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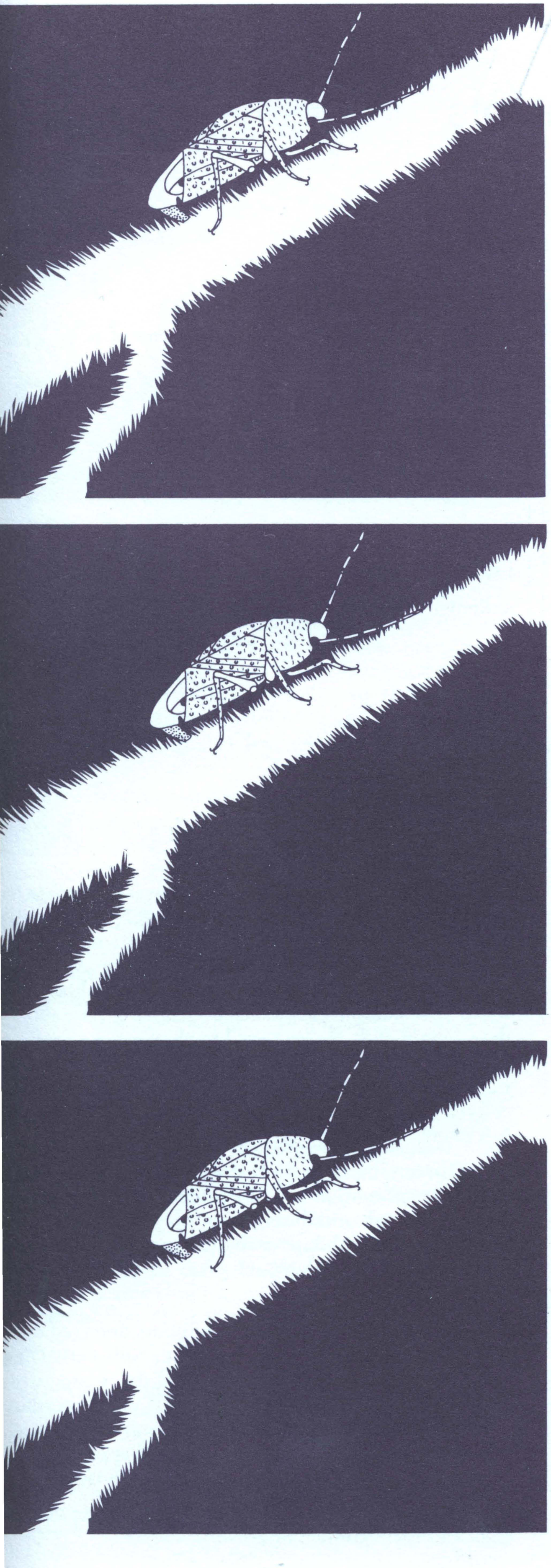

Seasonal Abundance and Dispersal of the Cotton Fleahopper

as Related to Host Plant Phenology

Contents

Summary

The cotton fleahopper poses a double threat to cotton production. One is the direct loss in yield and delayed maturity caused by the insects destroying early fruiting structures; the second is the possibility of a *Heliothis* spp. outbreak following chemical treatment aimed at the control of the cotton fleahopper.

Methods of managing the cotton fleahopper without adverse side effects and sacrificing yield and earliness of the crop are needed. Conditions determining when cotton is threatened by fleahopper migrations were studied.

The host plants of the cotton fleahopper, *Pseudatomoscelis seriatus* (Reuter), infested first during the growing season were those adjoining the previous year's croton (*Croton capitatus* Michx.) stalks, the primary overwintering host plant in the study area. Cudweed (*Gnaphalium* spp.), cutleaf eveningprimrose (*Oenothera laciniata* Hill var. *laciniata*), and croton for the current season were present. Cudweed served as a host for nymphs hatching from overwintering eggs and for subsequent generations, until plant senescence in late June.

Cutleaf eveningprimrose, not adjacent to the previous year's croton, was not infested until first generation adults were present. Initial cotton fleahopper flight activity coincided with the time the first adults were detected on the host plants. Fluctuations in numbers of adult cotton fleahoppers on cutleaf eveningprimrose corresponded to the flowering pattern of the plant — decreased flowering and fewer adults present. Cutleaf eveningprimrose was infested about 20 days longer than cudweed.

Of two groups of showy sundrops (*O. speciosa* Nutt var. *speciosa*) were studied, one was subjected to simulated mowing and the other served as a control. Showy sundrops was initially infested by adults. Apparently, reproduction and population increase was low on this host. The manipulated plants remained a host about 30 days longer than the control but they were not infested as long in the season as cutleaf eveningprimrose. The numbers of adults on showy sundrops were apparently related to the flowering pattern and percent moisture of the plant.

Horsemint (*Monarda punctata* L.) was infested after first generation adults were available, and at times supported high numbers of cotton fleahoppers. Numbers of cotton fleahoppers sharply increased with flower bud initiation and declined prior to peak flower bud production.

The numbers of cotton fleahoppers detected on cotton did not increase until squaring. Substantial flight activity in late June coincided with decreasing prevalence of cotton fleahoppers on cutleaf eveningprimrose and horsemint and increasing numbers on cotton. The infestation level on cotton was low, and apparently little reproduction and population increase occurred.

Croton served as a host plant both for overwintering eggs and throughout the growing season.

Seasonal Abundance and Dispersal of the Cotton Fleahopper as Related to Host Plant Phenology

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The cotton fleahopper poses a double threat to cotton production. One is the direct loss in yield and delayed maturity caused by the insects destroying early fruiting structures; the second is the possibility of a *Heliothis* spp. outbreak following chemical treatment aimed at the control of the cotton fleahopper. Early in the growing season, beneficial insects are particularly effective in keeping *Heliothis* spp. in check. Frequently, insecticides applied for cotton fleahopper control lower the beneficial insect population, allowing *Heliothis* spp. to increase to damaging levels (Anonymous 1973; Gaines, 1942; Ewing and Ivy, 1943; Ridgway, et al., 1967).

Methods of managing the cotton fleahopper without adverse side effects and sacrifice of yield and earliness of the crop are needed. Since plant species other than cotton are also infested by the cotton fleahopper, the various alternate host plants probably influence the cotton fleahopper infestation in cotton.

The cotton fleahopper was present in the United States in the late 1800's but did not damage cotton until 1920 (Reinhard, 1926a). Early workers soon determined that cotton was not the only and perhaps not even the preferred host of the cotton fleahopper. Wherever croton (*Croton* spp.) occurred, Reinhard (1926b) found it to be the most important host plant. Fletcher (1940) observed that large numbers of the cotton fleahopper built up on the eveningprimroses (*Oenothera laciniata* Hill and *O. speciosa* Nutt.), and horsemint (*Monarda* spp.). *Oenothera laciniata* was especially important because it was available early in spring before croton came up. During this time it grew in the rosette form and afforded excellent protection for nymphs, especially from rain. Fletcher also reported *O. speciosa* as being a favorite food and the first plant on which he found adults in the spring.

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During April and May at College Station, Reinhard (1927) found purple cudweed (*Gnaphalium purpureum* L.) and *O. laciniata* frequently infested with fleahoppers. Hixon (1941) found cotton fleahoppers on 84 species of plants, with the most important species belonging to the genera *Oenothera, Monarda, Solanum,* and *Croton*.

Some confusion, however, exists as to when cotton fleahoppers transfer from alternate host plants to cotton. Reinhard (1926b) reported that during March, when overwintering eggs began to hatch, nymphs fed on practically any succulent weeds or even grass. Soon after reaching maturity, the insects mated and began to deposit eggs primarily in croton and cotton.

Reinhard (1928) stated that cotton fleahoppers hatching from overwintering eggs comprised the early destructive infestation. When climatic conditions delayed emergence of nymphs from overwintering eggs and cotton was planted at the average date, conditions were favorable for extensive injury to crop. However, in some sections of Texas, Reinhard (1927) detected emergence of cotton fleahoppers from overwintering before either cotton or croton was available as a food plant.

Fletcher (1940) reported that horsemint differed from croton and the species of *Oenothera* in that it was more attractive to cotton fleahoppers later in its life span. The adults left as these plants matured and became less attractive. Ewing (1927) observed a distinct migration, probably from horsemint, to cotton during the first 10 days of June, which was about the time or immediately before horsemint began to mature.

Thomas (1936) noted that as alternate host plants approached maturity, many adult cotton fleahoppers migrated to more favorable host plants. This transfer of hosts began about the time cotton came up and lasted about 1 month. Gaines and Ewing (1938) stated that adult cotton fleahoppers began to drift into cotton from native food plants during April, while most of the dispersal usually occurred from about the middle of May until the first part of June.

First generation adult cotton fleahoppers infested the late spring and early summer hosts, horsemint, silverleaf nightshade (*Solanum elaeagnifolium* Cav.), and in some cases *O. lacinata*, in observations by Hixon

(1941). He believed that cotton was attacked by adults leaving these host plants.

There is apparently some disagreement on the importance of fleahopper populations developing on alternate host plants. Eddy (1927) observed that croton and species of *Oenothera* served as a reservoir and continuous source of infestations as long as the host plants were available. Cotton growing in clean fields surrounded by woods or other situations remote from alternate host plants was not infested until late in the season and then did not develop heavy infestations. In the Rio Grande Valley of Texas, Schuster et al. (1969) suggested that native host plants did not greatly increase cotton fleahopper populations before cotton was growing. The numbers of fleahoppers increased simultaneously on both native and cultivated plants, and it appeared they were infested first by adults.

There is also disagreement as to the destination of nymphs as they hatch from overwintering eggs. Reinhard (1927, 1928) considered it likely that young nymphs may be carried considerable distances by wind and spread over the surrounding territory as they hatch from overwintering eggs. Early instar nymphs were on cotton plants in fields isolated from any source of infestations (Reinhard, 1926b) early in the season before the appearance of adults. However, in preliminary tests, Reinhard could not demonstrate that nymphs were blown in the air.

Glick (1939) exposed collecting screens from an airplane for more than 1,007 hours. He captured two adult fleahoppers and one nymph at 20 feet altitude, two adults at 200 feet, two adults at 1,000 feet, and one adult at 2,000 feet. Coad (1931) reported capturing cotton fleahoppers by airplane at altitudes of up to 5,000 feet.

Hixon (1941) found that nymphs hatching from overwintering eggs in *Croton capitatus* Michx. fed mainly on plants adjacent to that species. No fleahoppers were present on the same plants growing 100 feet from old croton. Nymphs did not appear to migrate; however, the adults were distinctly migratory. Thomas and Owen (1937) stated that some of the insects newly hatched from overwintering eggs are forced to feed on almost any form of tender vegetation.

When host plants mature, Fletcher (1940) theorized that the adults leave and may disperse by flight, assisted by the wind, over wide areas. Gaines and Ewing (1938) reported that during the winter of 1933-34 about 10,000 acres of croton were destroyed in Calhoun County, Texas, in an attempt to control the fleahopper. The initial infestation the next spring was considerably less, but there was a heavy reinfestation of adult cotton fleahoppers in the area apparently from a distance of at least 20 miles. Fleahoppers moving with the wind could thus be carried long distances. Gaines and Ewing (1938) also observed that cotton fleahoppers transferring from native food plants to cotton dispersed from about mid-May until the first part of June. Balloons released in various areas of Texas during this period drifted primarily to the north and northwest.

After extensive flooding of the Mississippi River in 1927, Glick (1939) found cotton fleahoppers extremely scarce. The wild host plants were killed by the flood, and until these plants were established again, the cotton fleahopper did negligible damage to cotton in the area. Glick's data suggest that fleahoppers do not always move great distances to cotton and thus tend to disagree with the findings of Gaines and Ewing.

Since weather conditions vary from year to year, influencing cotton planting dates and plant growth, calendar dates alone probably are insufficient for predicting when cotton fleahoppers will leave their alternate host plants. A better understanding of host plant and cotton fleahopper phenology may provide a more reliable basis for determining when cotton is threatened by fleahopper migrations.

Methods and Materials

Site and Plant Selection

The study of conditions determining when cotton is threatened by fleahopper migrations was conducted on the Ellis Unit farm of the Texas Department of Corrections, located about 15 miles northeast of Huntsville, Texas. The soil types ranged from loamy sand to heavy black clay. The primary host plants detected in the area were cudweed, cutleaf eveningprimrose, showy sundrops, horsemint or spotted beebalm, woolly croton or goatweed, and commercially planted cotton (*Gossypium hirsutum* L.).

Hixon (1941) reported that cotton fleahopper nymphs hatching from overwintering eggs feed on many species of plants adjacent to the overwintering host plants. In the study area, croton was apparently the primary overwintering host; therefore, plants growing under the previous year's croton were selected for study; cudweed and croton were the predominant hosts, accompanied by a lesser amount of cutleaf eveningprimrose. For comparison, cutleaf eveningprimrose and croton growing more than 200 feet from the previous year's croton were selected. The remaining alternate host plants included in the study, horsemint, showy sundrops and cotton, were not adjacent to a source of overwintering cotton fleahoppers.

Being a common roadside and ditchbank inhabitant, showy sundrops is subject to mowing during the growing season. Plants which are mowed often produce regrowth, thus delaying maturity and senescence. To determine the effect of this development on the cotton fleahopper infestation on such host plants, two adjacent locations of showy sundrops were used. The plants at one site were clipped just below the flower bud area to simulate mowing. Plants at an adjacent site, used as a control, were not clipped.

In each of the study sites, 10 to 15 plants of each species were labeled for data collection on the same plants each inspection period. An electric fence was placed around the plots to prevent cattle from chewing the labels.

Plant phenology records of the tagged plants were taken at weekly intervals during the growing season, except during foul weather. The cotton fleahopper infestation on the various host plant species was determined by sampling 20 plant terminals (on tagged plants) twice weekly with a D-Vac® hand vacuum sampler.

As an indication of plant succulence, the percent moisture of plants of each species was determined weekly by collecting the terminal 6-8 inches from 10 plants. The bud areas with all unfolded leaves removed and the leafless stem comprised separate samples. The samples were weighed before and after oven exposure to 200° C for 24 hours.

To anticipate fluctuation in plant moisture, the percent soil moisture was determined weekly. A sample consisting of the upper half and lower half of a 12-inch deep soil core was taken at each host plant area. The percent moisture was determined by weight before and after oven exposure to 200° C for 24 hours.

Cotton Fleahopper Aerial Movement

Cotton suffers the heaviest damage from cotton fleahopper attack during the early fruiting period of plant growth. Therefore, the time of cotton fleahopper movement from the alternate host to cotton is important. Information on the seasonal flight activities may also contribute to a better understanding of cotton fleahopper host sequence.

The seasonal flight activity of the cotton fleahopper vas determined by using seven traps, each consisting of -gallon size plastic cans, placed 6 feet above ground and oated with Tacky-Trap®. The traps were located in the nmediate vicinity of various host plants and in between tes of host plant occurrence. Traps were inspected twice eekly and recoated with Tacky-Trap® as needed.

The possibility of cotton fleahopper nymphs being ansported by the wind was investigated further. Aerial amples for cotton fleahopper nymphs which may be air orne were taken in the truck-mounted net described by lmand, et al. (1975).

Samples were taken from early March until late Sep- mber on the Ellis farm. The pickup truck with net tached was not driven in the growing area of plants so as ot to disturb the plants and insects present. The collec- on route was semi-circular with about a 1-mile radius. uring heavy emergence of cotton fleahopper nymphs in e spring at College Station, Texas, additional samples ere taken downwind from overwintered croton. Num- ers of adult cotton fleahoppers captured during the sea- n were used for determining seasonal flight activity.

The response of newly hatched first instar cotton eahopper nymphs to various wind speeds also was de- rmined in a wind tunnel with a testing area of about 3 ibic feet. Nymphs less than 24 hours old which had itched from overwintering eggs (procedure developed Sterling and Plapp, 1972) were collected for testing d held in 1-gallon cartons. An overwintered stem of oton collected from the field was placed in the carton; hen nymphs had moved onto it, the stem was removed d placed in the wind tunnel test chamber. Wind ve- cities up to about 30 miles per hour (mph) could be obtained, but sudden gusts of wind could not be simulated.

Results

Seasonal Abundance

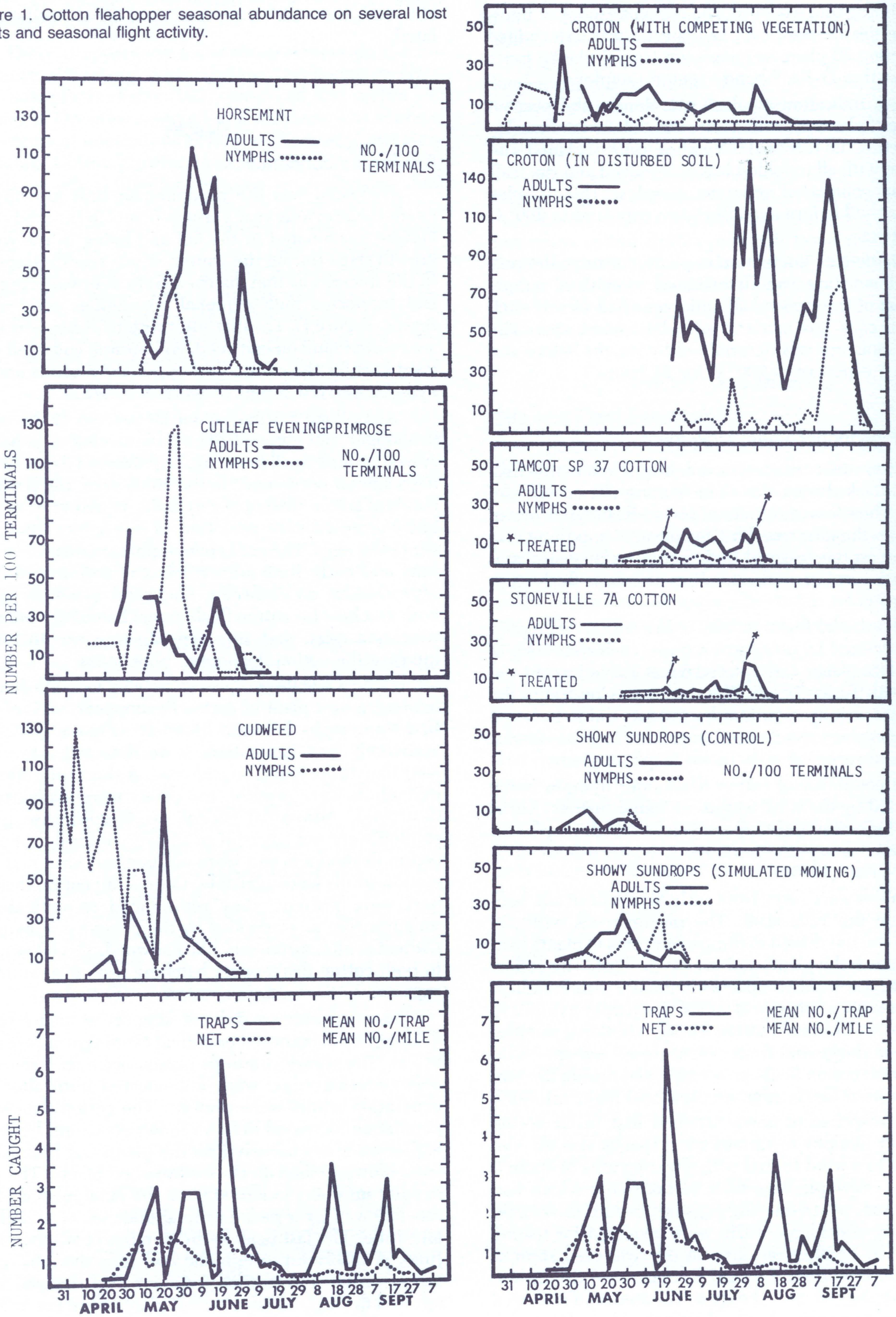
Cudweed was the predominant host growing beneath the previous year's croton plants in the study area. Having germinated in the fall and being in the rosette growth stage during the winter, it was readily accessible to the nymphs as they hatched from overwintering eggs and supported high nymphal populations early in the season (Figure 1). The first adult cotton fleahoppers in the area were found on cudweed. Apparently cudweed was a good host for the cotton fleahopper as 95 adults and 130 nymphs per 100 terminals were detected.

At College Station, about 90 percent of the cotton fleahopper emergence from overwintering eggs had occurred by mid-April (Sterling, unpublished data). Assuming a similar occurrence in the study area, the predominance of cotton fleahopper nymphs on cudweed in April likely represents the peak time of emergence from overwintering eggs. The peaks in nymphal abundance in early May and early June are evidence of cotton fleahopper reproduction on cudweed. Cudweed evidently serves both as a host for cotton fleahoppers hatching from overwintering eggs, and as a reproduction site to further increase the cotton fleahopper population.

Cutleaf eveningprimrose, growing beneath an overwintering host plant of cotton fleahoppers, was infested first by nymphs followed by adults (Figure 1). Adults, apparently first generation, were detected a few days later than those found on cudweed. A short time after the first adults were present, the plants were inadvertently destroyed. Additional cutleaf eveningprimrose plants studied were not adjacent to an overwintering source of cotton fleahoppers and were not infested until first generation adults were available. Once adult cotton fleahoppers were present, they reproduced on cutleaf eveningprimrose as evidenced by the presence of nymphs. Cutleaf eveningprimrose, like cudweed, served as a host to both cotton fleahoppers hatching from overwintering eggs and to the next generation.

Showy sundrops did not support as many cotton fleahoppers as cudweed or cutleaf eveningprimrose (Figure 1). The showy sundrops plants, not near a source of overwintering eggs, were not infested until after first generation adults were present. The cotton fleahopper population increased little on showy sundrops; however, higher numbers occurred on the plants cut back (simulated mowing) than on the undisturbed plants. The peak in adult numbers in late May on the manipulated plants was followed by a peak in the abundance of nymphs in mid-June. The last peak in the number of adults, in late June, probably represents the mid-June nymphs reaching maturity. Plants with frequent bud removal were infested throughout June; uncut plants were not infested past early June — a difference of about 3 weeks. This difference will be discussed in a later section.

Figure 1. Cotton fleahopper seasonal abundance on several host plants and seasonal flight activity.



Horsemint, also not near a source of nymphs hatching from overwintering eggs, was not infested until after the appearance of first generation adults (Figure 1). This plant was a good host for cotton fleahoppers and a site for reproduction. Although large numbers of adults were present on the host, low numbers of nymphs were present following the peak abundance in late May. The low nymphal population could have resulted from the presence of large numbers of *Orius* spp. Sampling error may also have influenced the number of nymphs detected. Cotton fleahopper nymphs predominantly inhabit the flower bud area, which, on horsemint, is very tight and affords numerous hiding places for the small insects. Since the low numbers of nymphs corresponded with the flowering pattern of horsemint, the vaccum sampler may have been inefficient in extracting the nymphs from the flower bud. Nevertheless, the presence of rather high numbers of nymphs at one time indicates the potential of cotton fleahoppers for increasing their numbers on horsemint.

On the two cotton varieties, the cotton fleahopper infestation was light and remained below damaging levels (Figure 1). The fast maturing, short season variety, Tamcot SP 37, supported somewhat higher numbers than Stoneville 7A. Tamcot SP 37 cotton seemingly was a host on which at least some reproduction and population increase occurred. The peaks in abundance of adults and nymphs possibly represent generations. It is doubtful that much reproduction occurred on Stoneville 7A cotton.

The last species of host plant included in the study, croton, not only provided overwintering quarters but also was a host throughout the growing season. The croton that grew up under the previous years' croton stalks were apparently infested first by nymphs hatching from overwintering eggs (Figure 1). A short time after the first appearance of adults, the plants were inadvertently destroyed, necessitating tagging additional plants. The second group of plants did not grow under a source of overwintering eggs and were infested first by adults. The plants were in pasture land with competing vegetation and maintained only slow growth. The highest numbers of adults detected were in late April and early May and probably represented first generation adults. Thereafter the population remained rather static and likely did not contribute to an increase in the overall cotton fleahopper population. It is also doubtful that many overwintering eggs were deposited in these host plants because the adult cotton fleahopper population was below detectible levels during the fall when overwintering eggs are deposited.

In another area of pasture, the soil was disturbed by discing, and a dense stand of croton resulted. Although this croton came up later, it grew faster and developed much larger plants than did the croton with competing vegetation. This larger, faster growing croton also supported a much larger cotton fleahopper population (Figure 1) than that undisturbed.

Seasonal Flight Activity

While neither the exact source of the adults captured in flight nor their destination was determined, a comparison of adult abundance on the various host plants with the peak times of flight may indicate which host plants cotton fleahoppers were leaving and the host plants to which they went.

The aerial net and the sticky traps yielded similar results in detecting cotton fleahopper flight. Although more cotton fleahoppers were captured on the sticky traps, the peak times of flight as determined by the two methods were in accord (Figure 1).

There were primarily five peaks of flight activity of cotton fleahoppers during the season. The first evidence of flight coincided with the detection of the first adults, first on cudweed, and a few days later on cutleaf eveningprimrose and croton. These host plants, growing under a source of overwintering cotton fleahoppers, were infested first by nymphs. The adults likely were first generation.

Flight activity during late April and early May coincided with detection of cotton fleahoppers on cutleaf eveningprimrose, showy sundrops, and horsemint not adjacent to an overwintering source. These adults undoubtedly were first generation leaving the nymphal host plants at maturity.

During mid and late May the number of adult cotton fleahoppers decreased on cudweed and cutleaf eveningprimrose and increased on showy sundrops and horsemint. Flight activity indicated that cotton fleahoppers were leaving cudweed and cutleaf eveningprimrose and going to showy sundrops and horsemint.

The relative peak abundance of cotton fleahoppers on cutleaf eveningprimrose, showy sundrops, and horsemint in mid-June was not accompanied by flight activity and probably represents reproduction on these hosts.

In late June a substantial increase in flight resulted in the greatest number of fleahoppers caught for the season. This coincided with a decrease in adult numbers on the two remaining seasonal weed hosts, cutleaf eveningprimrose and horsemint. The only known host plants remaining in July are cotton and croton.

Following a lull in July, flight activity increased in mid-August. Some cotton on the farm received insecticide treatment for *Heliothis* spp. control about this time, reducing cotton fleahopper numbers; probably they were going to croton. Although cotton fleahopper reproduction and population increase on cotton were not substantial, migration of the insects from 800 acres of cotton to fewer acres of croton could result in a heavy concentration on croton.

In early September much croton on the Ellis farm was mowed. The September peak in flight activity likely represents cotton fleahoppers leaving the mowed croton.

Aerial Movement of Cotton Fleahopper Nymphs

Cotton fleahopper nymphs were not captured in the aerial net. From early March until mid-April about 260,000 cubic feet of air was sampled. During that time about 90 percent of the nymphal emergence from overwintering eggs occurred (Sterling, unpublished data). It seems likely that if many of these nymphs were air borne, they would have been detected. Additionally, about 10 million cubic feet of air was sampled during the remainder of the season. Although high nymphal populations were in the area during the study, no air borne cotton fleahopper nymphs were detected.

In the wind tunnel, cotton fleahopper nymphs were frequently near the top of the test plant when the wind speed was low and there was no visible movement of the plants. When the wind speed increased, the nymphs tended to move to the lower portions of the plant where there was less whipping motion. At wind speeds up to about 30 mph, the cotton fleahopper nymphs were able to remain on the plant and move about.

Host Plant Phenology

Cudweed: While there are numerous reports of the various host plants of the cotton fleahopper, the more important hosts include only a few genera of plants. Cudweed was not included among the more preferred host plants; therefore, phenological data for cudweed were not considered in the original planning, and the data collected are not as detailed as desired.

Cudweed seeds germinate in the fall, and the plants are in the rosette stage until spring, when flower shoots originate from the rosette. Flower bud production on the cudweed plants was initiated in early April, and senescence occurred in late June. Cudweed was suitable as a host for feeding and reproduction during the rosette stage and through maturity.

Cutleaf Eveningprimrose: Coefficient of correlation and linear and curvilinear regression analyses were made of data pertaining to adult cotton fleahopper seasonal abundance on the various host plants, flowering pattern of the host plants, plant stem and bud moisture content, and soil moisture. Those having significance at the .05 level will be discussed.

The fluctuations in the numbers of adult cotton fleahoppers on cutleaf eveningprimrose during the growing season closely corresponded to the flowering pattern of the host plant (linear regression r = 0.85; parabolic regression r = 0.86). The adult cotton fleahopper population decreased as the number of flower buds decreased (Figure 2). The flowering pattern corresponded to the upper 6 inches of soil moisture with a lag of about 7 days (linear regression r = 0.96; parabolic regression r = 0.99). As the amount of soil moisture declined, both the number of flower buds and the number of adult cotton fleahoppers declined. When adequate soil moisture returned, flowering and the incidence of adult cotton fleahoppers increased (Figure 2).

Number of adult cotton fleahoppers and cutleaf eveningprimrose stem and bud moisture (maximum r value obtained = 0.62) were not significantly correlated. However, curvilinear (parabolic) and linear regressions were similar (r = 0.89 and 0.88 respectively) for plant moisture and soil moisture.

Showy Sundrops: Although relatively low numbers of cotton fleahoppers were detected on the showy sundrops plants, a comparison of cotton fleahopper numbers and the plant phenology data on the two groups of showy sundrops plants indicates some important occurrences (Figure 2). As mentioned earlier, showy sundrops were not infested until first generation adults were present. On the control plants, adult cotton fleahoppers reached the highest level during the peak of flower bud production. As the number of flower buds declined, so did the number of adult cotton fleahoppers and the plant moisture content. The plants were infested until senescence occurred in early June.

The flowering pattern on the manipulated showy sundrops plants and the control plants differed; the period of flower bud production was lengthened, and plant senescence was delayed about 3 weeks on the manipulated plants (Figure 2). The time of first occurrence of cotton fleahoppers was about the same on the control and manipulated plants, but the period of infestation was lengthened with the delay in plant senescence.

The peak numbers of adult cotton fleahoppers on the manipulated plants coincided with the time of highest number of flower buds; however, the adult cotton fleahopper numbers declined prior to a reduction in flowering (Figure 2). Numbers of adult cotton fleahoppers declined as plant moisture decreased.

For showy sundrops, both manipulated and control plants, results indicate that both flowering pattern and plant moisture influence the incidence of adult cotton fleahoppers. On the manipulated plants, the number of adult cotton fleahoppers decreased when flower bud production was still high but plant moisture was decreasing. Later, increased plant moisture content was accompanied by a reduction in flowering without a subsequent rise to previous levels in the number of adult cotton fleahoppers.

On the control plants, plant moisture and flower bud production decreased, coincidental with a decline in adult cotton fleahopper population. A subsequent short term increase in plant moisture was accompanied by a continual decrease in flowering and continued low incidence of adult cotton fleahoppers.

Regression analysis showed a parabolic relationship between plant moisture and the upper 6 inches soil moisture content (mean r = 0.89). Plant moisture had a delay response of about 14 days to decreasing soil moisture; in cutleaf eveningprimrose, the delay response was about 7 days. The difference in the delay responses of the two *Oenothera* species was likely due to soil type: cutleaf eveningprimrose was growing in a loamy sand and showy sundrops in a clay type soil. Clay soil has a slower rate of penetration and percolation and a greater water-holding capacity than sandy soil.

Horsemint: Cotton fleahopper numbers on horsemint did not closely follow the flowering habits of the

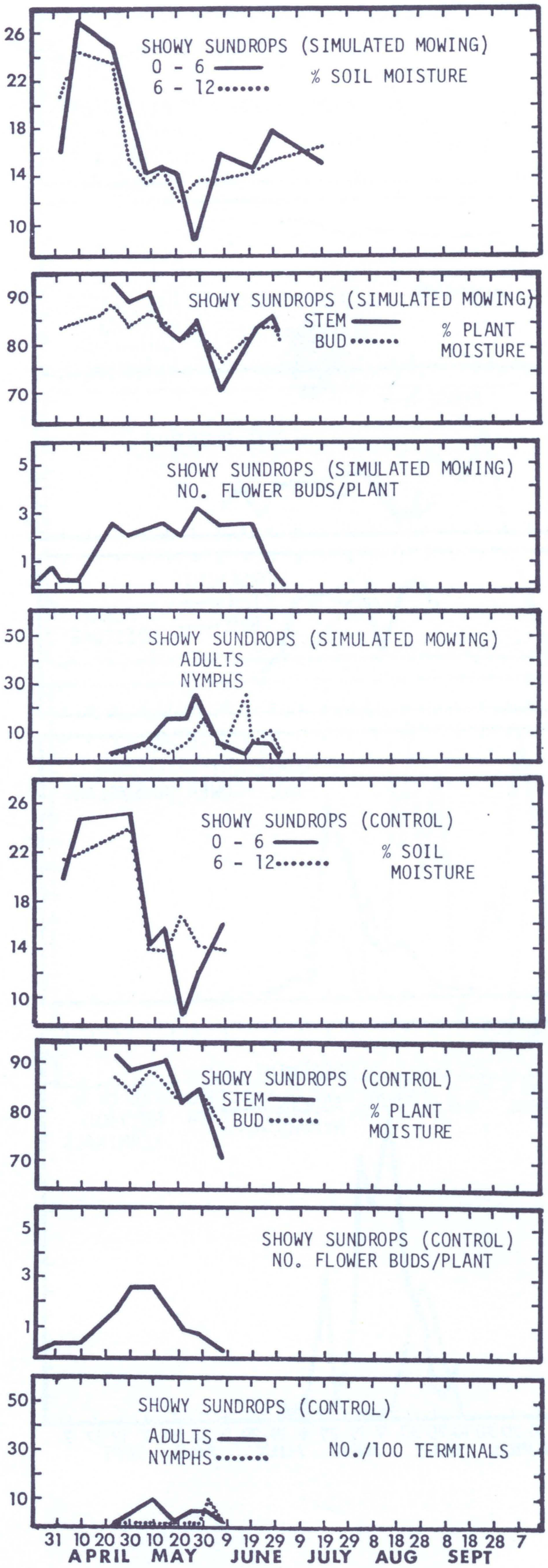
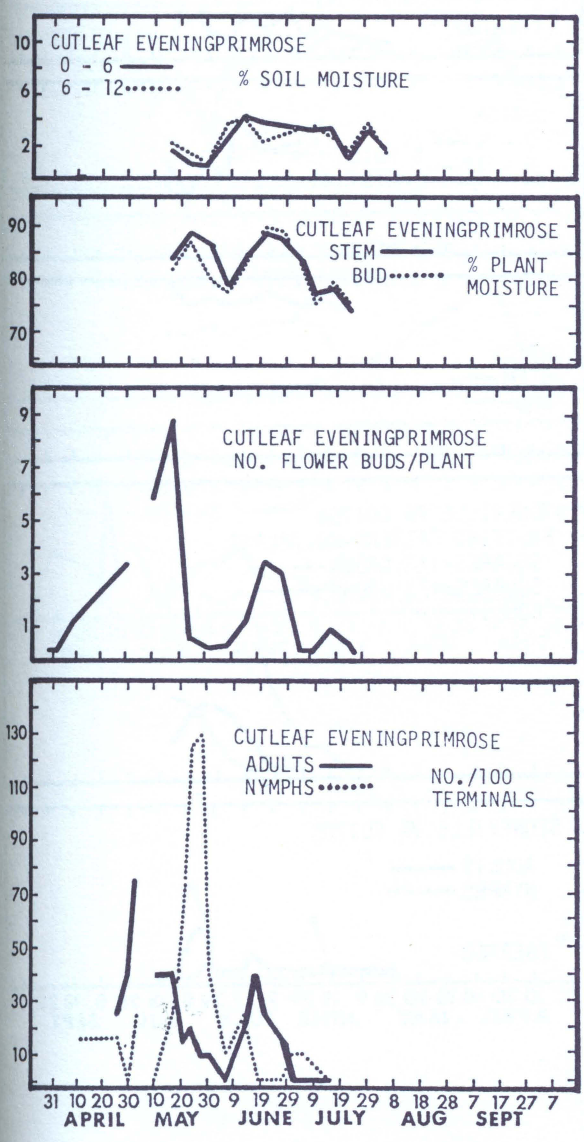


Figure 2. Comparison of host plant phenology, plant moisture, soil moisture, and cotton fleahopper seasonal abundance.



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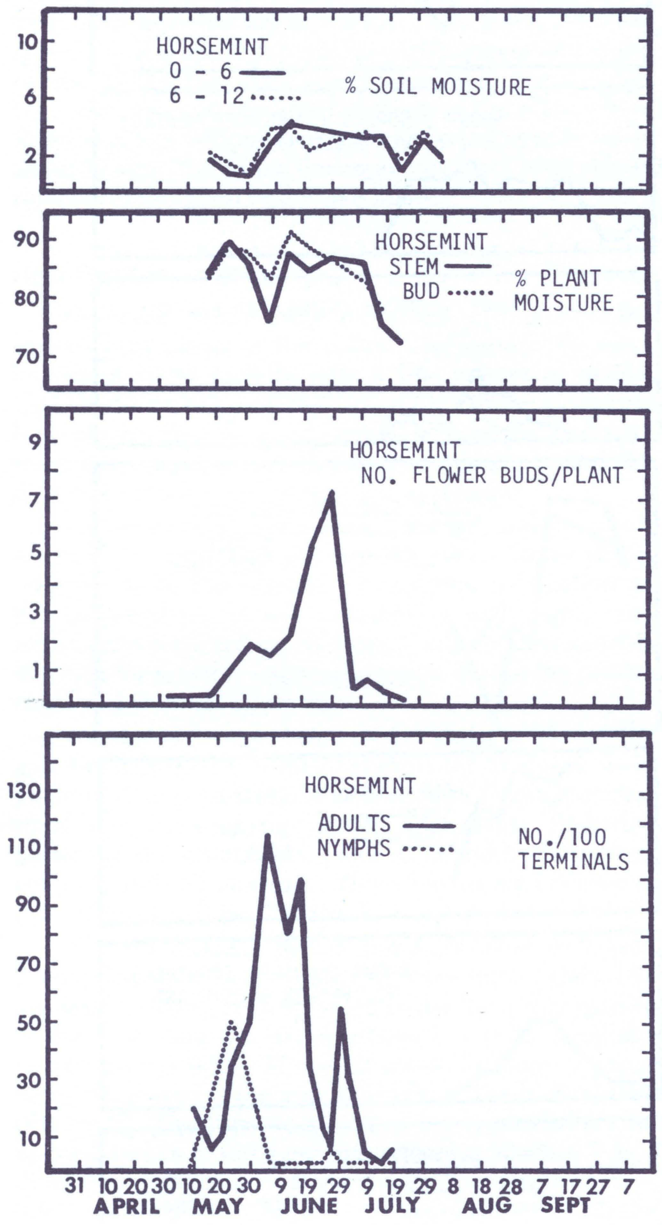

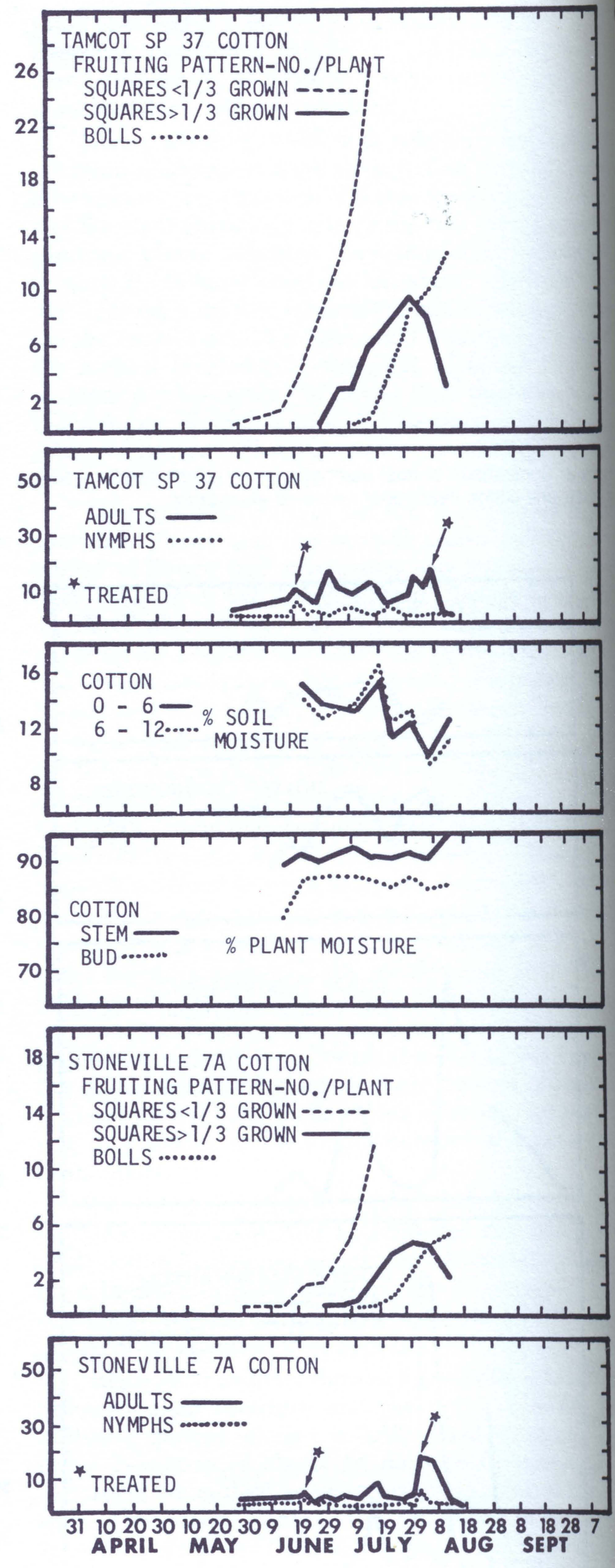

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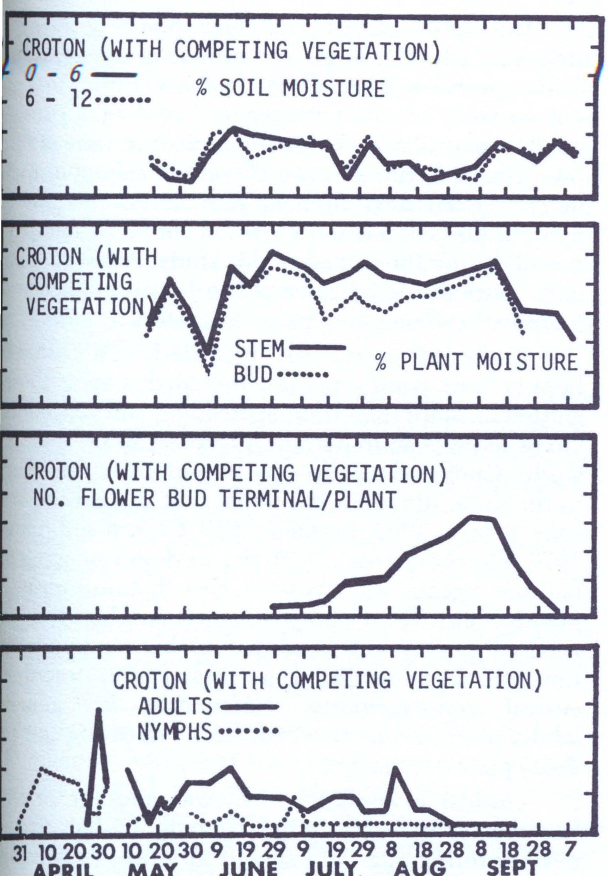

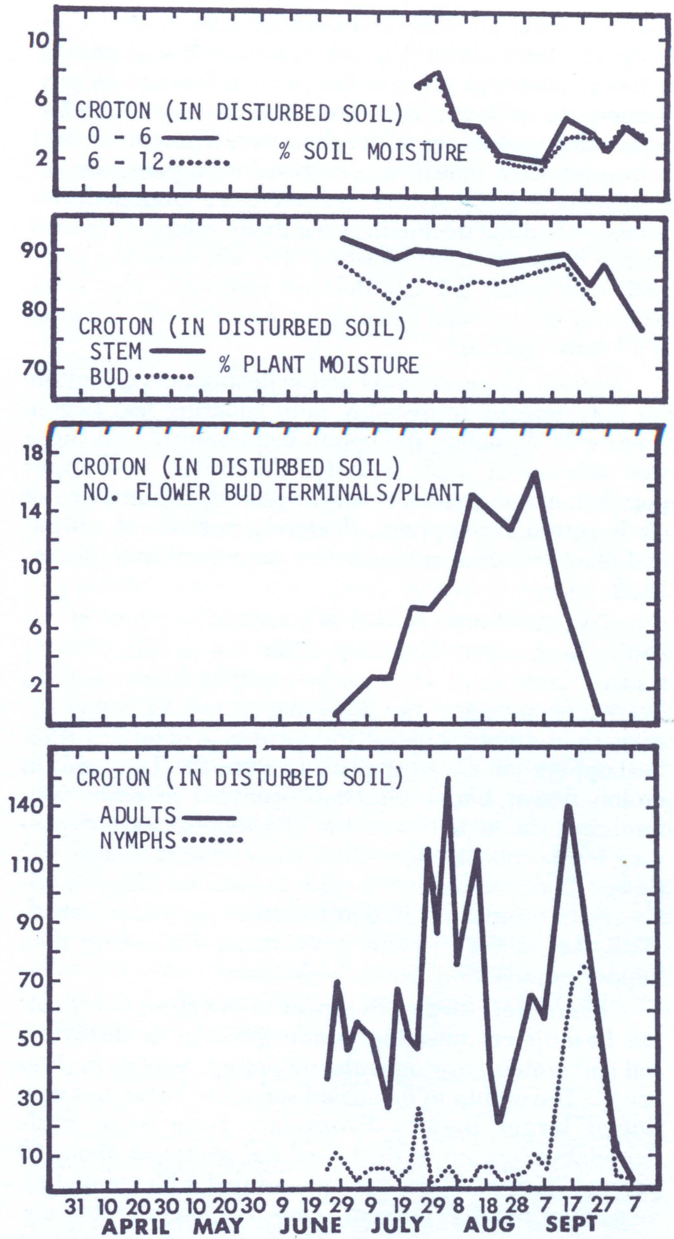

plant (Figure 2). The numbers of insects increased sharply at the time of flower bud initiation; the peak in numbers occurred prior to the peak in flower bud production. There was a significant inverse correlation between the prevalence of adult cotton fleahoppers and horsemint stem moisture, described by a parabolic regression (r = 0.75). As the stem moisture increased, the number of adults declined. A parabolic relationship also existed between stem moisture and soil moisture (r = 0.85) with about a 7-day delayed response. This is an expected relationship since the horsemint was growing in a loamy sand soil.

Cotton: The number of cotton fleahoppers on cotton did not increase appreciably until squaring had begun (Figure 2). Although the cotton had emerged and there was substantial flight activity, the cotton fleahopper population remained low until squaring. Abundance of adult cotton fleahoppers, flowering pattern of cotton, and plant moisture content were not significantly correlated.

Croton: Croton served as a season-long host of the cotton fleahopper. Growing under the previous year's stalks, plants were infested by nymphs hatching from overwintering eggs. The flowering pattern of croton apparently did not influence the incidence of adult cotton fleahoppers on the host plant (Figure 2). The peak in croton flower bud production occurred in early September at the same time cotton fleahoppers were depositing overwintering eggs. Both plant stem moisture and flower bud production began to decline about mid-September, indicating the initiation of plant senescence. With the advent of plant senescence, the cotton fleahopper population drastically declined.

There were large differences in the numbers of cotton fleahoppers infesting croton growing in disturbed soil and croton growing with competing vegetation (Figure 2). The croton in disturbed soil grew faster and produced larger plants. From late June until mid-September, croton in disturbed soil averaged about 89 percent stem moisture content and that with competing vegetation about 87 percent. Thus, the larger croton was somewhat more succulent. There were no significant statistical correlations among abundance of cotton fleahoppers, plant moisture, and flower bud production on croton. Plant moisture was significantly related to the upper 6 inches of soil moisture (parabolic regression r = 0.76) with about a 7-day delayed response. The croton was growing in a sandy soil.

Host Sequence

The host plants infested first in the season were those in the immediate proximity to a source of overwintering cotton fleahoppers; others were not infested until first generation adults were present.

Cudweed apparently served as an acceptable host until after early June; then the cotton fleahopper population declined on this host. Cutleaf eveningprimrose remained succulent about 20 days longer than cudweed; then cotton fleahopper numbers declined and plant maturity increased. Showy sundrops subjected to simulated mowing served as a host about 10 fewer days than cutleaf eveningprimrose; the control showy sundrops ceased as a host about 20 days before the manipulated plants, serving as a host for the shortest time. Considering only the seasonal weed host plants, horsemint sustained cotton fleahoppers later in the season than the other spring weeds but only about 1 week longer than cutleaf eveningprimrose. Croton served as a host throughout the season.

Discussion

The data indicate that host plants growing immediately adjacent to an overwintering source of cotton fleahoppers are infested first in the season. Host plants not so situated are not infested until first generation adults are available. These differences in time of infestation, coupled with absence of cotton fleahopper nymphs in the aerial net, suggest that aerial movement of nymphs was not a major means of cotton fleahopper dispersal during the period of this study. Adults are apparently responsible for most of the transfer of cotton fleahoppers from one host plant to another.

Cudweed, previously recorded as a cotton fleahopper host plant, was not included among those regarded as more important for feeding and reproduction. Cudweed was an important host plant in the area of this study. Cudweed can be very important in that it occurs in the same situations as croton; that is, disturbed sandy soils (Steere, 1969; Fernald, 1950; Correll and Johnston, 1970; Fletcher, 1940). With the seeds germinating in the fall and producing a rosette growth until spring, the plants could afford nymphs, newly hatched from overwintering eggs, with readily available food and protection, the same conditions as Eddy (1927) described for cutleaf eveningprimrose. Additionally, first generation adults produce on cudweed, thus increasing the cotton fleahopper population.

Cutleaf eveningprimrose was another important host plant. It was infested by nymphs hatching from overwintering eggs and served as a host to subsequent adults for reproduction. Like cudweed, cutleaf eveningprimrose germinates in the fall, producing a rosette-type growth, and occurs in the same situations as croton (Fletcher, 1940; Schuster et al., 1969; Steere, 1969; Reeves and Bain, 1947). Therefore, cutleaf eveningprimrose frequently would be found under overwintered croton stalks and would be immediately available to cotton fleahopper nymphs hatching from overwintering eggs.

The number of cotton fleahoppers present on cutleaf eveningprimrose apparently was influenced by the flowering pattern of the plant. A decrease in flower bud production was accompanied by a decrease in numbers of adult cotton fleahoppers. Flowering in cutleaf eveningprimrose was in turn influenced by the upper 6 inches of soil moisture. Being prevalent in sandy soils, which have low waterholding capacities, cutleaf eveningprimrose is subjected to fluctuations in soil moisture, depending upon the rainfall pattern. With fluctuations in soil moisture, the flowering pattern fluctuates which, in turn, produces oscillations in the adult cotton fleahopper numbers. The soil moisture could possibly be a prediction device for adult cotton fleahopper abandonment of cutleaf eveningprimrose until the plant reaches senescence in early summer.

The potential for increase of the cotton fleahopper population was not as great on showy sundrops as on the other early season host plants. Like cutleaf eveningprimrose and cudweed, showy sundrops germinates in the fall and produces a rosette-type growth until spring; however, it does not abound in the same habitat as cutleaf eveningprimrose, cudweed, and croton. Showy sundrops occurs later in disturbed soils (Fletcher, 1940); therefore, it would not be readily available to nymphs hatching from overwintering eggs. Data indicate that showy sundrops was apparently infested first by adults. Being prevalent during the same time of the season as cudweed and cutleaf eveningprimrose, yet not infested until first generation adults were present, showy sundrops has less likelihood of hosting cotton fleahopper population increase. However, removal of flower buds (simulated mowing) delayed senescence and lengthened the time showy sundrops was available as a host. Thus, the mowing of roadsides may increase the numbers of fleahoppers in the area.

The incidence of adult cotton fleahoppers on showy sundrops was related to plant moisture and the flowering pattern of the plant. These in turn were influenced by soil moisture. A delay of about 14 days in the response of the plant to changing soil moisture was apparently due to the clay soil type. As with cutleaf eveningprimrose, it may be possible to monitor soil moisture and plant conditions and predict when cotton fleahoppers will leave showy sundrops. However, senescence of these plants in early summer even in the presence of adequate soil moisture would complicate these predictions.

Apparently, horsemint was more suitable as a cotton fleahopper host plant later in the season when compared to cudweed, cutleaf eveningprimrose, and showy sundrops. Although horsemint was infested prior to flowering, the prevalence of adult cotton fleahoppers sharply increased as flowering increased. This is similar to observations by Fletcher (1940) that horsemint was more attractive to cotton fleahoppers later in its life pan.

Where croton is an important overwintering host, orsemint is unlikely to be an important host of nymphs atching from overwintering eggs. The two plant species e unlikely to be prevalent in the same immediate icinity at the same time. Croton is more abundant in eshly disturbed soil (Fletcher, 1940; Hixon, 1941), hereas horsemint is more abundant in areas fallow for veral years, and fluctuations in abundance seem to be lated to abundance of rainfall (Fletcher, 1940).

Adult cotton fleahoppers did not leave horsemint as owering declined but prior to peak flower bud producon. Fletcher reported that adult cotton fleahoppers left orsemint as the plants matured and became less attracve. In the current study, the plants had not reached maturity when the adults left, but some seed had begun to mature at the sites of the first flowers on the lower portions of the plants, which possibly could be interpreted as approaching maturity. Ewing's (1927) findings that adult cotton fleahoppers left horsemint about the time or immediately before horsemint began to mature appear to be more in agreement with the current findings.

Croton appeared in nearly pure stand in freshly disturbed soil and the plants, when compared with those in competing vegetation, grew quite large. In areas where grass was dominant, Fletcher (1940) reported few croton plants, and those small. The current findings were in agreement with those of Fletcher; in addition, more cotton fleahoppers were present on the plants in disturbed soil than on those in competing vegetation.

Although the adult cotton fleahopper population on croton (in disturbed soil) fluctuated considerably, the numbers of nymphs remained rather constant until early September when the numbers increased rapidly. Rainfall may have been influential in this sharp increase. Gaines (1933), reporting a sharp increase in the adult cotton fleahopper population on croton during the fall of 1931 and 1932, attributed the increase to rainfall which produced added plant growth, affording an ideal place for feeding and breeding. Reinhard (1926b) reported that rainfall was required for nymphal emergence from overwintering eggs. In the present study, the eggs from which the nymphs hatched in September could have been deposited earlier in the growing season but did not hatch because of lack of rainfall. Such may have been the case with Gaines' findings, although nymphal reccords were not presented. Rainfall could have induced a hatch of cotton fleahopper eggs subsequently reflected in the adult records (Gaines, 1933).

Gaines' (1933) data also suggest that croton is a doubtful source in contributing many cotton fleahoppers to the population on cotton. While croton is an important host plant of the cotton fleahopper, particularly for overwintering purposes, current data also indicate that cotton fleahoppers did not move into cotton from croton. Being one of the two remaining host plants at the time of movement into cotton, croton likely was competing with cotton for the cotton fleahopper population.

Cotton fleahoppers that infested cotton probably came primarily from horsemint and the species of *Oenothera*. The source of cotton fleahoppers moving into cotton, however, can be influenced by several factors. Apparently, large cotton fleahopper numbers do not appear on cotton until the initiation of squaring (initiate flower buds), which is also the time when cotton is very susceptible to fleahopper damage. Such was the case reported herein and reported by Gaines (1933). Gaines detected emergence of cotton fleahoppers from overwintering eggs during March and April of 1931 before cotton was up to a stand, which occurred in May 1931. According to his data, the cotton fleahopper population in cotton did not increase until early June, which likely corresponded to the initiation of squaring.

Although cotton in the current study was planted later than normal, since it was delayed by cool, wet conditions, the other alternate host plants likely progress in the same proportions each year. Had the cotton been planted, for example, 30 days earlier, cotton fleahoppers could have moved from cudweed as well as from the eveningprimroses and horsemint into cotton. The movement into cotton would also have been more prolonged.

The length of time a spring host plant is infested with cotton fleahoppers would be determined by existing weather conditions. Lack of adequate moisture would reduce the length of the infestation period by causing a decrease in plant moisture and flowering, forcing cotton fleahoppers to leave the host plant. The stage of development of cotton at this time would determine the source of cotton fleahoppers and the severity of the infestation.

The time of cotton fleahopper emergence from overwintering eggs also could influence the source of cotton fleahoppers infesting cotton. With adequate soil moisture, the alternate host plants could develop, but without adequate precipitation, overwintered cotton fleahopper eggs would not hatch. Conditions favorable for overwintered egg hatch would determine the time of entry of cotton fleahoppers into the host sequence and in turn influence the infestation on cotton.

Lack of rainfall could influence the abundance of alternate host plants and have a definite effect on the severity of the cotton fleahopper problem in cotton. During the study, lack of rainfall was not a problem. There was an abundance of host plants; however, by the time cotton began squaring and was infested by cotton fleahoppers, croton was the only wild host plant remaining attractive. Thus, after the initial movement into cotton, there was not a source of subsequent movement. Gaines (1933) reports similar circumstances in 1931. In early season, numbers of cotton fleahoppers infesting croton and caught on traps by Gaines remained rather steady until early June when they increased to a peak and then sharply declined. The numbers in cotton did not increase until shortly after the decline in numbers of cotton fleahoppers on weed hosts, probably coinciding with the initiation of squaring. Gaines stated that damaging infestations on cotton did not develop. Although Gaines reported the numbers of cotton fleahoppers caught on traps around fields of croton, his records probably also reflect cotton fleahoppers associated with other alternate host plants which occur in the same habitat as croton.

Gaines' data indicate that when there is a lack of alternate host plants, heavy infestations of cotton fleahoppers in cotton can be expected, a conclusion supported by Thomas and Owen (1937). The data of both the present and the Gaines' studies indicate that when alternate host plants are available, the time of squaring of cotton determines from which host plants the cotton fleahoppers will move into cotton and possibly the severity of the infestation. If initiation of squaring occurs before cotton fleahoppers leave the various alternate host plants, alternate host plants are competing for the cotton fleahoppers, and a prolonged movement into cotton can be expected. When cotton initiates squaring at the end of the early season host sequence or when lack of plant moisture forces the cotton fleahoppers to leave the weed host plants, a sudden movement into cotton will be likely, possibly resulting in heavy infestations in cotton.

Literature Cited

Almand, L. K., W. L. Sterling, and C. L. Green. 1975. A collapsible truck mounted aerial insect net. Tex. Agric. Exp. Stn. MP-1189.

Anonymous. 1973. Suggestions for controlling cotton insects in north Texas, blacklands and Gulf coast counties of Texas. Tex. Agric. Ext. Ser. L-218.

Coad, B. R. 1931. Insects captured by airplane are found at surprising heights. USDA Yearb. 1931. p. 320-3.

Correll, D. W., and M. C. Johnston. 1970. Manual of the Vascular Plants of Texas. Texas Research Foundation. Renner, TX. 1881 p.

Eddy, C. O. 1927. The cotton fleahopper. S. C. Agric. Exp. Stn. Bull. 235. 21p.

Ewing, K. P. 1927. Seasonal history and host plants of the cotton fleahopper. USDA mimeographed report. p. 22-29.

Ewing, K. P., and E. E. Ivy. 1943. Some factors influencing bollworm populations and damage. J. Econ. Entomol. 36:602-6.

Fernald, Merritt Lyndon. 1950. Gray's Manual of Botany. American Book Co. New York. 1632 p.

Fletcher, R. K. 1940. Certain host plants of the cotton fleahopper. J. Econ. Entomol. 33:456-9.

Gaines, J. C. 1933. A study of the cotton fleahopper with special reference to the spring emergence, dispersal and population. Ibid. 26:963-71.

— 1942. Effects of boll weevil control and cotton aphid control on yield. Ibid. 35:493-5.

Gaines, J. C., and K. P. Ewing. 1938. The relation of wind currents, as indicated by balloon drifts, to cotton fleahopper dispersal. Ibid. 31:674-7.

Glick, P. A. 1939. The distribution of insects, spiders and mites in the air. USDA Tech. Bull. 673. 150 p.

Hixon, Ephriam. 1941. The host relation of the cotton fleahopper. Iowa St. Coll. Jour. Sci. 17:66-8.

Reeves, R. G., and D. C. Bain. 1947. Flora of south central Texas. W. M. Welch Mfg. Co. Chicago. 298 p.

Reinhard, H. J. 1926a. The cotton fleahopper. Tex. Agric. Exp. Stn. 339. 39p.

— 1926b. Control of the cotton fleahopper in Texas. Tex. Agric. Exp. Stn. Cir. 40. 8 p.

— 1927. Control and spring emergence of the cotton fleahopper. Tex. Agric. Exp. Stn. - 356. 32 p.

— 1928. Hibernation of the cotton fleahopper. Ibid. 377. 26 p.

Ridgway, R. L., P. D. Lingren, C. B. Cowan, Jr., and J. W. Davis. 1967. Populations of arthropod predators and *Heliothis* spp. after applications of systemic insecticides on cotton. J. Econ. Entomol. 60:1012-15.

Schuster, Michael F., Clyde A. Richmond, J. C. Boling, and Harry M. Graham. 1969. Host plants of the cotton fleahopper in the Rio Grande Valley: phenology and hibernating quarters. Ibid. 62:1126-9.

Steere, William C. (ed.). 1969. Wild Flowers of the United States. Vol. 3. Texas. McGraw-Hill Book Co. New York. 553 p.

Sterling, Winfield, and F. W. Plapp, Jr. 1972. Insecticide dosage mortality studies on the cotton fleahopper. Tex. Agric. Exp. Stn. PR-3091. 9 p.

Thomas, F. L. 1936. Control of the cotton fleahopper. Tex. Agric. Exp. Stn. Circ. 77. 8 p.

Thomas, F. L., and W. L. Owen, Jr. 1937. Cotton fleahopper, an ecological problem. J. Econ. Entomol. 30:848-50.

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