followed by the same letter are not significantly different (*P* < 0.05; Duncan's (1955) New Multiple Range Test).

Cannabalism may be one factor causing the lower survival of larvae at an infestation level of four per plant. Factors such as disease and competition for food might also affect the survival of the larvae and would depend partly on the density of cutworms on the plant.

The level of infestation was highly correlated with the number of larvae found ($\underline{P} < 0.0001$). The correlation coefficient for this relationship was 0.77.

Larval Growth

Larval growth on the plant was estimated by measuring the total and average larval weight per plant. The effect of time of infestation on larval growth could not be determined due to lack of data on larval growth after jointing.

Average and total larval weight per plant were not affected by the level of infestation ($\underline{P} > 0.05$) (Table III). However, the mean average larval weight at an infestation level of two ($\bar{Y}_2 = 102.2$ mg) was significantly greater than that at level four ($\bar{Y}_4 = 58.2$ mg) ($\underline{P} < 0.10$) (Table XI, Appendix).

Total larval weight was positively correlated with number of larvae found ($\underline{P} < 0.05$; $r^2=0.51$), and average larval weight ($\underline{P} < 0.01$; $r^2=0.75$), though average larval weight was not related to the number of larvae found, but was more affected by the number of larvae initially placed on the plants.

Measuring Direct Damage to the Wheat Plant

Army cutworm damage to the plant was rated visually using the scale described in Chapter III. Due to the absence of data on damage after jointing, the effect of time of infestation on damage rating could not be measured.

As would be expected, the level of infestation had a large influence on damage rating ($\underline{P} < 0.0001$) (Table XI, Appendix). Four larvae did more damage ($\bar{Y}_4 = 4.11$) than two larvae ($\bar{Y}_2 = 2.33$) ($\underline{P} < 0.05$) (Table III) despite the observation that total weight of larvae found at these two levels were identical. When damage rating was regressed against number of larvae found and level of infestation (Fig. 1), the coefficient of correlation for the relationship between damage rating and the number of larvae found ($r^2=0.83$, $\underline{P} < 0.0001$) was greater than that for the level of infestation ($r^2=0.71$, $\underline{P} < 0.0001$). In determining the effect of the average larval weight, total larval weight, and number of larvae found on damage rating, the number of larvae found had the most significant effect on damage rating with a coefficient of determination of 0.83. (The coefficient of determination is the same as the correlation coefficient except that it is the result of modeling more than one independent variable to the response variable.) With the addition of each of the other variables, the R^2 value only increased slightly from 0.83 to 0.834. Consequently we can say that number of larvae found is the single most important influence on damage rating. Notice in Fig. 1 that the linear relationship between damage rating and number of larvae found is steeper than that of level of infestation, showing that larvae do more damage than is indicated by the level of infestation. Due to larval mortality in this experiment, the damage potential of larvae would have been underestimated if the actual level of larvae on the plants had not been monitored.

Indirect Damage to the Wheat Plant

Indirect damage to the wheat plant consists of all damage which is not a visible result of army cutworm feeding. Plant height, total weight of above ground dry matter, and all of the yield components were measured to determine whether or not they were affected by the defoliation caused by the army cutworm.

Though the time of infestation had no significant effect on any plant parameters, infested wheat plants before jointing had lower total seed weight than those damaged after jointing at every level.

Though larvae and damage rating were affected by the level of infestation, there was no lasting effect on the plants at time of harvest. Neither plant height, weight of above ground dry matter, number of tillers, number of heads, kernels per head, total seed weight, or weight per 1000 seeds were affected by the level of infestation (*P* >

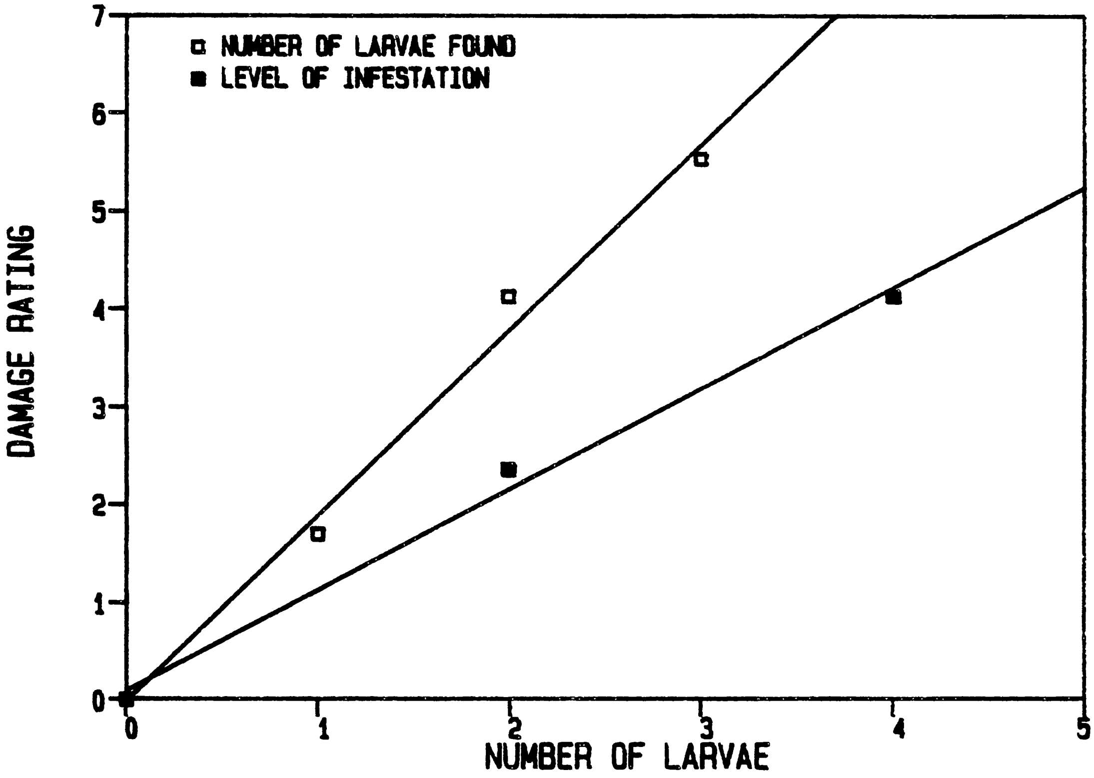

Figure 1. **Experiment 1: Linear Relationship Between Damage Rating and the Number of Larvae Infested or Found**

0.05), though total seed weight decreased with increasing infestation especially in plants damaged before jointing (Fig. 2).

In describing the relationship between total seed weight and the number and weight of larvae found on the plant, only average larval weight seemed to be at all correlated with total seed weight ($\underline{P} < 0.05$; $r^2=-0.40$). Average larval weight was also correlated with number of heads per plant ($\underline{P} < 0.01$; $r^2=-0.50$). Average larval weight was more correlated with plant parameters than any other larval variable, indicating that size of individual larvae also affects the amount of damage done to a plant, even though it is not as important as the number of larvae found on a plant. Indirect damage parameters of plant growth and yield were not correlated to the damage rating, thus reflecting the low amount of damage larvae caused.

Conclusions

Though the effect of time of infestation on larval survival and growth was not measured, the level of infestation did have an effect. As expected, when level of infestation became greater, significantly more larvae were found per plant. However, while the total weight of larvae on the plants remained the same, the average larval weight on the plants decreased ($\underline{P} < 0.10$). More larvae weighing less indicates an interaction such as competition or a disturbance response between individuals.

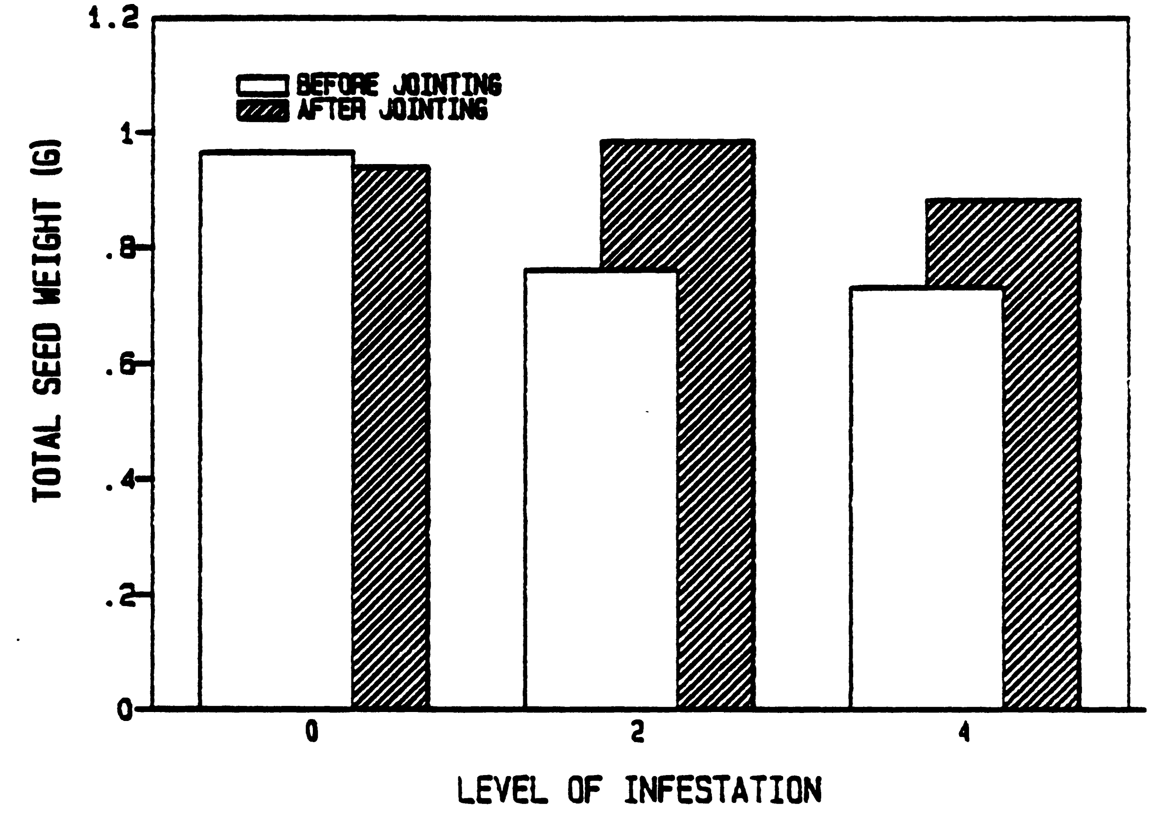

Figure 2. **Experiment 1: Total Seed Weight Per Plant at Each Time and Level of Infestation**

The effect of time of infestation on direct damage was not measured, but, the level of infestation positively affected the rating of direct damage, even though it was light. Since larval survival was only 50 to 75%, damage could be much greater at these same levels if survivability was improved.

Neither time or level of infestation had any effect on the plant in terms of height, weight of dry matter, or yield, though average larval weight was negatively correlated with total seed weight and number of heads. Total seed weight was less for plants damaged before jointing than after jointing, though the difference was not significant. Whether plants at late tillering are more susceptible to army cutworm damage, or preferred as a host and therefore damaged more than plants infested after jointing is not known. Since damage was light, the presence of an effect of army cutworm defoliation on plant growth or yield could not definitely be determined.

CHAPTER V

EXPERIMENT 2: THE EFFECT OF TIME AND LEVEL OF INFESTATION OF FIFTH INSTAR ARMY CUTWORMS ON THE GROWTH AND YIELD OF THE WINTER WHEAT VARIETY TAM W-101

In this experiment, larger larvae were used and a treatment where plants were clipped was added to insure that at least some plants were severely damaged. The main objective of this experiment, as in the one previously, was to determine if army cutworm defoliation was more detrimental to plants after jointing, than before jointing; and to determine the level of larval infestation that will cause a noticeable decrease in growth and loss in yield.

Materials and Methods

Germinated seeds of TAM W-101 were planted in the same soil mixture as used in Experiment 1. The plants were arranged in a 10 X 10 Latin square with ten replications of ten treatments. The treatments consisted of a factorial of two infestation times, before jointing and after jointing; and five damage levels. These levels consisted of four levels of larvae - 0, 1, 2, and 3 and a clipping treatment.

The plants were allowed to grow in the greenhouse until they reached the early tillering stage and then they were transferred to cold frames where they underwent a three-month vernalization. After vernalization, they were rearranged in a Latin square in the greenhouse.

Fourth to fifth instar larvae weighing 200 to 500 mg were used in the infestation which took place before jointing. The same size and stage of larvae were used after jointing. At the time of infestation, small cardboard dishes were inverted in each pot to provide shelter for the larvae. Larvae were left on the plants for a total period of twelve days. Larval counts and weights were recorded six and twelve days after infestation, though on the sixth day, new larvae were added to maintain the original level in the event of larval escape or death. The clipping treatment was carried out on the last day of the larval infestation. Plants were clipped three cm above the soil level before jointing, and about three cm above the first node after jointing.

Response variables taken for Experiment 2 are described in Table IV. These include the basic parameters describing the larval infestation and direct damage to the plant. Of these variables, adjusted total larval weight after six days (ADTTLLWT1), adjusted average larval weight after six days (ADAVGLWT1), difference in total larval weight (DFTTLLWT), and difference in average larval weight (DFAVGLWT) were calculated from weight data taken.

TABLE IV

EXPERIMENT 2: RESPONSE VARIABLES

VARIABLE	ABBREVIATION	DESCRIPTION
Number of larvae found	LARFND1	Number of larvae found 6 days after infesting.
	LARFND2	Number of larvae found 12 days after infesting.
Total larval weight	TTLLWT1	Total wt. of larvae 6 days after infesting (mg).
	TTLLWT2	Total wt of larvae 12 days after infesting (mg).
Adjusted total larval weight	ADTTLLWT1	Total wt. of larvae 6 days after infesting adjusted for larvae added (mg).
Average larval weight	AVGLWT1	Average wt. of larvae 6 days after infesting (mg).
	AVGLWT2	Average wt. of larvae 12 days after infesting (mg).
Adjusted average larval weight	ADAVGLWT1	Average wt. of larvae 6 days after infesting adjusted for larvae added (mg).
Difference in total larval weight	DFTTLLWT	Difference in total larval wt. from day 6 to day 12 (mg).
Difference in average larval weight	DFAVGLWT	Difference in average larval wt. from day 6 to day 12 (mg).

TABLE IV (Continued)

VARIABLE	ABBREVIATION	DESCRIPTION
Damage rating	DMGRTG	A visual rating of damage on a scale of 0 to 9 where 0 = no defoliation and 9 = 100% defoliation. Taken twelve days after infestation.
Plant height	PLNTHT	Height of plant measured at time of harvest (cm).
Weight of dry matter	DRYMTR	Total weight of above ground plant parts (g).
Number of tillers	TLRS	Number of tillers measured at harvest.
Number of heads	HDS	Number of heads per plant at harvest.
Number of kernels per head	KRNLHD	Number of kernels per head per plant.
Total seed weight per plant	TTLSDWT	Total weight of seed per plant (mg).
Seed weight per 1000 seed	SDWT1000	The thousand seed equivalent of total seed weight per plant (g).

Since larval weights were taken after six and after twelve days, growth differences as represented by change in larval weight over this six day period (from day 6 to day 12) are not accurate unless larval weights after six days are adjusted for the addition of larvae. Adjusted total larval weight is equal to the total larval weight after six days plus the weight of larvae added. Adjusted average larval weight is equal to the adjusted total larval weight divided by the level of infestation. The adjusted total larval weight was used to find the difference in total larval weight from day six to day twelve of the infestation period by using the following equation. . .

DFTTLLWT=TTLLWT2-ADTTLLWT1

The adjusted average larval weight was used to find the difference in average larval weight from day six to day twelve of the infestation in this equation. . .

DFAVGLWT=AVGLWT2-ADAVGLWT1

Results and Discussion

Survival and Growth of the Army Cutworm

Response parameters describing the larvae have been divided into those describing larval survival on the plants, and those describing both total and average larval growth (wt.). Each of the major variables, namely number of larvae found, total weight of larvae, and average weight of larvae, taken six days and twelve days after infestation, are delineated with a one (1) for the first sampling period and a two (2) for the second sampling period.

Larval Survival

The survival of larvae on the plant is important in determining how closely the final level of larval numbers on the plant matches the initial level infested. In this experiment, a search was made for larvae six (LARFND1) and twelve (LARFND2) days after the initial infestation. The number of larvae found were then divided by the initial level of infestation to account for the proportion of original larvae at that point in the infestation period. Larvae not accounted for were assumed to be dead, though they may have evaded the search, escaped the caged plant, or pupated. Search procedures were thorough, however, so the number evading the search was probably minimal.

The results of an analysis of variance shows that the time of infestation, either before jointing or after jointing, had little effect on the number of larvae found ($\underline{P} < 0.05$) (Table V). However, an equal or greater amount of larvae were accounted for in the infestation before jointing than that of the one after jointing (Table VI). The lowest proportion of larvae found, a value of 0.70, occurred in level two, six days after infestation in the after jointing stage of plant growth.

TABLE V

EXPERIMENT 2: MEAN SEPARATION BY TIME OF INFESTATION

PLANT STAGE	LARFND1 (#)	LARFND2 (#)	TTLLWT1 (mg)	TTLLWT2 (mg)	ADTTLLWT (mg)
BEFORE JOINTING	1.38 a	1.50 a	354.5 a	494.0 a	519.3 a
AFTER JOINTING	1.23 a	1.45 a	287.3 b	381.5 b	513.0 a

PLANT STAGE	AVGLWT1 (mg)	AVGLWT2 (mg)	ADAVGLWT1 (mg)	DFTTLLWT (mg)	DFAVGLWT (mg)	DMGRTG (#)
BEFORE JOINTING	263.4 a	348.4 a	271.4 a	139.3 a	79.9 a	2.8 a
AFTER JOINTING	211.6 b	267.6 b	257.8 a	-4.3 b	9.7 b	1.5 b

PLANT STAGE	PLNTHT (cm)	DRYMTR (g)	TLRS (#)	HDS (#)	TTLSDWT (mg)	KRNLHD (#)	SDWT 1000 (g)
BEFORE JOINTING	58.7 a	4.85 a	3.5 a	2.7 a	1566.2 a	15 a	38.8 a
AFTER JOINTING	59.5 a	5.29 b	3.5 a	2.6 a	1623.1 a	15 a	37.1 a

Means in the same column followed by the same letter are not significantly different ($\underline{P} < .05$; Duncan's New Multiple Range Test, [Duncan, 1955]).

TABLE VI

EXPERIMENT 2: LARVAL SURVIVAL PROPORTIONAL TO THE LEVEL OF INFESTATION[1]

LEVEL	6 DAYS AFTER INFESTING		12 DAYS AFTER INFESTING	
	BEFORE JOINTING	AFTER JOINTING	BEFORE JOINTING	AFTER JOINTING
1	0.90	0.90	1.00	1.00
2	0.90	0.70	1.00	0.95
3	0.93	0.87	1.00	0.97

[1] Survival equals number of larvae found / the number infested.

As would be expected, the number of larvae found varied greatly with the level of infestation ($\underline{P} < 0.0001$) (Table XIII, Appendix). The actual survival of larvae on the plants, however, was not affected by the level of infestation (Table VI) as it was in Experiment 1. Larval survival seemed to be greater at twelve days than at six days. Since new larvae were added from the same batch originally used to infest on day six, larvae added may have been a little older and therefore better able to survive on the plants. Also, the plants in this experiment were grown in the greenhouse, not taken from the field, thus they may not have been exposed to as many insect pathogens as the other plants, which may have contributed to the greater mortality of larvae in Experiment 1.

In further describing the relationship between number of larvae and level, Table VII shows the mean number of larvae found at each level. As would be expected, all are different from each other ($\underline{P} < 0.05$) and as the level of infestation increases, so does the number of larvae found. The correlation coefficient between the level of infestation and the number of larvae found at day six is 0.80 ($\underline{P} < 0.0001$). The correlation coefficient between the level of infestation and the number of larvae found at day twelve is 0.96 ($\underline{P} < 0.0001$). There was little difference between larval numbers found before or after jointing, and, the number of larvae found closely approximated the initial level of infestation (Table VII).

TABLE VII

EXPERIMENT 2: MEAN SEPARATION BY LEVEL OF INFESTATION

LEVEL	LARFND1 (#)	LARFND2 (#)	TTLLWT1 (mg)	TTLLWT2 (mg)	ADTTLLWT (mg)
0	0.00 a	0.00 a	0.0 a	0.0 a	-----
1	0.90 b	1.00 b	258.0 b	335.5 b	290.5 a
2	1.60 c	1.95 c	379.0 c	612.0 c	504.5 b
3	2.70 d	2.95 d	646.5 d	803.5 d	753.5 c

LEVEL	AVGLWT1 (mg)	AVGLWT2 (mg)	ADAVGLWT1 (mg)	DFTTLLWT (mg)	DFAVGLWT (mg)	DMGRTG (#)
0	-----	-------	--------	--------	--------	0.0 a
1	258.0 a	335.5 a	290.5 a	45.0 a	45.0 a	1.3 b
2	225.8 a	315.0 ab	252.3 b	107.5 a	62.8 a	3.3 c
3	228.8 a	273.4 b	251.2 b	50.0 a	22.3 b	4.0 d

LEVEL	PLNTHT (cm)	DRYMTR (g)	TLRS (#)	HDS (#)	TTLSDWT (mg)	KRNLHD (#)	SDWT1000 (g)
0	58.5 b	5.69 a	3.9 ab	2.6 ab	1636.7 b	15 a	37.8 a
1	60.9 a	5.77 a	3.4 bc	2.9 a	1905.3 a	16 a	40.8 a
2	60.2 ab	5.15 b	3.6 ab	2.7 ab	1684.4 b	15 a	41.1 a
3	58.9 b	5.49 ab	4.0 a	2.9 a	1609.6 b	14 a	39.8 a
Clipped	56.8 c	3.25 c	3.0 c	2.3 b	1137.1 c	16 a	30.1 b

Means in the same column followed by the same letter are not significantly different (*P* < 0.05; Duncan's New Multiple Range Test, (Duncan, 1955)).

There was no interaction between time and level for number of larvae found ($\underline{P} > 0.05$) (Table XIV, Appendix) indicating that similar numbers of larvae were found at each plant stage. The number of larvae found regressed against level of infestation is shown in Figure 3.

Total Larval Growth

The density of larvae on a plant can often have a great effect on the feeding behavior of larvae because of competition for food and disturbance. In this experiment, total larval growth was used to estimate the relative amount of plant material consumed by the larvae. Total larval growth was estimated by measuring the total larval weight after six days (TTLLWT1) and after twelve days (TTLLWT2).

The total larval weight after six days and after twelve days were greater before jointing than after jointing as shown in Table V ($\underline{P} < 0.05$). Since all larvae chosen for infestation were fifth instars weighing between 200 and 500 mg, the lower weight of larvae in the infestation after jointing must be due to some factor not encountered in the before jointing infestation period.

One such factor might be temperature, since, the greenhouse during the after jointing period was warmer than in the before jointing period by about 5°C, and army cutworm larvae are very intolerant of high temperatures. Personal observation in rearing these insects has shown that

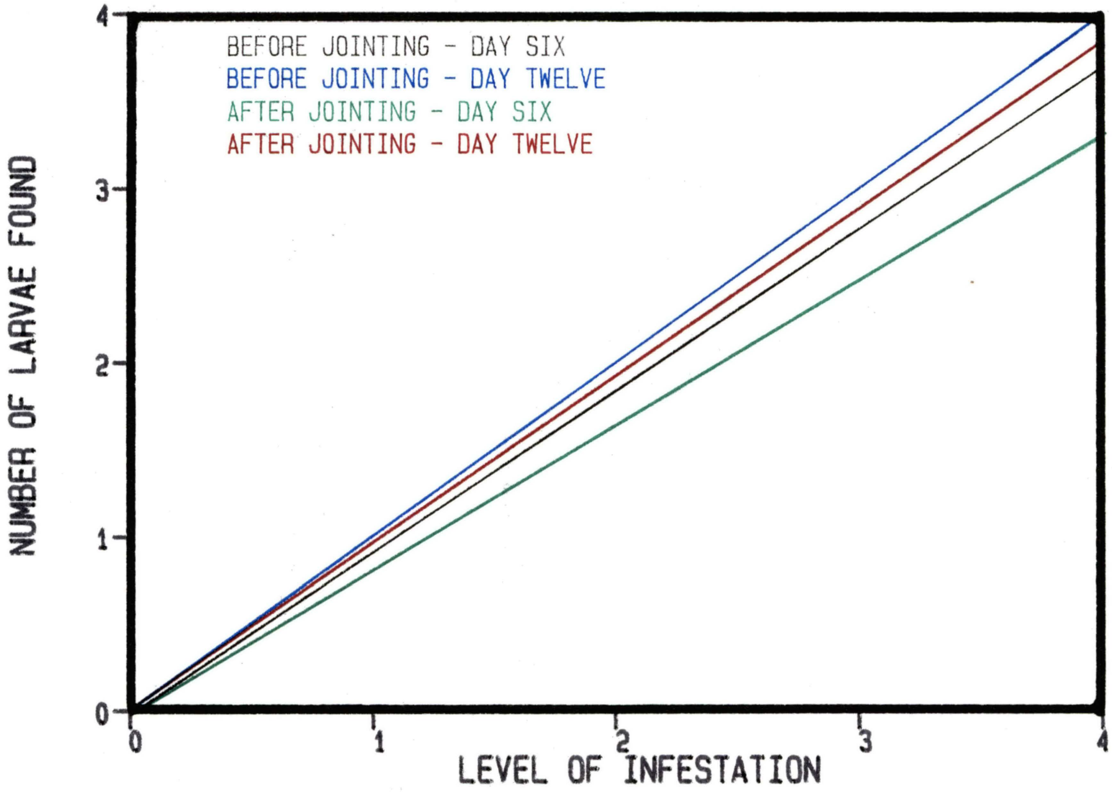

Figure 3. **Experiment 2: Linear Relationship Between Number of Larvae Found and the Level of Infestation by Time**

survival and growth rate of the army cutworm larvae in the laboratory decreases in the summer months, when temperatures often exceed 30°C in the laboratory.

Another explanation for this phenomena may lie within the plant itself. Army cutworm larvae seem to prefer the lower, younger leaves of the wheat plant (Painter, 1954). After jointing, these leaves are not as prevalent, having matured. Young leaves present at this time are found progressively higher on the plant. Though the production of tillers provides a new supply of these leaves, these plants had few tillers. Consequently, the larvae were forced to compete for food that was scarce and less desirable. Leaf and plant age greatly affect the plant consumption by the larvae of a number of noctuids. The fall armyworm (<u>Spodoptera</u> <u>frugiperda</u> [J. E. Smith]), for example, decreased consumption of peanut leaves as the plants matured. First-instar larvae reared on peanut leaves 40 days old took longer to develop, had lower pupal weights, and had higher mortality through their development than larvae reared on leaves five days old (Garner and Lynch, 1981).

The level of infestation affected the total larval weight on the plant as well ($\underline{P} < 0.0001$) (Table XIII, Appendix). This was expected since total larval weight depends on the number of larvae on the plant. The total larval weight was different at each level, and increased as the infestation level increased ($\underline{P} < 0.05$) (Table VII).

This is a good indication that each level of infestation is truly different from the other and that no overlap occurs. The correlation coefficient between total larval weight six days after infestation and the level of infestation was 0.73 ($\underline{P} < 0.0001$). The correlation coefficient between the total larval weight twelve days after infestation and the level of infestation was 0.82 ($\underline{P} < 0.0001$). The linear relationship between total larval weight and level of infestation is shown in Figure 4. The interaction between time and level of infestation was not statistically significant ($\underline{P} > 0.05$) (Table XIV, Appendix).

Difference in Total Larval Growth

Two variables, adjusted total larval weight (ADTTLWT1) and the difference in total larval weight (DFTTLLWT) were used to measure the change in larval growth from day six to day twelve of the infestation.

The time of infestation had no effect on the adjusted total larval weight ($\underline{P} > 0.05$) (Table V). However, the time of infestation did have an effect on the total larval weight before adjustment. Evidently, the weight of added larvae served to lessen these differences.

On the other hand, the difference in total larval weight was greatly effected by the time of infestation ($\underline{P} < 0.0001$) (Table XII, Appendix). The change in total larval weight before jointing ($Y_b = 139.3$ mg) was greater than that after jointing ($Y_a = -4.3$ mg) ($P < 0.05$) (Table V). The

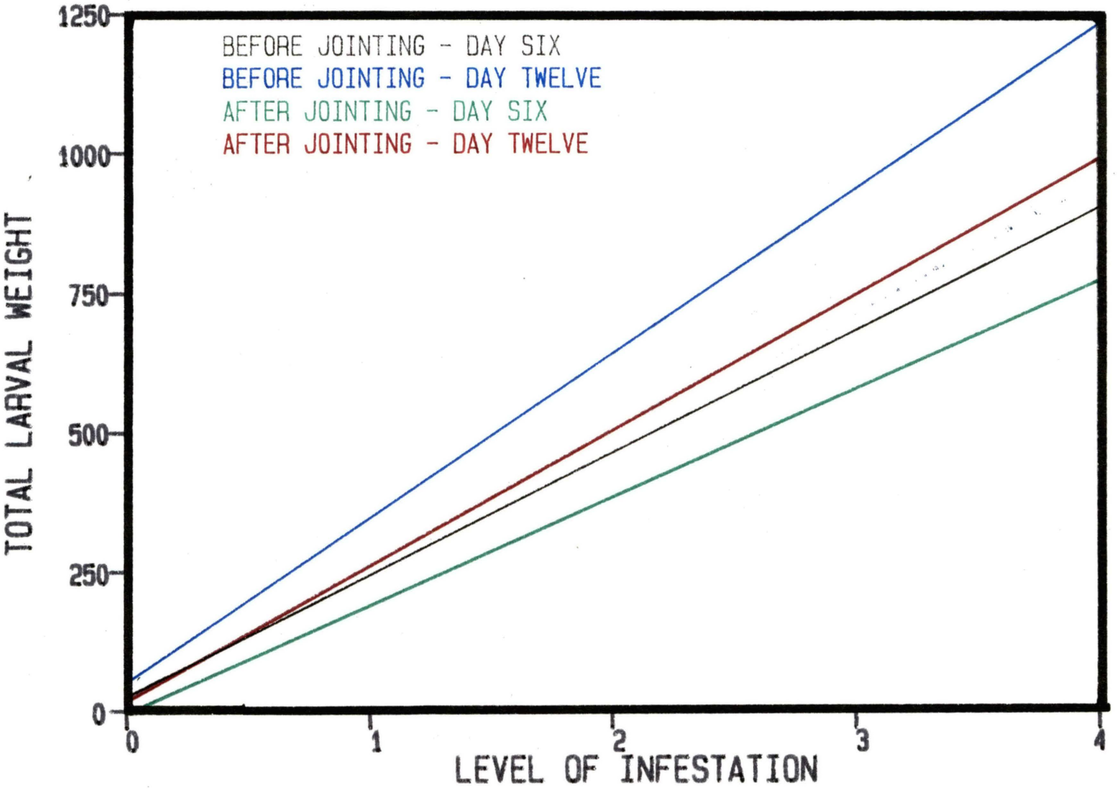

Figure 4. **Experiment 2: Linear Relationship Between Total Larval Weight and the Level of Infestation by Time**

magnitude of the difference in weight before jointing was high, representing an increase in weight over six days. The difference in weight after jointing was very small in comparison, and actually represented a decrease in weight over six days. While this weight loss might be due to actual loss of weight by individual larvae, the actual negative value is most likely due to little or no growth, and the subsequent negative effect of lost larvae.

Adjusted total larval weight was greatly affected by level of infestation ($\underline{P} < 0.0001$) (Table XIII, Appendix). This relationship is positive, with the weight of three larvae being greater than one (Table VII). This was expected since total weight of larvae on a plant does to some extent depend on the larval density.

The difference in total larval weight, however, was not affected by the level of infestation ($\underline{P} > 0.05$) (Table VII). Since it is logical to assume that three larvae will gain more total weight than one, this result is contrary to what might be expected. This is due in part to the interaction between level and time of infestation.

Figure 5 shows the adjusted total larval weight at day six and total larval weight twelve days after infestation before jointing and after jointing. The adjusted total larval weight before jointing and after jointing were almost identical, further evidence that adjusted total larval weight did not differ by time of infestation. Total larval weight at day twelve after jointing seems to be nearly

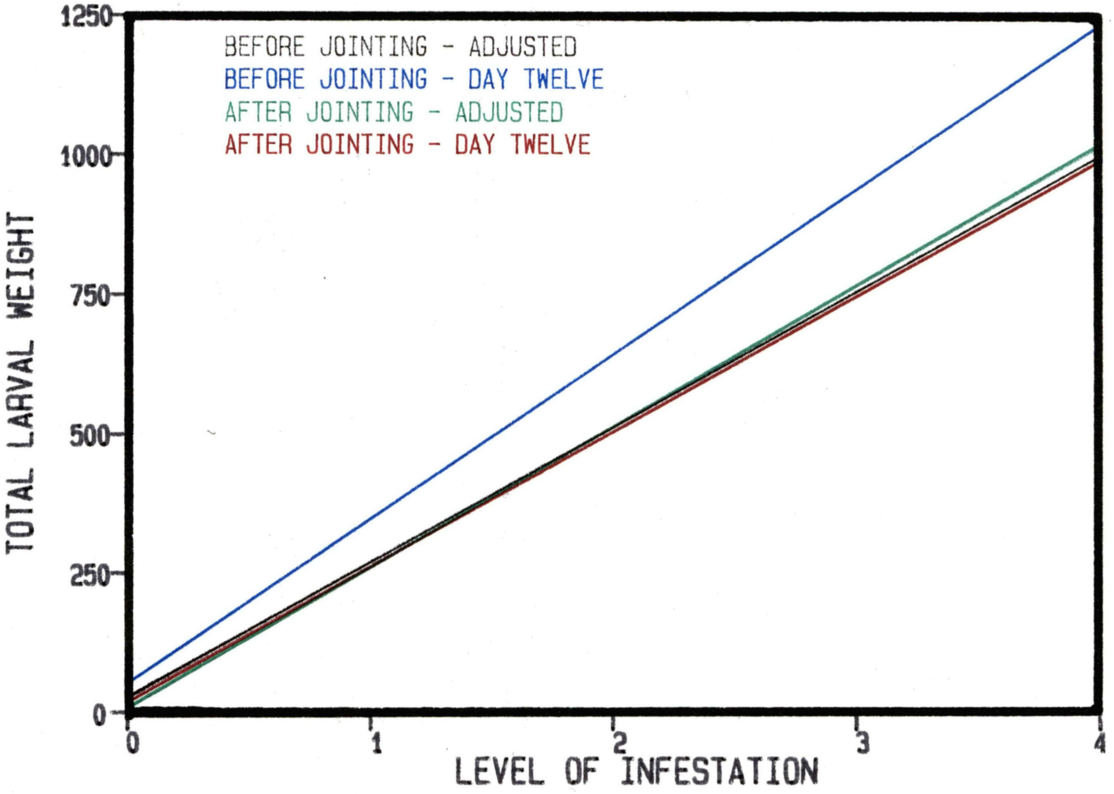

Figure 5. **Experiment 2: Linear Relationship Between Adjusted Total Larval Weight and the Level of Infestation by Time**

identical with the adjusted average larval weight, while before jointing, the total larval weight at twelve days is much higher. Examination of the magnitude and direction of difference between adjusted total weight and total weight at day twelve shows that there is a difference between those lines before jointing, where level of infestation seems to have a definite effect on this difference. On the other hand, the magnitude of the difference between lines describing the infestation after jointing is quite small, and varies little with increasing infestation.

The actual difference in total larval weight regressed against level is shown in Figure 6. Figure 6 also supports the conclusion that greater growth was occurring before jointing than after jointing. Notice that before jointing, the difference in total larval weight increased with increasing level of infestation. After jointing, however, the difference in weight decreased with increasing infestation. The contrasting effect that level of infestation had on the difference in total larval weight before jointing versus after jointing may explain why the level of larvae was not significant overall.

Average Larval Growth

While total larval weight measures larval growth as a group, average larval weight measures individual larval growth. This individual larval growth was estimated by measuring average larval weight at six days (AVGLWT1) and at twelve days (AVGLWT2) after infestation.

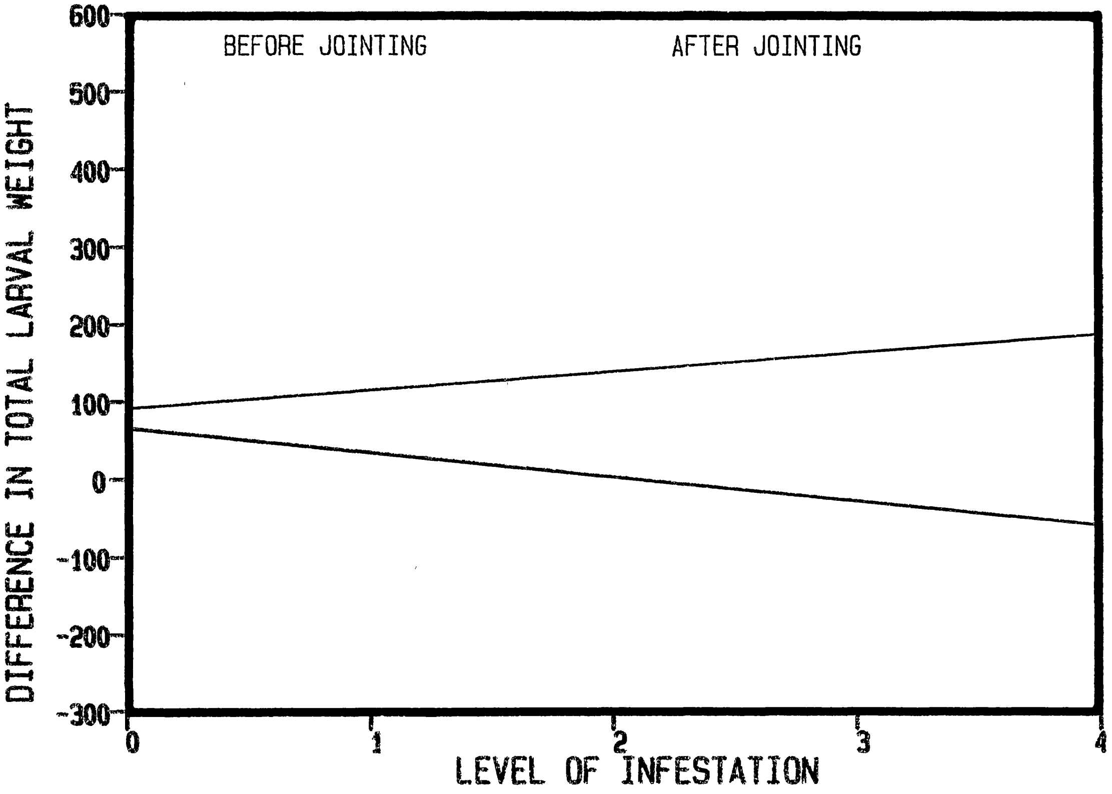

Figure 6. **Experiment 2: Linear Relationship Between the Difference in Total Larval Weight and the Level of Infestation by Time**

The time of infestation had a definite effect on the average larval weight after six and twelve days ($\underline{P} < 0.05$) (Table V). As in the case of total larval weight, the average weight of larvae placed on the plant before jointing was greater than the average weight of larvae placed on after jointing. Again, all larvae were initially of the same approximate weight, indicating that average larval weight after jointing was adversely affected either by higher temperatures or less palatable leaf material as discussed earlier for total larval weight. The decrease in total larval weight after jointing is due to a decrease in average larval weight, and not in a decrease in the number of larvae found.

The level of infestation was found to have no effect on average larval weight after six days ($\underline{P} > 0.05$) (Table VII), while it did have an effect on the average larval weight after twelve days ($\underline{P} < 0.05$) (Table VII). As in Experiment 1, average larval weight at twelve days decreased as the infestation level increased. This could be caused by disturbance or competition between larvae.

The significant interaction between time and level of infestation on average larval weight after twelve days ($\underline{P} < 0.05$) (Table XIV, Appendix) does suggest a difference in behavior of average larval weight before and after jointing. Average larval weight does definitely seem to decrease as level of infestation increases before jointing (Fig. 7), however, after jointing, average larval weight

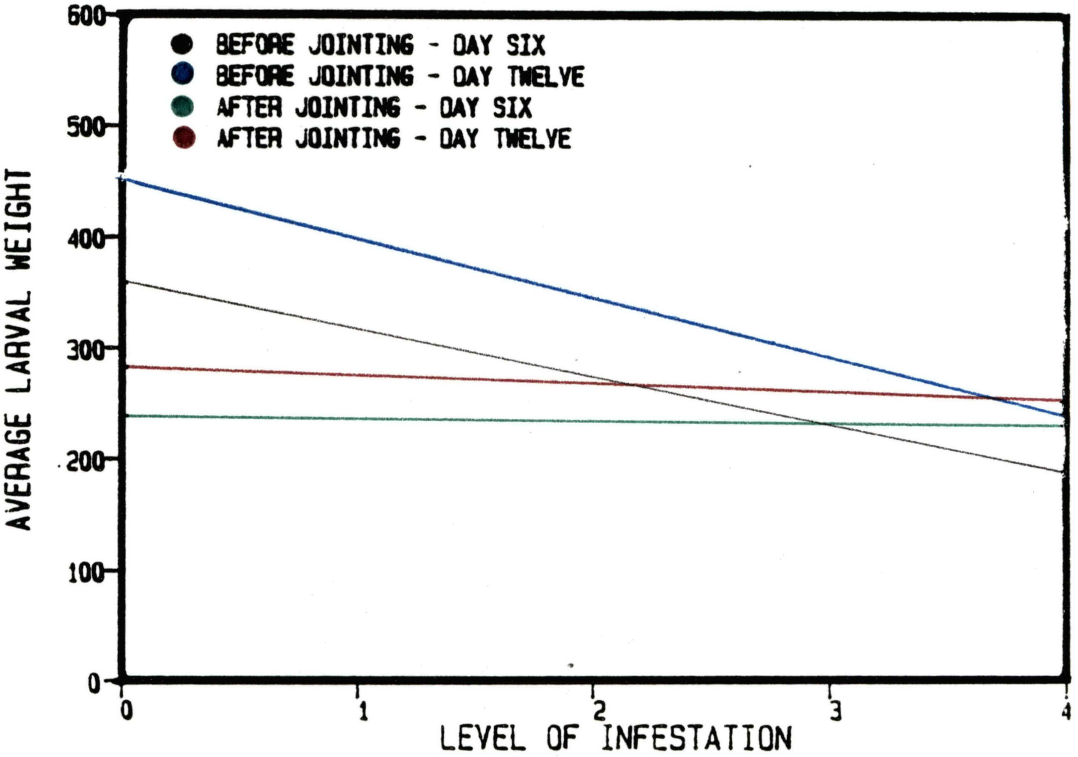

Figure 7. Experiment 2: Linear Relationship Between Average Larval Weight and the Level of Infestation by Time

seems to stay the same regardless of the level of infestation.

Average larval weight after twelve days shows a similar trend in that average weight definitely decreases with increasing level of infestation before jointing, but stays the same at each level after jointing. Thus the relationship (Fig. 8) shows that the level of infestation greatly influenced average larval weight before jointing but seemed to have little effect after jointing.

Difference in Average Larval Growth.

Two variables, adjusted average larval weight (ADAVGLWT1) and the difference in average larval weight (DFAVGLWT) were used to measure the change in individual larval growth from day six to day twelve of the infestation.

The time of infestation had no effect on the adjusted average larval weight ($P < 0.05$) (Table V). The time of infestation did have an effect on average larval weight before adjustment, however, indicating that the addition of larvae served to lessen the differences between average weight before jointing and after jointing.

Alternatively, the difference in average larval weight was greatly influenced by the time of infestation ($P < 0.0001$) (Table XII, Appendix). The gain in average larval weight was 79.9 mg before jointing and only 9.7 mg after jointing, indicating that larval growth before jointing was greater than that after jointing ($P < 0.05$) (Table V). This

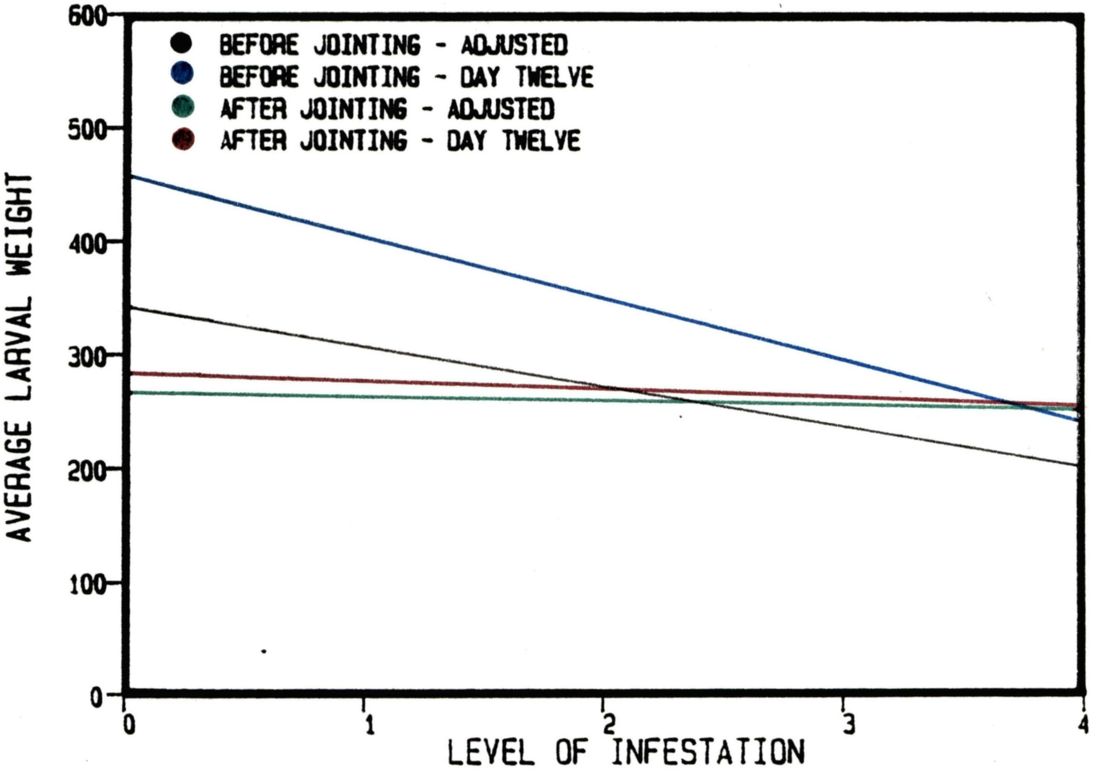

Figure 8. **Experiment 2: Linear Relationship Between Adjusted Average Larval Weight and the Level of Infestation By Time**

is further evidence that the negative difference in total larval weight was due to larval mortality and not to actual overall weight loss in individual larvae.

The level of infestation also had an effect on the adjusted average larval weight ($\underline{P} < 0.05$) (Table VII). This effect was inversely proportional to the level of infestation, with larvae at level one weighing about 290 mg and larvae at levels two and three weighing about 250 mg.

The level of infestation also affected the difference in average larval weight ($\underline{P} < 0.01$) (Table XIII, Appendix). The mean weight gain per larvae was only 22.3 mg for level three overall, but 45.0 to 62.8 mg at levels one and two respectively (Table VII).

There was an interaction between main effects in adjusted average larval weight, but not in the difference in average larval weight (Table XIV, Appendix). Figure 8 shows average larval weight adjusted at six days and average larval weight after twelve days. There is little difference in the adjusted average weight before jointing or after jointing, though the weight before jointing seems to be more affected by level. In comparison with the average larval weight on the last day of infestation, however, the difference in average larval weight as represented by the difference between the two lines in each plant stage is much larger for the before jointing infestation. Also the difference in average larval weight was more strongly affected by level before jointing. Figure 9 shows the

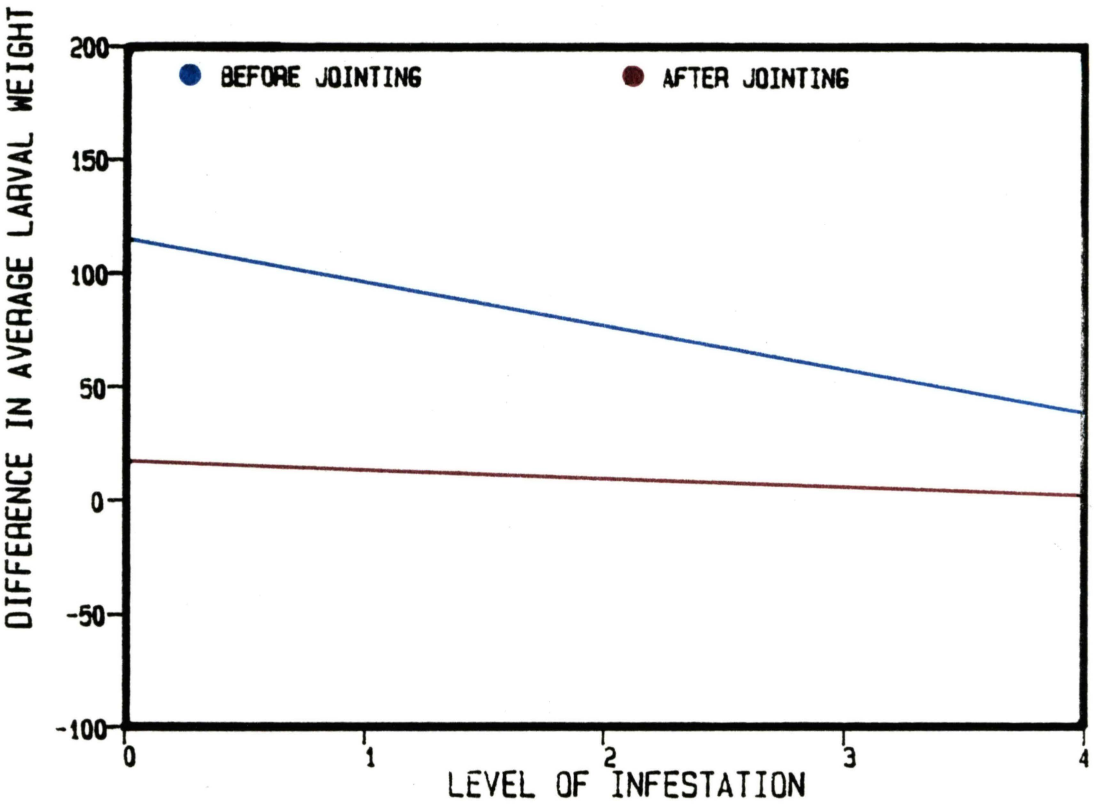

Figure 9. Experiment 2: Linear Relationship Between the Difference in Average Larval Weight and the Level of Infestation By Time

actual difference in average larval weight. The actual increase in average larval weight was very small for the after jointing infestation (Table VII) (only 9.7 mg) whereas the increase in average larval weight over this six-day period before jointing was much larger (79.9 mg). In addition, there is a difference by level in average larval weight (Table VII) ($P < 0.05$), however, Figure 9 shows that much of this difference is due to average larval weight differences before jointing. The correlation coefficient describing the relationship between difference in average larval weight and level of infestation is 0.73.

Direct Damage to the Wheat Plant

A visual damage rating from 0 to 9 was used to measure direct damage to the wheat plant immediately after army cutworm infestation.

Whether the infestation was before or after jointing greatly affected the amount of damage larvae did to the wheat plants. The effect of time of infestation on the damage rating as shown by the mean damage rating before jointing ($Y_b = 2.8$) was significantly higher than that after jointing ($Y_a = 1.5$) ($\underline{P} < 0.05$) (Table V).

As expected, the number of larvae on the plant also greatly affected the amount of damage. This is shown in Table VII where three larvae caused more damage ($Y_3 = 4.0$) than two larvae ($Y_2 = 3.3$) which, in turn, caused more damage than an infestation level of one ($Y_1 = 1.3$) ($\underline{P} < 0.05$).

The damage rating was affected by an interaction between time and level of infestation ($\underline{P} < 0.0001$) (Table XIV, Appendix). This can be clearly seen in Figure 10. The slopes of these two lines differ; the increase in damage rating as the level of infestation increased was much greater in plants infested before jointing. This indicates the progressive nature of the damage to the plants before jointing which is not as characteristic of plants after jointing. This may explain the greater weight gain of larvae on plants before jointing.

Damage rating was found to be highly correlated ($\underline{P} < 0.0001$) with number of larvae found after six ($r^2 = 0.76$) and twelve ($r^2 = 0.81$) days; the total weight of larvae found after six ($r^2 = 0.73$) and twelve ($r^2 = 0.84$) days; and the difference in total larval weight ($r^2 = 0.47$). In determining what combination of larval variables most affected the damage rating, total larval weight after twelve days, difference in total larval weight, and number of larvae found on day six had a greater influence on damage rating that any other two or three factor model ($R^2 = 0.67$).

Indirect Damage to the Wheat Plant

Plant height, dry matter, number of tillers, number of heads, number of kernels per head, total seed weight, and weight per 1000 seed were all measured to determine if larval feeding had any lasting effect on the wheat plant.

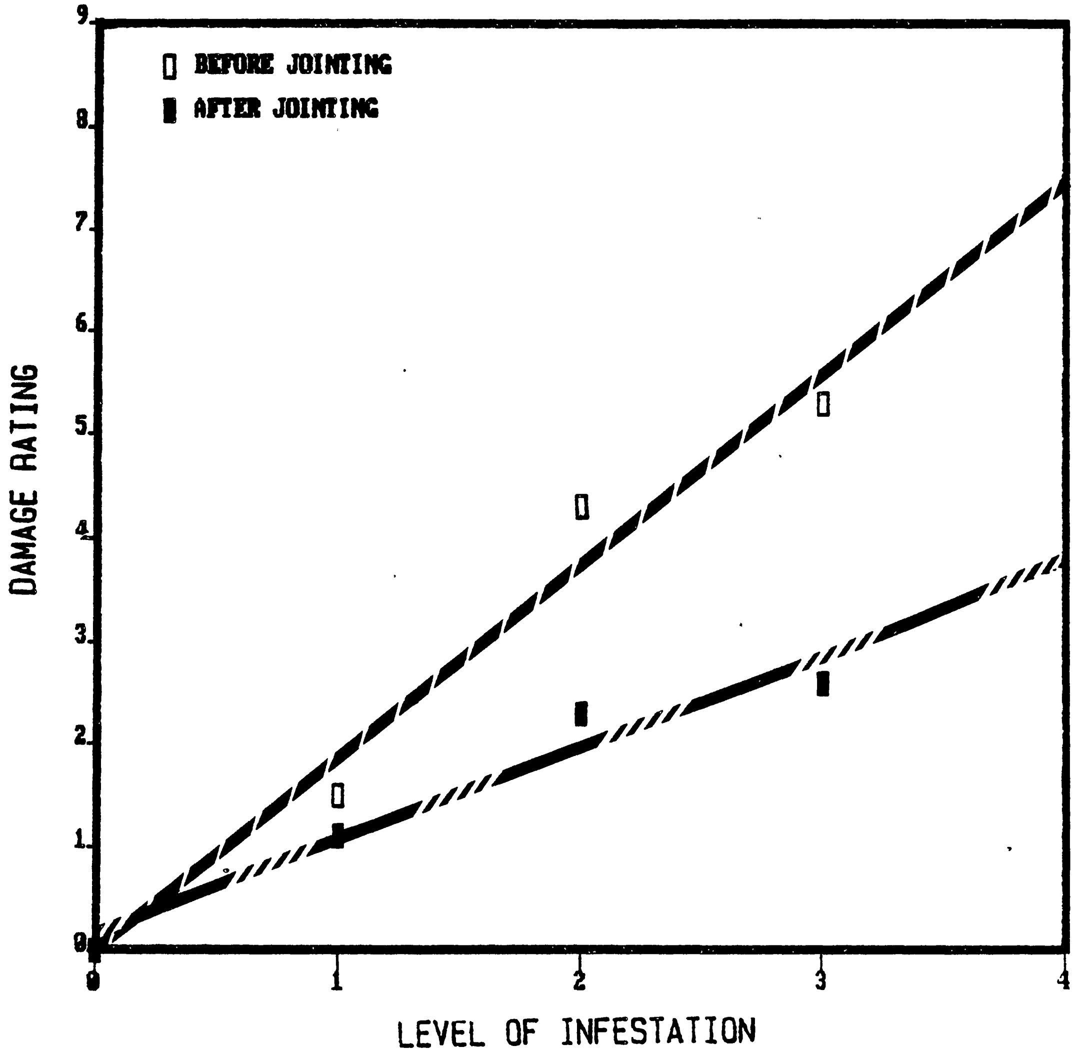

Figure 10. Experiment 2: Linear Relationship Between the Damage Rating and Level of Infestation By Time

The stage at which larval defoliation occurred, either before or after jointing, greatly affected the amount of dry matter produced ($\underline{P} < 0.05$) (Table V). Shoots of plants infested after jointing ($Y_a = 5.29$) weighed more than shoots of plants infested before jointing ($Y_b = 4.85$) at harvest. None of the other variables measuring indirect damage were affected by plant stage ($\underline{P} > 0.05$).

The number of larvae on a plant affected all of the variables for measuring indirect damage except kernels per head ($\underline{P} < 0.05$) (Table VII). In some cases, the effect of infestation level on plant measurements was erratic. For example, the number of tillers, though significantly affected by the number of larvae and clipping applied to the plant ($\underline{P} < 0.01$) (Table XIII, Appendix), decreased at level one, then increased through level three, and then decreased again (Table VII). Number of heads ($\underline{P} < 0.05$) (Table XIII, Appendix) changed even more erraticly with infestation level (Table VII).

In other cases, plants seemed to compensate for defoliation damage through an initial increase in growth. Though plant height was one of the variables most affected by level of infestation ($\underline{P} < 0.0001$) (Table XIII, Appendix), Table VII shows an overall decrease in plant height despite the fact that all plants infested with larvae are higher than the controls. The weight of above ground dry matter was also greatly affected by level of infestation ($\underline{P} < 0.0001$) (Table XIII, Appendix), however, as Table VII shows, the overall decrease in dry matter is erratic as level of infestation increases. Total seed weight gradually decreased as infestation level increased ($\underline{P} < 0.0001$) (Table XIII, Appendix) even though the seed weight of all infested plants was greater than that of the control (Table VII). Finally, weight per thousand seed showed a similar trend, with seed weight being highest at an infestation level of two (Table VII), even though seed weight was highly affected by level of infestation ($\underline{P} < 0.0001$) (Table XII, Appendix).

In all variables, clipping plants was most detrimental to growth and yield ($\underline{P} < 0.05$) (Table VII).

Only two variables, as affected by the level of infestation, reacted differently to larval damage occurring before jointing versus after jointing ($\underline{P} < 0.01$) (Table XIV, Appendix). One of these variables was the weight of above ground dry matter (Fig. 11). Before jointing, dry matter steadily decreased with an increasing infestation level. After jointing, dry matter increased through the infestation level of three, and fell sharply in clipped plants. Total seed weight (Fig. 12) rose slightly at an infestation level of one before jointing and then steadily decreased through plant clipping. Total seed weight, after jointing, increased greatly at level one, decreased only slightly as infestation level increased, then fell sharply when plants were clipped. After jointing, plants infested with larvae all had greater dry matter and total seed weights than the control plants. One explanation for this phenomenon could

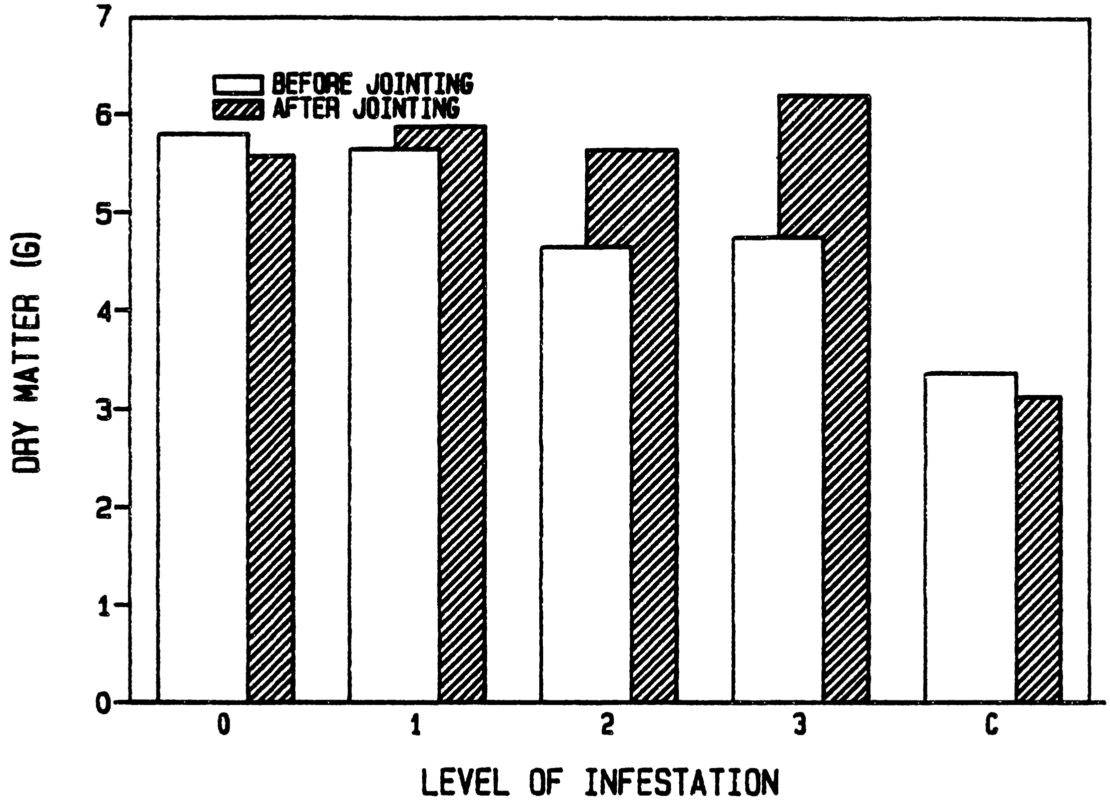

Figure 11. Experiment 2: Weight of Above Ground Dry Matter Before Jointing and After Jointing at Each Level of Infestation

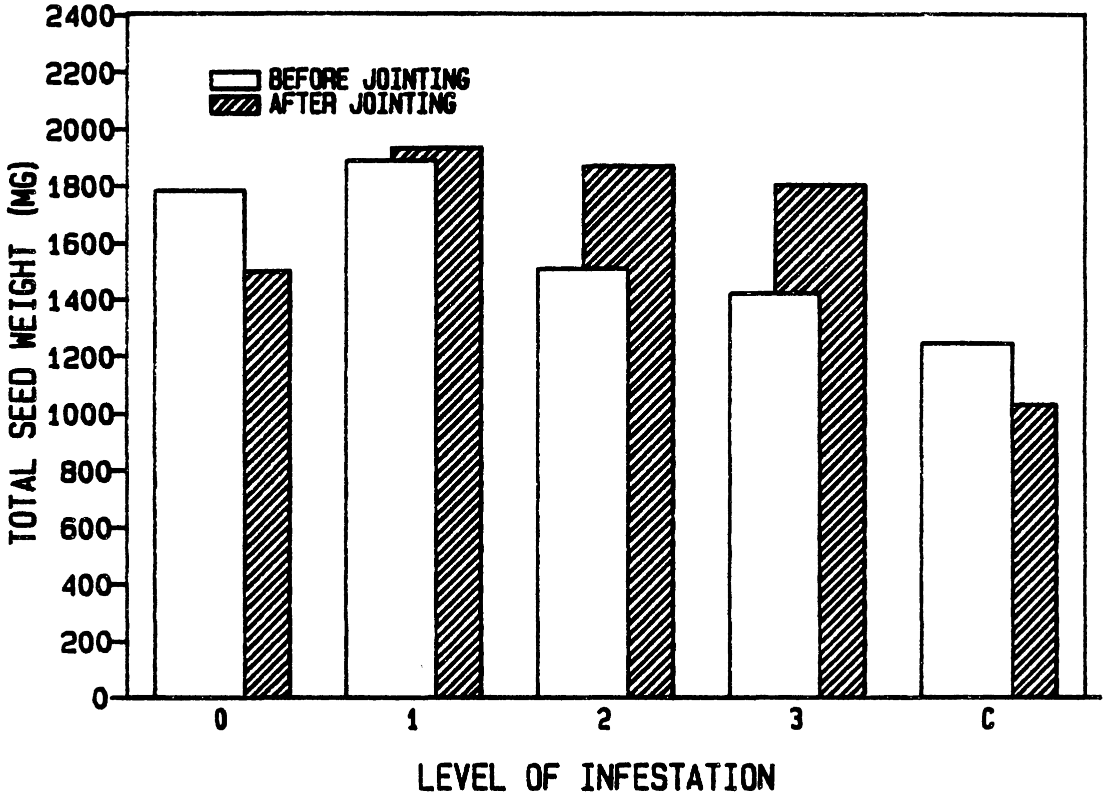

Figure 12. Experiment 2: Total Seed Weight Before Jointing and After Jointing at Each Level of Infestation.

be the small amount of damage inflicted to plants after jointing by the larvae. The damage rating, after jointing, was 1.1 for level one, 2.3 for level two, and 2.6 for level three compared with 1.5, 4.3, and 5.3 respectively before jointing. Plants after jointing suffered only slightly more damage than plants infested with one larvae before jointing.

None of the measurements of indirect damage was significantly correlated to any of the parameters describing larval survival or growth ($\underline{P} > 0.05$). Plant height was correlated to damage rating ($\underline{P} < 0.01$) with an r^2 value of -0.35. Dry matter was highly correlated to damage rating ($\underline{P} < 0.0001$) with an r^2 value of -0.72. The number of tillers was slightly correlated to damage rating ($\underline{P} < 0.05$) with an r^2 of -0.23, while weight per thousand seed was highly correlated to damage rating ($\underline{P} < 0.0001$) with an r^2 of -0.40. Total seed weight was also highly correlated to damage rating ($\underline{P} < 0.0001$) with an r^2 of -0.51.

Conclusions

Army cutworm survival was not affected by time. The actual number of larvae found was the same before jointing and after jointing, indicating that survival on the plants was the same. Larval growth was affected by time, however. Both total and average weight of larvae on plants before jointing were greater than those on plants after jointing, indicating that conditions before jointing were probably better for larval growth. The actual increase in total and average weight of larvae per plant over six days was also much greater before jointing. Younger and more palatable leaf tissue and lower temperatures in the greenhouse are probably responsible. Plants infested before jointing were more heavily damaged than plants infested after jointing.

Indirect damage, unlike direct damage and larval growth, was not greatly affected by the time of infestation. Weight of above ground dry matter was significantly greater after jointing, perhaps because less defoliation occurred on plants at this time.

The level of infestation greatly affected both the larvae and the plant. Though larval survival was not affected, the number of larvae found definitely increased as the level of infestation increased. So did the total larval weight. Average larval weight tended to decrease as infestation level increased. This trend also occurred in Experiment 1. The difference in average larval weight was significantly lower at the infestation level of three than at levels one or two suggesting a detrimental effect of competition or disturbance at higher larval densities. The difference in total larval weight was the same at all infestation levels.

Direct damage to the wheat plants also increased with increasing level of infestation, indicating that one larvae does not do as much damage to a wheat plant as three.

Indirect damage was also affected by the level of infestation, however, the relationship was not a purely linear one. Overall, plant height, dry matter, tillers per plant, heads per plant, total seed weight, and weight per thousand seed seemed to decrease with increasing level of infestation, however, often damaged plants grew more and had greater yields than the controls. This may be due to compensation by the plants for larval defoliation, resulting in an enhancement in the value of the parameters mentioned above. In addition, plants infested after jointing seemed to exhibit a greater ability to compensate for larval damage. This may be due to the lower amount of damage inflicted on plants after jointing.

In all cases, clipping caused the greatest decrease in measures of indirect damage.

CHAPTER VI

EXPERIMENT 3: THE EFFECT OF LEVEL OF INFESTATION OF FIFTH INSTAR ARMY CUTWORMS ON THE GROWTH OF THE WINTER WHEAT VARIETIES STURDY AND TAM W-101

Though a visual rating of damage is a valuable tool in determining the effect of an insect on a plant, it is still subjective. Consequently, a rating scale must either be detailed, indicating how much damage constitutes a certain rating, or done by only one person to insure uniformity of results. An alternative to a damage rating system is the quantitative measurement of damage. The objectives of this test were to quantify army cutworm defoliation; to determination the short-term effects of larval defoliation on the roots and shoots of plants; and to determine differences in plant reaction between the drought and insect-susceptible variety Sturdy and TAM W-101.

Materials and Methods

Germinated seeds of TAM W-101 and Sturdy were planted at a depth of 3 cm in fritted clay in plastic cone-shaped "conetainers" 21 cm high and 4 cm in dia.. The conetainers were arranged in a 10 X 10 Latin square with ten replications per treatment. Treatments consisted of a factorial of the two varieties, and four levels of larvae - 0, 2, 4, and 6. All response parameters are described in Table VIII.

Larvae were contained on plants by using cages made from Lexan tubing 3.5 cm in dia. and cut into 30 cm lengths. A hole 3.5 cm in dia. was cut in the side of the cage to allow adequate ventilation. This hole and the top of the cage were covered with white chiffon fabric. Larvae were left on the plants for ten days, and then counted.

A Licor portable area meter, model LI-5000, was used to measure total leaf areas (cm^2) of each plant before and after infestation. The leaf area after infestation (LAAFT) can be described as a function of the leaf area before infestation (LABEF) by using the following formula:

$$LARATIO=LAAFT/LABEF$$

The resulting leaf area ratio (LARATIO) of each plant can then be compared with the mean leaf area ratio of the control plants (uninfested) to determine the amount of leaf area or growth potential lost due to the larval infestation. Sturdy and TAM W-101 had different mean leaf area ratios. This ratio was 1.83 for Sturdy and 2.04 for TAM W-101. Using these values as constants (CONST_S and CONST_T respectively), the percent of defoliation at each

TABLE VIII

EXPERIMENT 3: RESPONSE VARIABLES

VARIABLE	ABBREVIATION	DESCRIPTION
Number of larvae found	LARFND	Number of larvae found after infestation.
Total larval weight	TTLLWT	Total weight of larvae after infestation (mg).
Average larval weight	AVGLWT	Average weight of larvae after infestation (mg).
Damage rating	DMGRTG	A visual rating of damage based on a scale of 0 to 9, where 0 = no defoliation and 9 = 100% defoliation. Taken twelve days after infestation.
Leaf area before infestation	LABEF	Plant leaf area before infestation (cm^2).
Leaf area after infestation	LAAFT	Plant leaf area after infestation (cm^2).
% Defoliation	%DEFOL	Percent defoliation.
Plant height	PLNTHT	Plant height taken after infestation (cm).
Root weight	RTWT	Root weight taken after infestation (g).
Shoot weight	SHWT	Shoot weight taken after infestation (g).
Root to shoot ratio	RSRATIO	Root wt. over shoot wt.

level of infestation was determined by the following formula.

%DEFOL = (CONST_S OR T - LARATIO) / (CONST_S OR T) X 100

The %DEFOL is an estimate of the amount of larval defoliation, however, slower plant growth due to damage by the larvae shows up as actual consumption of plant material in this equation.

Results and Discussion

Survival and Growth of the Army Cutworm

Response parameters describing the larvae have been separated into those describing larval survival on the plants, and those describing larval growth, both total and average.

Larval Survival

Larval survival was measured by the number of larvae found (LARFND). The same number of larvae overall were found on both TAM W-101 and Sturdy, indicating that variety had no effect on larval survival (Table IX). The number of larvae found did, however, increase significantly with level of infestation ($P < 0.05$) (Table X). Unlike in Experiment 2, however, less larvae were found than were put on. Actual survival, calculated by dividing the number of larvae found by the level of infestation, varied only slightly with level of infestation. Survival at level two was 72.5%; level four 70.0%; and level six, a little lower at 62.0%. The small

TABLE IX

EXPERIMENT 3: MEAN SEPARATION BY VARIETY

VARIETY	LARFND (#)	TTLLWT (mg)	AVGLWT (mg)	DMGRTG (#)
STURDY	1.66 a	478.6 a	0.2 a	2.96 a
TAM-W101	1.52 a	396.4 a	0.2 a	3.20 a

VARIETY	LABEF (cm^2)	LAAFT (cm^2)	%DEFOL
STURDY	56.3 a	77.1 a	27.0 a
TAM-W101	42.0 b	66.4 b	18.0 a

VARIETY	PLNTHT (cm)	RTWT (g)	SHWT (g)	RSRATIO
STURDY	30.9 a	2.76 a	2.46 a	1.21 a
TAM-W101	28.4 b	2.21 b	2.33 a	0.97 b

Means in the same column followed by the same letter are not significantly different ($\underline{P} < 0.05$; Duncan's New Multiple Range Test, (Duncan, 1955)).

TABLE X

EXPERIMENT 3: MEAN SEPARATION BY LEVEL OF INFESTATION

LEVEL	LARFND (#)	TTLLWT (mg)	AVGLWT (mg)	DMGRTG (#)
0	0.00 a	0.0 a	--------	0.0 a
2	1.45 b	541.0 b	346.0 ab	4.5 b
4	2.80 c	631.5 b	283.0 a	4.9 b
6	3.70 d	1015.0 c	386.0 b	6.0 c

LEVEL	LABEF (cm^2)	LAAFT (cm^2)	%DEFOL
0	49.97 a	93.93 a	-0.002 a
2	47.29 a	61.76 b	31.800 b
4	48.20 a	56.84 b	37.200 b
6	50.21 a	52.07 b	43.800 b

LEVEL	PLNTHT (cm)	RTWT (g)	SHWT (g)	RSRATIO
0	33.6 a	2.73 a	2.73 a	1.02 a
2	28.8 b	2.28 bc	2.16 b	1.12 a
4	28.2 b	2.14 c	2.14 b	1.04 a
6	24.0 c	2.55 ab	2.23 b	1.23 a

Means in the same column followed by the same letter are not significantly different ($\underline{P}$ <.05; Duncan's New Multiple Range Test, (Duncan, 1955)).

area in which the larvae were confined is probably responsible for this low survival. Such confinement can increase disturbance and cannabalism.

Larval Growth

Larval growth was measured by two variables, total larval weight (TTLLWT), and average larval weight (AVGLWT). Neither of these variables was affected by the variety of wheat on which they were infested (Table IX), however, both were greatly affected by the level of infestation ($\underline{P} < 0.0001$) (Table XVI, Appendix). Total larval weight increased as infestation level increased, with those at levels two and four weighing less than those at level six ($\underline{P} < 0.05$)(Table X). Average larval weight decreased from 346.0 mg at level two to 283.0 mg at level four, then increased to 386.0 mg at level six. In the two previous experiments, average larval weight decreased with increasing level of infestation. Relatively low survival of army cutworms may explain the increase in larval weight at an infestation level of six. The mean number of larvae found at level six was only one greater than the number found on plants infested with four larvae (Table X). Though average larval weight was not significantly affected by variety, Figure 13 shows that average larval weight on TAM W-101 did decrease as the level of infestation increased. Larvae on Sturdy, however, acted erraticly. This may be due to experimental error.

Figure 13. Experiment 3: Average Larval Weight at Each Level of Infestation by Variety

Measuring Direct Damage to the Wheat Plant

Damage Rating

Damage rating (DMGRTG) was the same for both varieties ($P > 0.05$)(Table IX), however, it increased with increasing infestation level ($P < 0.05$) (Table X, Fig. 14). The damage rating for level two and four were similar while plants infested with six larvae were more heavily damaged.

Leaf Area

Leaf area before infestation differed significantly between varieties ($P < 0.0001$) (Table XV, Appendix). The variety Sturdy had a greater leaf area ($Y_S = 56.3$ cm^2) than TAM W-101 ($Y_T = 42.0$ cm^2) (Table IX). After infestation, Sturdy had a greater leaf area ($Y_S = 77.1$ cm^2) than TAM W-101 ($Y_T = 66.4$ cm^2) ($P < 0.05$). The percent defoliation was the same for both varieties ($P <$ 0.05) (Table IX).

The level of infestation had no effect on the leaf area before infestation ($P > 0.05$) (Table X), as would be expected, however, infestation had an effect on the leaf area after infestation ($P < 0.0001$) (Table XVI, Appendix). The leaf area of the control plants after infestation was much greater ($Y_0 = 93.93$ cm^2) than that of infested plants ($Y_2 = 61.76$ cm^2; $Y_4 = 56.84$ cm^2; $Y_6 = 52.07$ cm^2) ($P < 0.05$) (Table X). The percent defoliation of infested plants ($Y_2 = 31.8\%$; $Y_4 = 37.2\%$; and $Y_6 =$

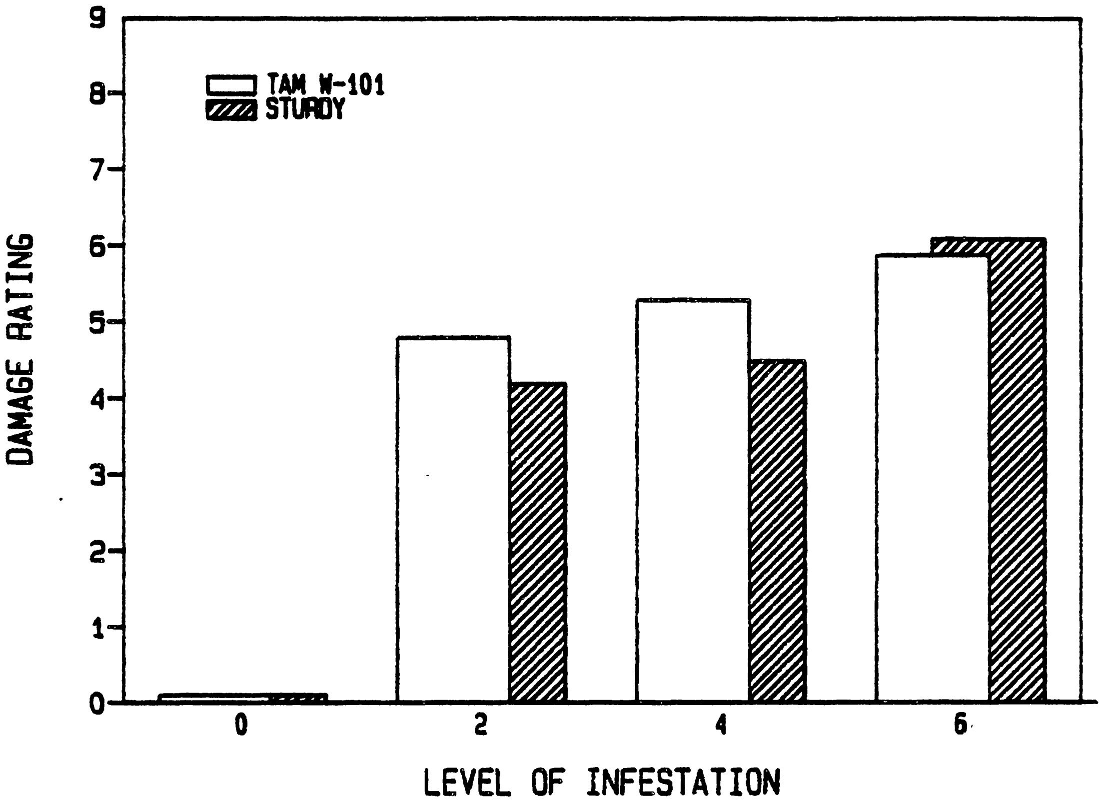

Figure 14. Experiment 3: Damage Rating at Each Level of Infestation by Variety

43.8%) which were not different (Table X) was greater than that of the control plants with no defoliation ($\underline{P} < 0.05$). There was no difference in leaf area after infestation or percent defoliation in infested plants. This may reflect the similarity in number of larvae found and damage rating of infested plants.

Damage rating and the percent defoliation were highly correlated with one another ($\underline{P} < 0.0001$; $r^2=-0.67$), thus, damage rating is a good measure of actual defoliation.

Indirect Damage to the Wheat Plant

Plant height, root weight, shoot weight, and root-to-shoot ratio of Sturdy and TAM W-101 were measured to determine indirect larval damage. Sturdy was significantly greater than TAM W-101 in height, root weight, and root-to-shoot ratio ($\underline{P} < 0.05$) (Table IX), but did not differ in shoot weight ($\underline{P} > 0.05$).

The level of infestation had a significant effect on plant height, root weight, and shoot weight ($\underline{P} < 0.05$) (Table X). Plant height decreased with increasing level of infestation. Plants infested with two and four larvae had lower root weights than the control. Plants infested with six larvae, on the other hand, had greater root weights than the lower levels and were not significantly different than the controls ($\underline{P} < 0.05$) (Table X). Root weight changed according to level in the same pattern in both varieties

(Fig. 15). The increase in root weight at level six may be due to experimental error; or some form of compensatory growth by the plant. Though infested plants had significantly lower shoot weights (Table X, Fig. 16) than uninfested plants, the shoot weights of infested plants did not change greatly with level of infestation. The fact that damage ratings and the actual percent of defoliation were similar for levels two through six, probably explains the lack of difference in shoot weights in infested plants.

Conclusions

Variety had no effect on any of the larval variables indicating that larvae grew equally well on Sturdy and TAM W-101. Neither damage rating nor the percent defoliation differed with variety, indicating that larvae responded equally on both varieties. In terms of plant response after infestation, Sturdy was taller, had heavier roots, and a greater root to shoot ratio than TAM W-101. Sturdy also had a larger leaf area than TAM W-101 after infestation, though, there was no difference in shoot weight between the two varieties after infestation . The relationship between shoot weight and leaf area should be further studied. If the leaves of one variety of wheat are actually heavier per cm^2 than another variety, the leaf area consumed may not be an adequate determination of damage.

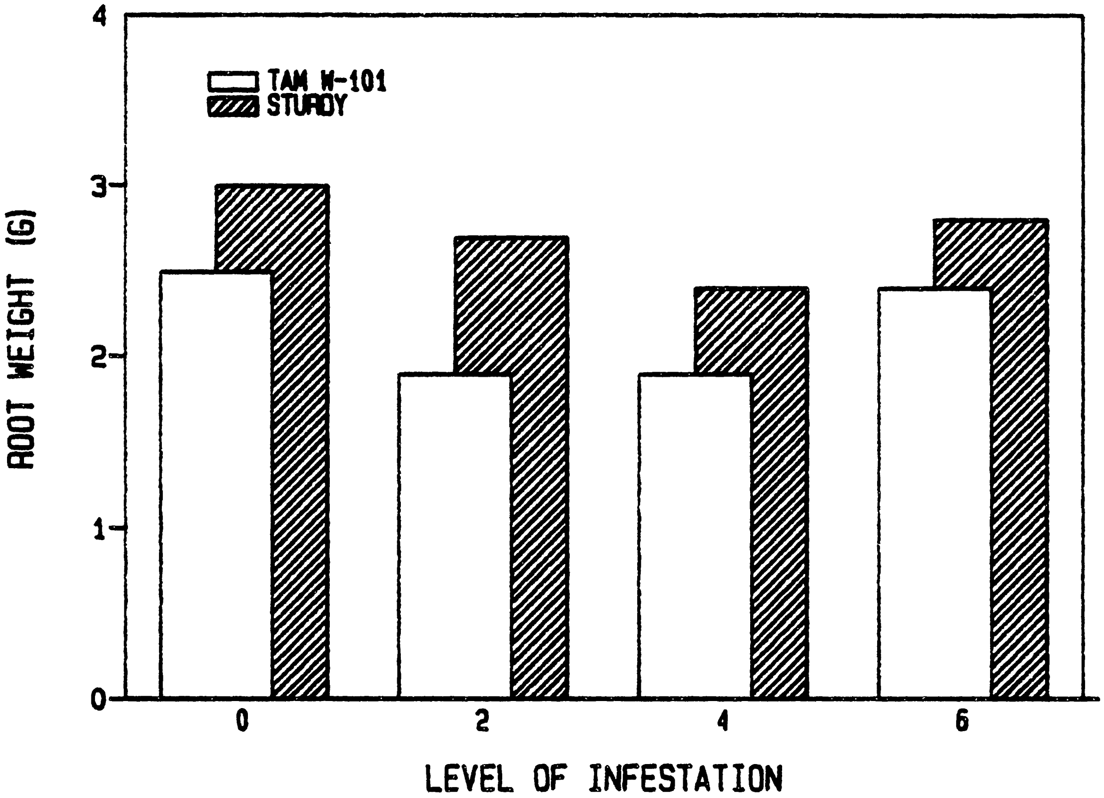

Figure 15. Experiment 3: Root Weight at Each Level of Infestation by Variety

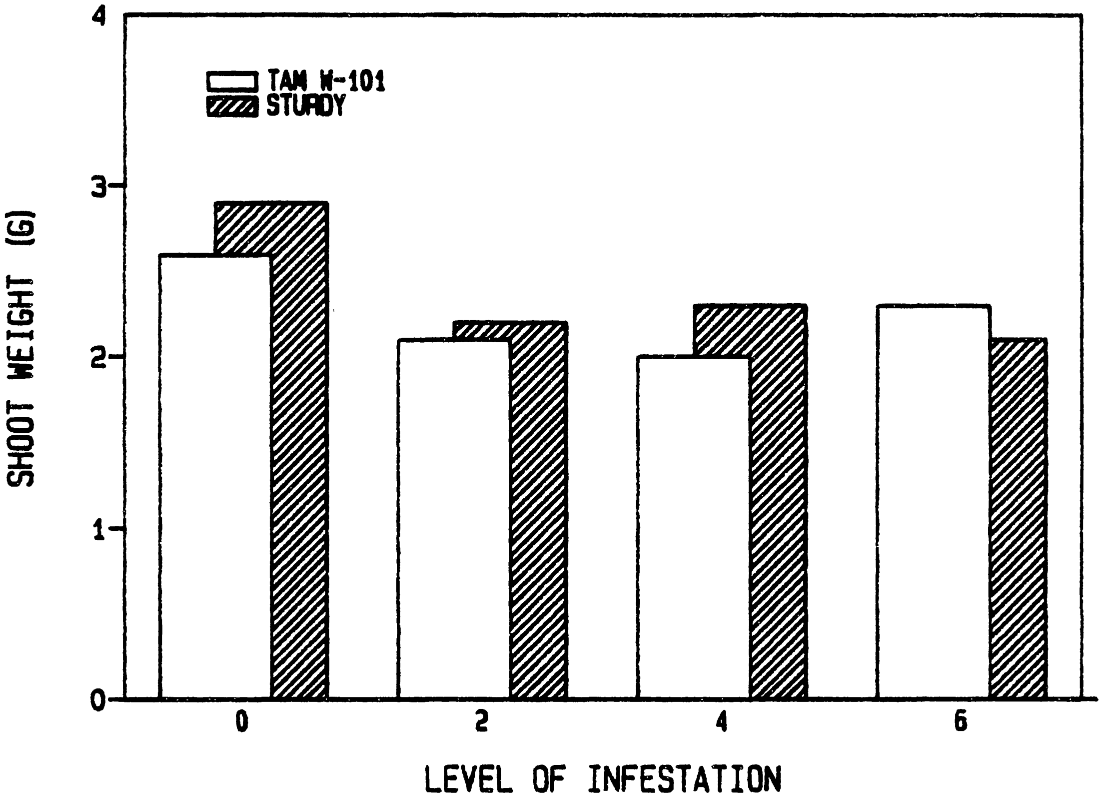

Figure 16: Experiment 3: Shoot Weight at Each Level of Infestation by Variety

The level of infestation affected larvae and the plant much as it did in Experiments 1 and 2. For instance, the number of larvae found, and total weight of larvae on the plants, increased with increasing infestation level. Average larval weight on TAM W-101 decreased with increasing infestation level as was true in Experiments 1 and 2. The average larval weight behaved differently on Sturdy, however, decreasing through level four and then increasing at level six by more than 100 mg. Though the decrease in average larval weight may only be true over a certain range of infestation levels, the reason for this inconsistency in average larval weight on Sturdy may be due to experimental error.

Damage rating, and percent defoliation increased with increasing level of infestation, though this increase was small, possibly due to the similarity in larval number found at all infestation levels. Leaf area after infestation of plants infested with larvae was much less than the controls, though differences amoung infested plants were small. Damage rating and the percent of defoliation were highly correlated with one another, indicating the damage rating is a good measure of actual defoliation.

Plant height, and to a lesser extent root weight and shoot weight decreased as level of infestation increased. An increase in root weight in both varieties at a level of infestation of six larvae per plant is also difficult to explain. Though there may be some sort of compensatory root growth by the plant, this phenomena may also be due to experimental error.

CHAPTER VII

DISCUSSION

In general, as the number of larvae on a plant increased, larval survival and growth decreased. The most likely explanation for this phenomenon is increased competition and disturbance between larvae at higher levels of infestation. Cannibalism may also be responsible for the decreased larval survival at high infestation levels. Most larvae of species in the genus Euxoa will eat other larvae of the same species (Hinks and Byers, 1976). While four larvae per plant may not seem to be a high density, it would be equivalent to about 48 larvae per foot of row in a wheat field. Cannibalism has been noted at densities this high by both Strickland (1916) and Wilcox (1898).

Though time of infestation did not affect larval survival, it did affect larval growth. Larvae did not thrive as well on plants after jointing as indicated by lower larval weight after jointing and relatively no weight gain by larvae over a six-day period. More intense competition for food between larvae, and higher temperatures that result in larval desiccation are the most obvious reasons for this weight loss. Leaf tissue after jointing may also be less palatable to the army cutworm due to its older age. This may result in lower larval weight gains. Other noctuids require young leaves for optimal growth and development. For instance, fall armyworms feeding on old peanut leaves were found by Garner and Lynch (1981) to have lower survival and consume less leaf tissue throughout their development than larvae fed on younger leaves. Many reports of severe army cutworm damage after jointing have been recorded, however, especially in the North where the weather is cooler and more conducive to army cutworm development. Consequently, larvae may have no difficulty feeding on wheat after jointing in a field situation, where they are not confined to one plant and forced to consume older leaf tissue to survive.

Feeding damage increased as level of infestation increased in every case, though the ratings varied by test. This variability in damage at a constant level of infestation may make the determination of an economic threshold for this insect very difficult. The number of larvae found on each plant was most highly correlated with damage rating, however, total larval weight on the plant affected the rating also. Percent defoliation increased as more larvae were put on plants. It was also highly correlated to the damage rating, indicating that a visual rating of damage was a good measure of actual defoliation.

Damage to plants after jointing was not as severe as damage to plants before jointing. This is probably related to the failure of larvae to grow on plants after jointing.

Dean and Smith (1935) and Painter et. al. (1954) observed that army cutworm larvae prefer young leaves and shoots of the wheat plant, thus leaves of plants after jointing may not be as suitable for army cutworm feeding as those before jointing.

Plant growth and yield, on the whole, decreased with increasing level of infestation. In most cases, however, the plant overcompensated for low amounts of defoliation, resulting in increased growth and yield over that of the controls. This compensation for defoliation by an insect has been noted in a number of other crops including tobacco defoliated by corn earworm and tobacco budworm (Kolodny-Hirsch and Harrison, 1982). On the average, a damage rating of 5 and over in winter wheat plants attacked by army cutworm larvae resulted in decreased plant height, weight of above ground dry matter, weight per thousand seed, and total seed weight per plant. In using the measurements of actual defoliation from Experiment 3, this damage rating corresponds to 30-40% defoliation. This is assuming, however, that damage rating corresponded to the same amount of defoliation in both experiments.

Though the results of this test indicate that winter wheat can withstand a great deal of army cutworm defoliation without a significant loss in yield, the damage potential of the army cutworm may be higher than shown here for two reasons. First, wheat plants were subjected to army cutworm damage only two weeks. Normally, larvae feed intermittently up to six months in the field. The effect of this chronic defoliation throughout much of the wheat plants development may be more detrimental than shown here. Secondly, sixth and seventh instar larvae may consume much greater amounts of leaf tissue than fifth instars. In a study which has yet to be published, sixth instar larvae at levels of 2, 4, and 8 per pot caused up to 90% defoliation of wheat plants in less than three days. Consequently, the amount of leaf material consumed by each instar of army cutworm larvae needs to be determined before an economic threshold can be developed.

The development of a degree-day model for larval growth is also needed. By having such a model, the time at which larvae reach fifth or sixth instar could be determined and fields could be monitored at this time for signs of defoliation. If populations of army cutworms are high and/or defoliation is prevalent, pesticides or other forms of control could be applied. The phenological stage of the wheat plant is also important, since, defoliation may be greater before jointing, but cause more damage to the plant after jointing in terms of reduced growth and yield loss.

Though the determination of an economic threshold for this insect is important, the cause of army cutworm outbreaks is crucial to the control of this insect. Because outbreaks seem to occur in a cycle, weather has been implicated as an important factor in army cutworm occurrence. Though weather conditions on the Great Plains do influence outbreaks of this insect (Seamans, 1934), little work has been done on how weather influences the population of adults in the Rocky Mountains. More study of the effects of weather on the population of army cutworms is needed before outbreaks can be predicted.

The relationship of tillage practices to army cutworm outbreaks should also be studied, since, fall plowing (Daniels, 1964; Gillette, 1904) and late-planting of wheat (Kantack et. al., 1979) have resulted in low army cutworm populations in infested areas. Such cultural practices are important in controlling insects in wheat due to the low market value of the crop.

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APPENDIX

ANALYSIS OF VARIANCE TABLES

TABLE XI

EXPERIMENT 1: ANALYSIS OF VARIANCE
EFFECT OF LEVEL OF INFESTATION

VARIABLE	SUM OF SQUARES	DF	MEAN SQUARE ERROR	DF	F	PR > F
LARFND	20.96	2	.23	16	45.3	.0001
TTLLWT	0.00	1	15325.00	8	0.0	1.0000
AVGLWT	8712.00	1	2321.00	8	3.8	.0887
DMGRTG	76.52	2	1.22	16	31.4	.0001
PLNTHT	78.07	2	68.67	35	0.6	.5715
DRYMTR	0.49	2	0.52	35	0.5	.6268
TLRS	0.25	2	0.55	35	0.2	.7961
HDS	0.75	2	0.36	35	1.0	.3660
KRNLHD	30.10	2	12.31	32	1.2	.3078
TTLSDWT	0.27	2	0.07	32	2.0	.1583
SDWT1000	89.67	2	37.69	32	1.2	.3175

TABLE XII

EXPERIMENT 2: ANALYSIS OF VARIANCE
EFFECT OF TIME OF INFESTATION

VARIABLE	SUM OF SQUARES	DF	MEAN SQUARE ERROR	DF	F	PR > F
LARFND1	0.45	1	0.21	54	2.1	.1527
LARFND2	0.05	1	0.05	54	0.9	.3396
TTLLWT1	90451.25	1	15566.90	54	5.8	.0194
TTLLWT2	253125.00	1	14223.36	54	17.8	.0001
ADTTLLWT1	601.70	1	9707.56	36	0.1	.8048
AVGLWT1	40300.42	1	5916.09	36	6.8	.0131
AVGLWT2	98010.42	1	4908.63	36	20.0	.0001
ADAVGLWT1	2778.94	1	2804.53	36	1.0	.3262
DFTTLLWT	309601.67	1	11276.15	36	27.5	.0001
DFAVGLWT	67782.41	1	1494.68	36	45.4	.0001
DMGRTG	26.01	1	0.44	72	59.4	.0001
PLNTHT	14.44	1	7.65	72	1.9	.1738
DRYMTR	4.80	1	0.55	72	8.7	.0043
TLRS	0.09	1	0.70	72	0.1	.7210
HDS	0.04	1	0.41	72	0.1	.7557
TTLSDWT	80712.81	1	122288.30	72	0.7	.4192
KRNLHD	0.01	1	13.12	72	0.0	.9868
SDWT1000	69.72	1	42.08	72	1.7	.2021

TABLE XIII

EXPERIMENT 2: ANALYSIS OF VARIANCE EFFECT OF LEVEL OF INFESTATION

VARIABLE	SUM OF SQUARES	DF	MEAN SQUARE ERROR	DF	F	PR > F
LARFND1	78.00	3	0.21	54	121.6	.0001
LARFND2	96.05	3	0.05	54	594.5	.0001
TTLLWT1	4326483.75	3	15566.90	54	92.6	.0001
TTLLWT2	7324325.00	3	14223.36	54	171.7	.0001
ADTTLLWT1	2147773.33	2	9707.56	36	110.62	.0001
AVGLWT1	12668.43	2	5916.09	36	1.1	.3534
AVGLWT2	40025.09	2	4908.63	36	4.1	.0254
ADAVGLWT1	20075.65	2	2804.53	36	3.58	.0382
DFTTLLWT	48250.00	2	11276.15	36	2.1	.1324
DFAVGLWT	16485.83	2	1494.68	36	5.5	.0081
DMGRTG	748.04	2	0.44	72	427.2	.0001
PLNTHT	203.24	4	7.65	72	6.6	.0001
DRYMTR	87.46	4	0.55	72	39.6	.0001
TLRS	13.70	4	0.70	72	4.9	.0015
HDS	5.44	4	0.41	72	3.3	.0150
TTLSDWT	6318874.70	4	122288.30	72	12.92	.0001
KRNLHD	53.91	4	13.12	72	1.0	.3988
SDWT1000	1653.86	4	42.08	72	9.8	.0001

TABLE XIV

EXPERIMENT 2: ANALYSIS OF VARIANCE INTERACTION BETWEEN TIME AND LEVEL

VARIABLE	SUM OF SQUARES	DF	MEAN SQUARE ERROR	DF	F	PR > F
LARFND1	0.56	3	0.21	54	0.9	.4690
LARFND2	0.05	3	0.05	54	0.3	.8184
TTLLWT1	30353.75	3	15566.90	54	0.65	.5864
TTLLWT2	94365.00	3	14223.36	54	2.2	.0973
ADTTLLWT1	48813.33	2	9707.56	36	2.5	.0950
AVGLWT1	11315.83	2	5916.09	36	1.0	.3938
AVGLWT2	33165.83	2	4908.63	36	3.4	.0452
ADAVGLWT1	27177.87	2	2804.53	36	4.85	.0137
DFTTLLWT	33903.33	2	11276.15	36	1.5	.2360
DFAVGLWT	3022.31	2	1494.68	36	1.0	.3739
DMGRTG	31.24	4	0.44	72	17.84	.0001
PLNTHT	57.53	4	7.65	72	1.9	.1233
DRYMTR	11.32	4	0.55	72	5.1	.0011
TLRS	5.26	4	0.70	72	1.9	.1235
HDS	1.16	4	0.41	72	0.7	.5895
TTLSDWT	1932404.14	4	122288.30	72	3.95	.0059
KRNLHD	109.01	4	13.12	72	2.1	.0924
SDWT1000	316.70	4	42.08	72	1.9	.1229

TABLE XV

EXPERIMENT 3: ANALYSIS OF VARIANCE
THE EFFECT OF THE VARIETIES
STURDY AND TAM-W101

VARIABLE	SUM OF SQUARES	DF	MEAN SQUARE ERROR	DF	F	PR > F
LARFND	0.49	1	0.70	74	0.7	.4069
TTLLWT	168921.00	1	215436.00	74	0.8	.3788
AVGLWT	0.01	1	0.03	74	0.0	.8501
DMGRTG	1.44	1	1.43	74	1.0	.3186
LABEF	5098.82	1	74.41	74	68.5	.0001
LAAFT	2867.07	1	559.96	74	5.1	.0266
%DEFOL	2026.25	1	681.16	74	3.0	.0888
PLNTHT	161.29	1	18.77	74	8.6	.0045
RTWT	7.59	1	0.40	74	19.0	.0001
SHWT	0.43	1	0.42	74	1.0	.3192
RSRATIO	1.42	1	0.10	74	14.0	.0004

TABLE XVI

EXPERIMENT 3: ANALYSIS OF VARIANCE THE EFFECT OF LEVEL OF INFESTATION

VARIABLE	SUM OF SQUARES	DF	MEAN SQUARE ERROR	DF	F	PR > F
LARFND	219.84	3	0.70	74	104.0	.0001
TTLLWT	15293340.00	3	215436.50	74	23.7	.0001
AVGLWT	2.85	3	0.03	74	38.0	.0001
DMGRTG	656.56	3	1.43	74	153.3	.0001
LABEF	136.80	3	74.41	74	0.6	.6082
LAAFT	33875.30	3	559.96	74	20.2	.0001
%DEFOL	35345.79	3	681.16	74	17.3	.0001
PLNTHT	1333.51	3	18.77	74	23.7	.0001
RTWT	5.68	3	0.40	74	4.7	.0044
SHWT	7.67	3	0.42	74	6.1	.0010
RSRATIO	0.61	3	0.10	74	2.0	.1182

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