

A REVIEW OF THE SPIDER-MITE
PROBLEM ON GRAIN SORGHUM
AND CORN IN WEST TEXAS

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Summary and Conclusions

1. Intensive investigations during the 1972 and 1973 growing seasons revealed four species of spider-mites infesting corn and grain sorghum in West Texas. These were: Banks grass mite, *Oligonychus pratensis* (Banks); grass mite, *O. stickneyi* (McGregor) (corn only); two spotted spider-mite, *Tetranychus urticae* Koch; and carmine spider-mite, *T. cinnabarinus* (Boisduval) (grain sorghum only). Banks grass mite was the most frequent species encountered on both crops.
2. The recent wave of spider-mite outbreaks on grain sorghum and corn in West Texas is apparently the indirect result of the evolution (or importation) of a genetic race (biotype) of spider-mites (presumably *O. pratensis*) which can utilize these host plants more efficiently.
3. Spider-mite outbreaks are closely correlated with reproductive maturity in the plant and appear to be separated, temporally and spatially, from populations of effective natural enemies. Available evidence indicates that, in general, infestations need not be aggravated by pesticides in order to qualify as economic disasters.
4. Because of the genetic adaptability of spider-mite populations, those artificial control measures (including those directed to other pests) which can impose harsh selective pressure (e.g., chemical acaricides and/or insecticides, resistant host plants, sprinkler irrigation) on the population should not be expected to provide a long-term solution to the problem. These techniques should be exploited to provide a short-term remedy until more sophisticated management techniques (particularly integration of these with biological control) can be developed.
5. It is suggested that future research be directed toward developing a theoretical perspective for the grain sorghum agro-ecosystem in order to insure a scientifically expedient approach to developing pest-management programs.
6. Finally, unless a well founded research program is realized, profitable grain-sorghum production on the High Plains of West Texas may suffer the same devastation from spider-mites as did the El Paso area.

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A Review of the Spider-Mite Problem on Grain Sorghum and Corn in West Texas

L. E. Ehler*

Spider-mites (Acari:Tetranychidae) have recently become severe pests of grain sorghum (*Sorghum bicolor* (L.) Moench) and corn (*Zea mays* (L.)) in the Trans-Pecos and High Plains of Texas. In certain areas (e.g., El Paso Valley) some growers have refrained from planting these crops because of the attendant spider-mite problem. Furthermore, it appears that the spider-mite problem has grown more severe each year throughout West Texas.

Intensive investigations during the 1972 and 1973 growing seasons revealed that this situation was more complex than originally suspected and that a different, more fundamental approach was needed for providing an ecologically sound and economically rewarding solution. The purpose of this paper is to summarize the available knowledge germane to the situation and to suggest directions for future research to follow. Also, certain theoretical explorations relative to pest management in the sorghum agroecosystem are presented.

History of Spider-mite Outbreaks

Trans-Pecos

Pate and Neeb (1970, 1971) summarized the history of spider-mite outbreaks on corn, grain sorghum and forage sorghums in the Trans-Pecos area, especially El Paso, Reeves and Pecos Counties. The spider-mites in question were presumably Banks grass mite [*Oligonychus pratensis* (Banks)], although other species could have been involved (Ehler, 1973).

Spider-mites reached pest status on corn in 1967 and on grain sorghum in 1968. Similar outbreaks occurred on both crops in 1969 and have continued through the present. Pate and Neeb also reported that spider-mites were difficult to control with stan-

dard insecticides and acaricides although they presented no direct evidence to indicate spider-mite resistance to these materials.

A concomitant decline in grain sorghum production in this area was reported by Ward (1973) who speculated that a major cause for this was the lack of successful chemical control of spider-mites. Ward also noted that spider-mites in this area may possess genetic resistance to the available chemical acaricides and insecticides.

High Plains

Outbreaks of spider-mites were first reported on grain sorghum on the High Plains in 1967 (Huddleston *et al.*, 1968) and have increased in severity since then (C. R. Ward, personal communication). The intensity of spider-mite infestations on the High Plains has generally been less than in the Trans-Pecos region.

Several chemical acaricides and insecticides have been effective in controlling spider-mites on grain sorghum (Ward *et al.*, 1972; Teetes, 1973) although the degree of control is often erratic. Ward *et al.* (1971) presented limited evidence which indicated spider-mites were developing resistance to pesticides although no direct evidence is available to corroborate this conjecture.

High Plains grain sorghum is especially in danger of spider-mite outbreaks since the average crop usually receives at least one application of organo-phosphate insecticide for control of greenbug [*Schizaphis graminum* (Rondani)] and/or corn leaf aphid [*Rhopalosiphum maidis* (Fitch)]. These treatments have, in general, been made since 1968 when explosive outbreaks of greenbug first occurred. Thus, aphid control could yield the attendant phenomena of resistance and secondary outbreaks of spider-mites.

Taxonomic Considerations

Ehler (1973) demonstrated that spider-mites on grain sorghum and corn, previously considered to be Banks grass mite [*Oligonychus pratensis* (Banks)], could in fact be other species or represent multiple-species infestations. Since different species of spider-mites may show differing susceptibilities to acaricides (Smith and Bryan, 1951; Leigh, 1963) and

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because different species on the same host may inflict different kinds of damage to plants (Flaherty and Huffaker, 1970), it is necessary to obtain proper identification of the spider-mites in order to control, observe or experiment with them. It is the purpose of the following sections to describe suitable techniques for preparing spider-mites for study and to present keys and diagnostic characters for separating species encountered on grain sorghum and corn in Texas.

Preparation of Specimens

Spider-mites can be collected and stored in either lacto-phenol (3 parts lactic acid, 1 part phenol crystals) or in ethyl alcohol. Specimens should be mounted in a modified Hoyer's medium (Pritchard and Baker, 1955) which can be obtained by mixing the following ingredients in sequence:

Distilled water50 grams
Gum arabic (flakes)30 grams
Chloral hydrate200 grams
Glycerine20 grams

Specimens are usually mounted according to their sex. Females should be mounted dorso-ventrally whereas males must be mounted laterally for proper study of the aedeagus. The latter process is easily accomplished by placing a 22 mm² coverslip on the preparation and, while observing the specimen under the microscope, gently sliding the coverslip in the proper direction until the specimen's aedeagus is in proper lateral profile. For semi-permanent mounts and to facilitate use of the oil-immersion objective, preparations should be placed on a hot plate or slide warmer and kept ca. 50°C until the medium has hardened. Finally, the mount can be ringed, preferably with Glyptal®, for further protection. Specimens should be examined with the aid of a phase-contrast microscope although most diagnostic features can be discerned with a light microscope. Boudreaux and Dosse (1963a) recommend an alternative method for preparing *Tetranychus* females for study; however, the above described technique is usually adequate.

Diagnosis

The systematic position of spider-mites has been described by Pritchard and Baker (1955) and can be summarized as follows: spider-mites belong to the family Tetranychidae which consists of those prostigmatid mites having the paired basal segments of the chelicerae fused into the pouch-like lobe (stylophore) in which are anchored the proximal ends of the movable digits or stylets (Tetranychoida) and in which the fourth palpal segment bears a distinct thumb-claw process and the dorsum of the body bears not more than 16 pairs of setae. These characteristics can be used to separate spider-mites from other groups of mites.

Identification

Since, during 2 years of intensive surveys, only four species of spider-mites have been collected on

corn and grain sorghum in Texas (Ehler, 1973), a simple key, presented below, should serve to distinguish specimens of those species. A detailed account of the morphology of spider-mites has been given by Pritchard and Baker (1955) and is not presented here; illustrating material from their work is referred to as needed, however. *Oligonychus* males are required for species determinations whereas *Tetranychus* females are adequate for identification to species level.

Key to Species of Spider-Mites Known to Occur on Corn and Grain Sorghum in Texas¹

- Empodium claw-like and equal in length to proximo-ventral hairs (Figure 305); peritreme straight distally and ending in a simple bulb(*Oligonychus*) 2
Empodial claw shorter than proximo-ventral hairs, often not visible (Figure 387); peritreme recurved distally (Figure 3)(*Tetranychus*) 3
- Knob of (male) aedeagus not over ¼ as long as dorsal arm of shaft (Figure 306) *pratensis* (Banks)
Knob of aedeagus ca. ⅓ as long as dorsal arm of shaft (Figure 297)*stickneyi* (McGregor)
- Color of live summer females green (usually with 2 dark food spots); dorsal integumentary folds (striae) bearing semi-oblong lobes; eggs usually white*urticae* Koch
Color of live summer females carmine, often with 4 dark spots; dorsal integumentary folds bearing triangular lobes; eggs usually with a trace of red*cinnabarinus* (Boisduval)

Biological Notes

Oligonychus pratensis (Banks), Pritchard and Baker (1955)

Commonly known as Banks grass mite (others include date mite and timothy mite), *O. pratensis* was originally described as *Tetranychus pratensis* (Banks, 1912) from timothy grass near Pullman, Washington. Other names include *Paratetranychus pratensis* Banks, *P. simplex* Banks, *P. heteronychus* Ewing, and *Tetranychus simplex* Banks. Pritchard and Baker (1955) proposed the new combination *Oligonychus pratensis* (Banks).

Diagnosis. Pritchard and Baker (1955) state that in *O. pratensis* the distal knob (or enlargement) of the aedeagus is ca. twice the width of the stem of the knob, the axis of the knob forms a distinct angle with the axis of the shaft, the dorsal margin of the knob is nearly straight with the tip slightly down or curved or angulate, the anterior projection of the knob is bluntly angulate, the posterior angulation acute and there is no constriction of the shaft. The knob is ca. ¼ the length of the dorsal arm of the shaft, whereas, it is ⅓ the length of the dorsal arm in *O. stickneyi*. Also, the knob is smaller than in *O. stickneyi*. In males, the

¹Figures refer to those in Pritchard and Baker (1955); illustrations of *T. urticae* and *T. cinnabarinus* are in Boudreaux (1956) and Boudreaux and Dosse (1963a).

proximo-ventral hairs of tarsus I are fused to form a claw-like structure. Females of *O. pratensis* and *O. stickneyi* are indistinguishable.

Distribution. Banks grass mite (BGM) has been collected throughout the corn and grain sorghum producing regions of Texas, including the Rio Grande Valley (Walter and Wene, 1956; Dean, 1957), and Trans-Pecos, High Plains and Central Texas (Ehler, 1973). Pritchard and Baker (1955) reported that BGM occurred in California, Oregon, Washington, Utah, Kansas, New Mexico, Louisiana and Florida. Additional records include Missouri (Thewke and Enns, 1970), Arizona (Tuttle and Baker, 1964), and Georgia (Flechtmann and Hunter, 1971). Records from outside the U.S. include Mexico (Beer and Lang 1958, Estebanes and Baker, 1966), Central America (Baker and Pritchard, 1962), and South Africa (Meyer and Ryke, 1959).

These records indicate that BGM is perhaps native to North America although this conclusion remains tentative until the tetranychid fauna of South America, other areas of Africa and Asia are more thoroughly described. The South African record would then represent an introduction from North America. Present evidence substantiates this hypothesis, i.e., BGM was not collected in Mauritius and the Congo (Baker and Pritchard, 1960), not in the Philippines (Rimando 1962), Australia (Womersley, 1940), Brazil (Ehara, 1966, Flechtmann and Baker, 1970, Paschoal, 1970) and not in Paraguay (Aranda and Flechtmann, 1971).

Host Plants. Banks grass mite is generally restricted to monocotyledenous plants, particularly grasses. Malcolm (1955) listed over 80 species of grasses in 17 genera which were infested by BGM. Pritchard and Baker (1955), Tuttle and Baker (1968) and McGregor and Stickney (1965) also present host plant information for BGM. In Texas, Ehler (1973) reported *O. pratensis* on corn and grain sorghum. An up to date host list is not presented here.

Oligonychus stickneyi (McGregor), Pritchard and Baker (1955)

This spider-mite was originally described as *Paratetranychus stickneyi* and designated a "grass mite" by McGregor (1939). Pritchard and Baker (1955) proposed the new combination of *Oligonychus stickneyi* (McGregor).

Diagnosis. According to Pritchard and Baker (1955) males of *O. stickneyi* can be recognized by the knob of the aedeagus, which is ca. $\frac{1}{3}$ the length of the dorsal arm of the shaft. In addition, the anterior margin is broadly rounded, the caudal is acutely angulate, and the axis of the knob forms less than a 30 degree angle with the axis of the shaft. The shaft is sharply constricted before the dorsal bend. As in *O. pratensis* males, the proximo-ventral hairs of tarsus I are fused and form a claw-like structure. The knob of the aedeagus in *O. stickneyi* is larger than in *O. pratensis* and in the latter species the knob is not over $\frac{1}{4}$ the length of the dorsal arm of the shaft. Presently, only

males can be used in species determinations. Females of *O. pratensis* and *stickneyi* are indistinguishable.

Distribution. Pritchard and Baker (1955) report grass mite occurring in California, Arizona, Florida and Mexico. Ehler (1973) reported this species in Texas (El Paso County). The writer is aware of no reports of grass mite in areas other than the U.S. and Mexico. This would indicate that this spider-mite is native to North America.

Host Plants. Pritchard and Baker (1955) studied grass mite from corn, Bermuda grass and maiden cane grass. McGregor (1950) recorded grass mite from 11 different grasses. This mite has been collected from corn in Texas but not from grain sorghum.

Tetranychus urticae Koch, Boudreaux and Dosse (1963b)

This species is the common two-spotted spider-mite which has been commonly referred to in the literature as *Tetranychus bimaculatus* Harvey and *T. telarius* (Linnaeus). Boudreaux (1956) gave species rank to *T. telarius* (= *urticae*) and the closely related *T. cinnabarinus* which previously comprised the *T. telarius* complex. Boudreaux and Dosse (1963b) then proposed *T. urticae* as the proper name for two-spotted spider-mite. These authors also presented a complete synonymy.

Diagnosis. According to Boudreaux (1956), *T. urticae* summer females are basically green (occasionally yellowish or dark green) and possess "semi-oblong" lobes (often semi-circular). In *T. cinnabarinus*, the summer females are carmine and the lobes are pointed and usually triangular. Diapausing females of *T. urticae*, collected from greenhouses during the winter, may be carmine (H. B. Boudreaux, personal communication). Females are adequate for making species determinations. For determining males, study of the aedeagus is required; since the attendant diagnostic features are difficult to observe and because artifacts are easily encountered, it is suggested that only females be used for species determinations.

Distribution. Two-spotted spider-mite is a cosmopolitan species which can be collected from most cultivated crops and many wild hosts. In Texas, Ehler (1973) collected *T. urticae* on corn and grain sorghum although most collections were from corn. In view of recent systematic revisions, much of the literature pertaining to the host records of *T. urticae* (and *T. cinnabarinus*) is open to question since it is not possible to determine presently which species was actually being studied. For this reason, host records are not presented for either species. Such records for *T. telarius* (= *T. cinnabarinus* + *urticae*) are given by Pritchard and Baker (1955).

Tetranychus cinnabarinus (Boisduval), Boudreaux (1956)

This species is known as carmine spider-mite (also "red spider") and for many years was considered to be conspecific with what is now considered *T. urticae* Koch. The binomen *T. cinnabarinus* was

proposed by Boudreaux (1956); Boudreaux and Dosse (1963b) presented a complete synonymy.

Diagnosis. Boudreaux's (1956) description of *T. cinnabarinus* can be summarized as follows: Basic color of summer female carmine (restricted to area caudad of eyes; body anterior of eyes yellowish), usually 4 dark spots laterally, dorsal integumentary folds (striae) with triangular lobes (some may be semi-circular). The shape of the lobes of the striae and the basic color of the summer females will serve to distinguish *T. cinnabarinis* and *T. urticae*. Boudreaux described differences in male aedeagi of these species; however, this distinction is often difficult to observe. Hence, this issue is not considered here.

Distribution. Pritchard (in Boudreaux, 1956) reported *T. cinnabarinus* from the U.S., Europe, Israel, Turkey, Argentina and Japan. It is likely that this species is cosmopolitan.

In Texas, Ehler (1973) reported *T. cinnabarinus* taken from corn in College Station and recent collections reveal the species to occur on grain sorghum in this area. Carmine spider-mite occurs sporadically on grain sorghum on the High Plains.

Frequency

During the 1972 and 1973 growing seasons, samples of spider-mites were taken from grain sorghum and corn in 3 areas: High Plains (Lubbock, Hale, Lamb, Deaf Smith, Swisher and Castro Counties), Trans-Pecos (El Paso, Pecos and Reeves Counties), and College Station (Brazos County). One sample was taken per field per growing season, normally when spider-mites were relatively abundant. Usually, 10-20 specimens per sample were examined and determined to species level.

In samples from 11 High Plains corn fields, 8 contained *O. pratensis*, 2 contained *T. urticae* and 1 contained a mixture of these species. In Trans-Pecos corn, all 5 fields sampled were infested with *O. pratensis* whereas 2 of the 5 contained multiple-species infestations, i.e., *O. pratensis* + *O. stickneyi* and *O. pratensis* + *O. stickneyi* + *T. urticae*. The latter fields were virtually destroyed by the spider-mites (see Figures 3 and 4). In College Station, 3 corn fields were sampled; 2 were infested with *T. cinnabarinus* and 1 was infested with *O. pratensis*. Banks grass mite occurred most frequently in West Texas corn although researchers and growers should anticipate *T. urticae* and *O. stickneyi*, particularly in combination with *O. pratensis*.

All samples from 17 High Plains grain sorghum fields contained *O. pratensis*, including multiple-species infestations with *T. urticae* (1 case) and *T. cinnabarinus* (2 cases). In Trans-Pecos, only 5 fields of grain sorghum were sampled — all contained only *O. pratensis*. In College Station, samples from 3 grain sorghum fields each contained a different species, i.e., *O. pratensis*, *T. urticae* and *T. cinnabarinus*. Banks grass mite was the predominant species on grain sorghum in West Texas. (However, in greenhouse

sorghum, *T. urticae* often replaces *O. pratensis* as the predominant species.)

Ecological Considerations

Ecological investigations can proceed in a sophisticated manner only when the organisms to be studied can be segregated taxonomically. In the previous section, such taxonomic considerations were detailed. The purpose of this section is to summarize available ecological data relative to spider-mites and the factors which affect their population fluctuations.

Sampling

General aspects of sampling tetranychid populations have been reviewed by Huffaker *et al.* (1970) who reported numerous techniques for estimating population parameters. Jeppson (1951) used the method of counting adult females in the field — a technique used in most of the present studies. The density of females (number per plant) is a sufficient index of population trends. Natural enemies and other associates can usually be counted directly (preferably on a per plant basis) since they are larger in size and fewer in number. For the study of population dynamics, it is best to express mite population density in terms of number per plant since number per leaf, used alone, could easily lead to artifacts in the data due to spatial pattern of the mites. For purposes of gathering efficacy data for chemical agents, Ward *et al.* (1972) employed a stratified sampling technique which was sufficient for assessing chemical control.

Phenology

Observations relative to seasonal occurrence of the spider-mites in question have dealt largely with Banks grass mite. This species is present throughout the growing season on Johnsongrass (*Sorghum halepense*) and can be found infesting this plant in late fall and early spring. Presumably, BGM overwinters on Johnsongrass although hibernal diapause has not been established. (BGM infests numerous grasses in Texas; Johnsongrass, which is widely distributed, was the major host plant sampled. Hence this discussion relates largely to this plant.)

Malcolm (1955) reported that fertilized BGM females (and a few males and immatures) overwintered although he did not report diapause in the species. Malcolm also demonstrated that BGM overwintered near the base of the previously infested plant in the debris and top soil. Samples which were taken from previously heavily infested corn and grain sorghum fields in West Texas during the winter months did not yield any BGM when processed via a Berlese funnel. These samples included stalk, leaf litter and top soil. The data indicate that, in West Texas, BGM does not successfully overwinter in previously infested fields, although more intensive surveys may yield contrary evidence. In conclusion, any perennial grass (e.g., *S. halepense*) should serve to perpetuate temporal continuity in BGM populations, whereas annual species (e.g., corn, grain sorghum) would seem less suitable.

Incidence on corn and grain sorghum.

Pate and Neeb (1971) observed a relationship between rate of spider-mite population increase and stage of maturity of the grain sorghum plant. In the present study, this phenomenon was documented for both corn and grain sorghum.

In grain sorghum, spider-mites are usually present at low levels during the vegetative stages of growth and increase rapidly, often exponentially, after the plant has reached reproductive maturity (Figures 1 and 2). In general, this rapid increase in density occurs during the dough stage of seed maturation, usually when ca. 50 percent of the seeds are at hard dough. However, as is apparent from Figures 1 and 2, there can be considerable variation in the expression of this phenomenon.

The general relationship between spider-mite surges and plant or seed maturity on grain sorghum has been observed regardless of year, plant varieties, cultural practices (e.g., fertilizer, irrigation) and pesticide history of the crop. These data imply a strong correlation between spider-mite population growth and the physiological condition of the host plant. At this developmental stage, concomitant variables in the plant include sugars, alcohol-extractable proteins and alkali-extractable proteins (Wall and Blessin, 1970).

In corn, the rapid increase in spider-mite density was closely associated with the tassel (bloom) stage (Figures 3 and 4). However, since only 2 fields were observed, it is premature to offer a precise conclusion relative to this point.

Natural Control

The ecology and natural control of spider-mite populations has been treated exhaustively by Huffaker *et al.* (1969, 1970), McMurtry *et al.* (1970) and van de Vrie *et al.* (1972). These authors summarize and critically analyze the two central hypotheses concerning spider-mite outbreaks, namely, reproductive stimulation by pesticides and fertilizers versus inhibition of predator efficiency via pesticide interference. In essence, either phenomenon can act singly or can interact with the other to engender serious outbreaks of spider-mites. In the following discussion, these hypotheses are considered relative to spider-mite outbreaks on corn and grain sorghum in West Texas.

Predators. In the present study, only insect and acarine predators of spider-mites were observed. Insectan parasites (parasitoids) and bacterial pathogens have not been reported from spider-mites (Huffaker *et al.* 1969); also, no pathogenic agents have been isolated from the spider-mites in question although these are likely to occur.

The following predators have been observed feeding on either adults or developmental stages of spider-mites (especially BGM) on corn and/or grain sorghum in Texas:

Coccinellidae

Stethorus punctum (LeConte)²

Stethorus atomus Casey^{2, 3}

Hippodamia convergens Guerin-Meneville²

Olla abdominalis (Say)²

Anthocoridae

Orius insidiosus (Say)^{2, 3}

Orius tristicolor (White)³

Thripidae

Scolothrips sexmaculatus (Pergande)^{2, 3}

Chrysopidae

Chrysopa rufilabrus Burmeister²

Chrysopa carnea Stephens³

Phytoseiidae

Amblyseius (= *Typhlodromis*) *fallacis* (Garmen)²

Typhlodromus mesembrinus Dean²

Tydeidae

Pronematus ubiquitousus (McGregor)²

Cecidomyiidae

(?) *Arthrocnodax* sp.³

Pertinent biological features of these and other spider-mite predators have been outlined by McMurtry *et al.* (1970).

Evaluation of predation. In the absence of experimental evidence which would quantify the role of predators in controlling or regulating spider-mite populations, we can only make correlative assessments of the relationship, that is, the numerical response of predators to the increase in density of prey (Figures 3 and 4).

The available evidence corroborates the observations of Pate (personal communication) that the delayed response, primarily reproductive, of the predators is not sufficient to subjugate spider-mite outbreaks and, hence, to avoid economic loss. This is illustrated in Figures 3 and 4, which describe the predator-prey interaction in two corn fields near El Paso during 1972. In general, spider-mites (a variable mixture of *O. pratensis* and *O. stickneyi* in these cases) were present at very low densities throughout the growing season and increased rapidly when the plants reached reproductive maturity, or, 50 percent bloom. Most of the predators present (i.e., *Orius*, *Chrysopa* and *Scolothrips*) did not show a strong numerical response to the prey density increase, whereas *Stethorus* almost completed one generation. The data suggest that *Stethorus*, especially because of its host specificity, might be an effective natural-control agent if manipulated properly.

In grain sorghum, similar phenomena occur and, generally, the same natural enemies are involved. In this study, densities of spider-mites seldom reached levels sufficient to maintain the number of enemies found in corn near El Paso.

²Observations of Dean (1957).

³Observations of the writer and associates.

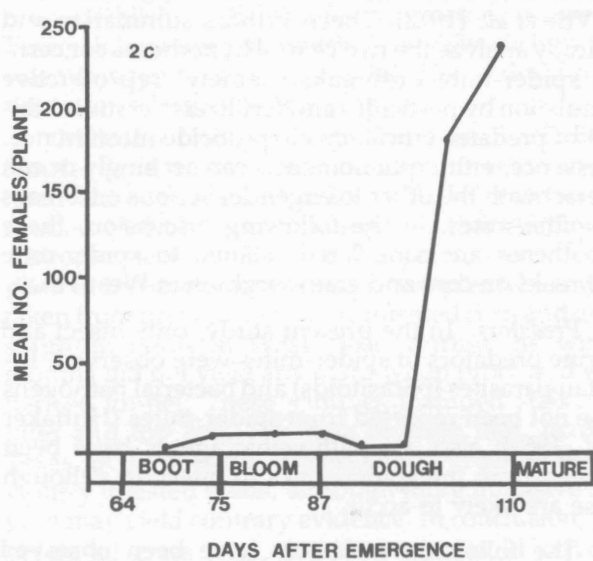
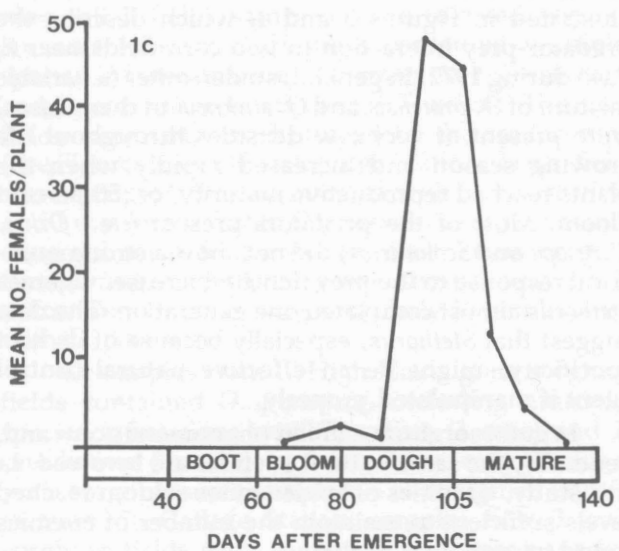
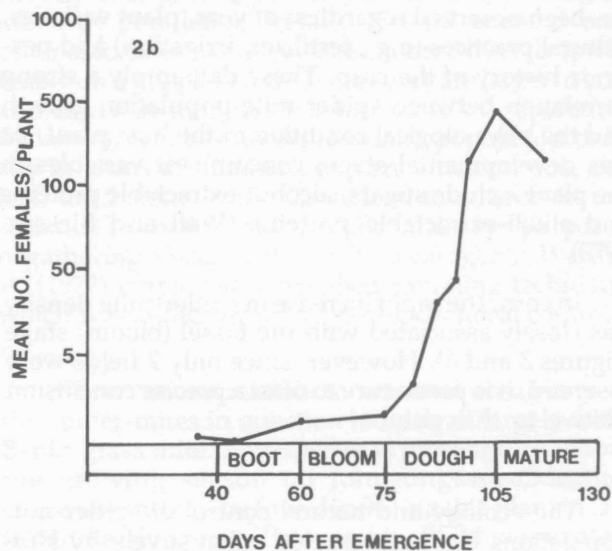
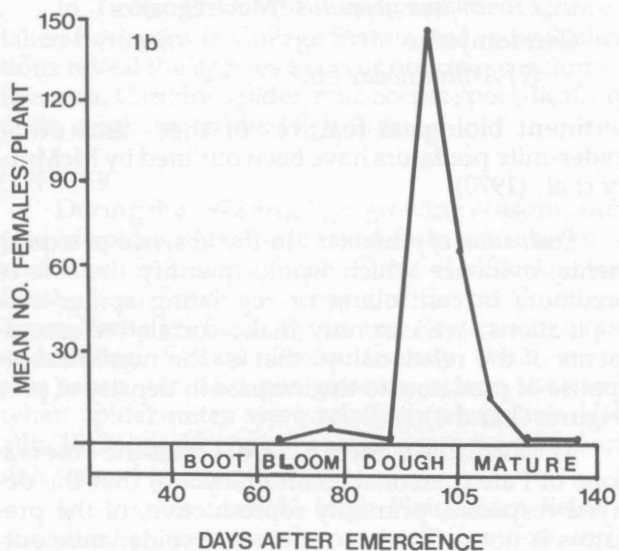
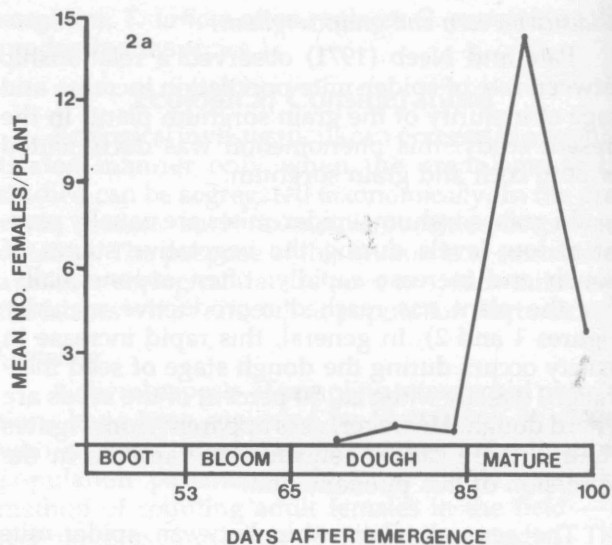
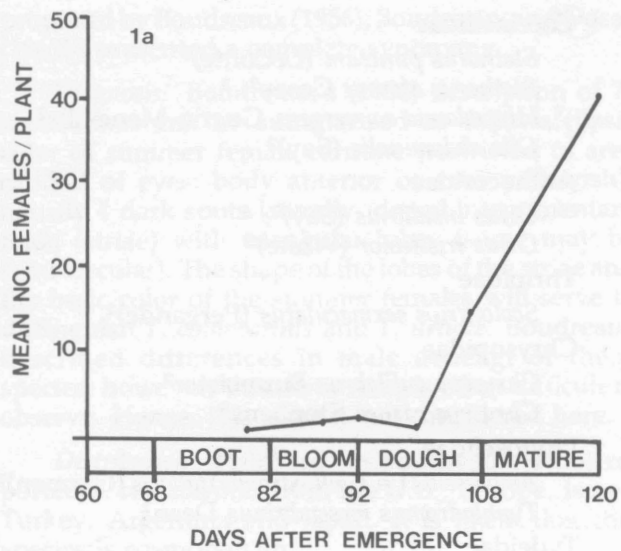


Figure 1. Population trends of spider-mites (predominantly *O. pratensis*) in High Plains grain sorghum fields at Slaton (a) and Springlake (b and c) during 1972.

Figure 2. Population trends of spider-mites (predominantly *O. pratensis*) in High Plains grain sorghum fields at Abernathy during 1972 (a) and Slaton (b) and Idalou (c) during 1973.

Pesticide influence. Numerous lines of evidence can be used to evaluate the influence of pesticides (namely, acaricides and insecticides) on spider-mite outbreaks, either via pest stimulation or natural enemy inhibition, or both. The general conclusion reached here may or may not be applicable to localized areas since, in certain areas, chemical control has been erratic (suggesting local genetic differences) and in other areas spider-mite outbreaks may be associated with chemical control of aphids on grain sorghum.

Pate and Neeb (1971) reported that, during 1967, spider-mites were a problem in the Trans-Pecos area regardless of the use of organo-phosphate acaricides. In fact, the two corn fields sampled in 1972 near El Paso (Figures 3 and 4) were literally destroyed by spider-mites and neither field received a pesticide application of any sort. These observations strongly suggest that spider-mite infestations in the Trans-Pecos area need not be exacerbated by pesticides in order to qualify as economic disaster.

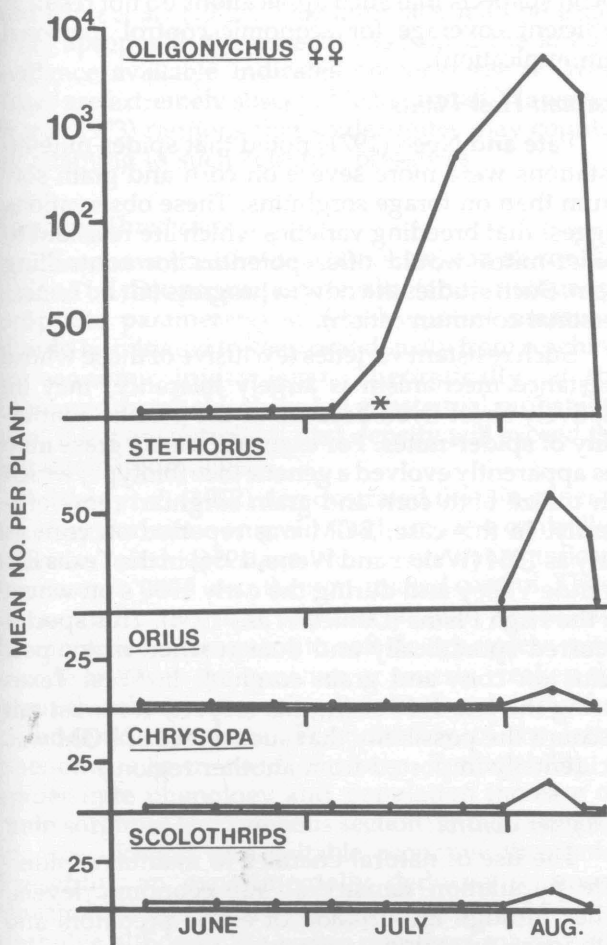


Figure 3. Population trends of spider-mites (a mixture of *O. pratensis* and *O. stickneyi*) and natural enemies on field corn near Clint (El Paso Co.) during 1972. Asterisk denotes 50 percent tassel in plants.

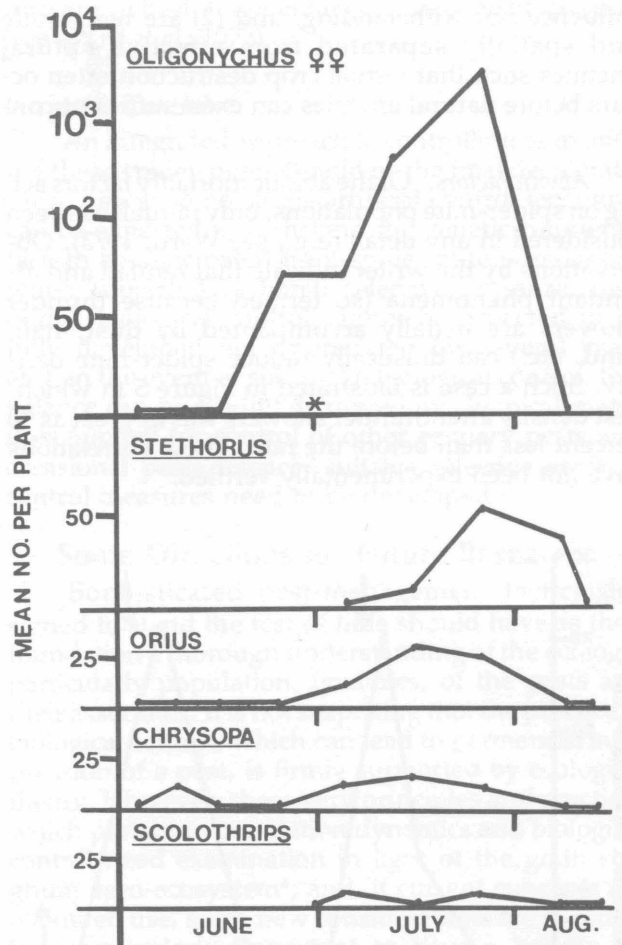


Figure 4. Population trends of spider-mites (a mixture of *O. pratensis* and *O. stickneyi*) and natural enemies on field corn near Fabens (El Paso Co.) during 1972. Asterisk denotes 50 percent tassel in plants.

In High Plains grain sorghum, spider-mite (predominantly *O. pratensis*) infestations do not appear, in general, to be aggravated by pesticides. For example, Huddleston *et al* (1968) reported outbreaks of spider-mites during 1967 — one year prior to initiation of massive chemical control measures for greenbug. Secondly, and more definitively, in a series of experiments conducted by the writer, application of the insecticides disulfoton (LC, 0.1 AI/A), disulfoton (G, 0.5 AI/A), parathion (EC, 0.5 AI/A) and phorate (G, 0.5 AI/A) did not engender increases in spider-mite density over the nontreated control. In fact, in most instances, the spider-mite density was significantly reduced and seldom resurged to a level comparable to the control. In most of these studies, natural enemies of the spider-mites were absent or at low levels and did not become abundant until spider-mites had reached near economic injury levels. These data establish that the hypothesis of pesticide influence on spider-mite outbreaks cannot be accepted.

To summarize, available evidence indicates that spider-mite outbreaks are (1) conditioned by the physiological condition of the host plant, pesticide

influence notwithstanding, and (2) are temporally and spatially separated from effective natural enemies such that virtual crop destruction often occurs before natural enemies can exert sufficient control.

Abiotic factors. Of the abiotic mortality factors acting on spider-mite populations, only rainfall has been considered in any detail (e.g., see Ward, 1973). Observations by the writer indicate that rainfall and attendant phenomena (so termed because thunder showers are usually accompanied by dust, hail, wind, etc.) can drastically reduce spider-mite density. Such a case is illustrated in Figure 5 in which pest density after thunder showers was as great as 90 percent less than before the rain. These correlations have not been experimentally verified.

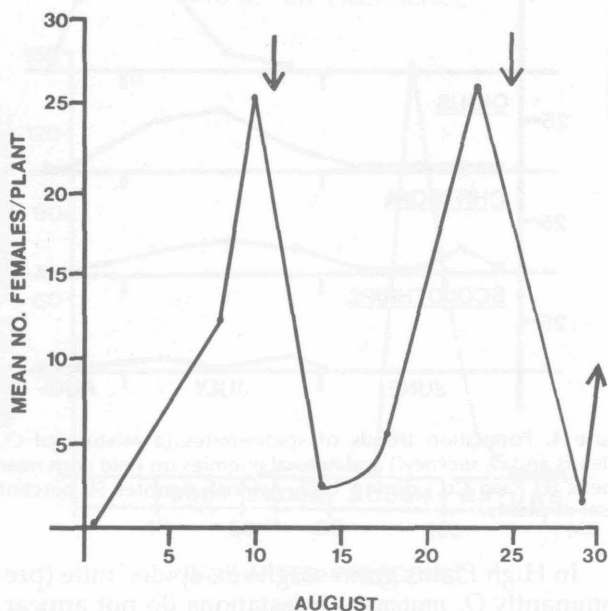


Figure 5. Populations trends of spider-mites (predominantly *O. pratensis*) on grain sorghum near Fabens (El Paso Co.) during August, 1972. Arrows denote rainfall of ca 1.0" on Aug. 12 and ca 4.0" on Aug. 26.

Control Considerations

A proper appreciation for the taxonomic problems (if any) and ecological complexity of a pest problem is prerequisite for developing a solution which is both ecologically sound and economically rewarding. A remaining topic to be discussed, then, is control of spider-mites on corn and grain sorghum. Also, some specific directions for future research are presented. In the present case, control actions are desired; hence, the concept of integrated control (Smith and Reynolds, 1966) would seem most appropriate and should be the final desiderata.

Chemical control

Although chemical control of spider-mites has been erratic and appears to be breaking down (Ward,

1973), insecticides and acaricides will likely remain the most potent short-term tactic for controlling spider-mites. However, in view of the genetic adaptability of spider-mites (Helle and Overmeer, 1973), it can be expected that genetic counter-selection by spider-mite populations will render effective chemical materials ineffective in a few years or in a few generations. Adaptability (prompt response to chemical selection in this case) in spider-mites is particularly enhanced by the haplo-diploid sex-determination mechanism (arrhenotoky) (Helle and Overmeer, 1973) which allows for immediate expression of mutations in the male, whether mutations are recessive or dominant. Hence, there is a prompt interaction between mutation and selection. In the present case, all spider-mite species involved are presumed to be arrhenotokous.

It is imperative that exclusive reliance on chemical control be avoided and that chemicals be applied only when necessary and in a prescribed manner. With respect to the latter point, it is questionable whether or not aerial applications of acaricides on mature corn can lead to sufficient spray coverage so as to produce economic control. In California, O. G. Bacon suspects that such applications do not result in sufficient coverage for economic control (personal communication).

Resistant Host Plants

Pate and Neeb (1971) noted that spider-mite infestations were more severe on corn and grain sorghum than on forage sorghums. These observations suggest that breeding varieties which are resistant to spider-mites would offer potential for controlling them. Such studies are now in progress (G. L. Teetes, personal communication).

Such resistant varieties (exclusive of those whose resistance mechanism is largely tolerance) may be relatively short-lived because of the genetic adaptability of spider-mites. For example, Banks grass mite has apparently evolved a genetic race (biotype) which can utilize both corn and grain sorghum more efficiently. In this case, BGM was reported on corn as early as 1954 (Walter and Wene, 1956) in the Texas Rio Grande Valley and during the early 1950's on wheat on the High Plains (Daniels *et al.*, 1956). This species occurred sporadically and then reached major pest status on corn and grain sorghum in West Texas during the late 1960's. (In this respect, we must not discount the possibility that such a race of BGM was accidentally imported from another region.)

Biological Control

The use of natural enemies to maintain spider-mite population density at sub-economic levels, either through importation of exotic predators and pathogens or manipulation of native enemies, is a viable approach, and should be further exploited. Since, in the opinion of the writer, proper theoretical perspective for such tactics relative to the grain sorghum and/or corn agro-ecosystems is partially lack-

ing, the entire issue will be treated in the next major section.

Unexploited Techniques

A number of biological processes in spider-mites are presently being studied and, presumably, some of these should have practical applications in control. In a series of papers, Cone *et al.* (1971a, 1971b and 1972) have presented evidence for a sex pheromone in *T. urticae*. The behavior of mature males of this species parallels that observed by the writer in *O. pratensis*. It is feasible that manipulation of spider-mites using pheromones could be used to control outbreaks or to preclude their development.

Pathogens of spider-mites include fungi and viruses (McMurtry *et al.*, 1970) although extensive research has not been directed toward these agents for control. The writer is aware of no published reports of pathogens of *O. pratensis* and *O. stickneyi*, the major pest species in West Texas. Microbial control of spider-mites offers some promise and should likewise be exploited in the present case.

Sprinkler irrigations have been used to suppress spider-mite densities by Hudson and Beirne (1970) and Kinn *et al.* (1972). This approach may be especially apropos in the present case since the limited evidence available indicates spider-mites in West Texas are extremely susceptible to rainfall. However, Ward (1973) cautions that spider-mites may counter by adapting to such selective pressures.

Economic Thresholds

Economic threshold (action level) can be considered to be that population density (and/or other appropriate parameters) at which control measures should be initiated to keep pest density from reaching an economic injury level. Theoretically, at the economic threshold, there is a substantial probability that, if left uncontrolled, pest density will exceed the economic injury level.

Ward *et al.* (1972) demonstrated that, in general, when spider-mites on grain sorghum were controlled after the soft dough stage, there were not significant increases in yield over the non-treated control. These data indicate that spider-mites need not be controlled subsequent to soft dough unless mites invade and web the panicum or severely weaken the plant thereby predisposing it to stalk-rot and other pathogenic organisms. Predictability of the latter phenomena is in need of study. Predictability of spider-mite phenology and population increase on grain sorghum (see previous section) should enhance the specification of a suitable economic threshold. Presently, an experimentally deduced economic threshold is lacking. Development of such a level is desirable although the writer questions massive experimentation to determine an economic threshold in those areas where spider-mites are presumed to be resistant to available chemical acaricides and insecticides. Economic aspects of spider-mite control on

corn are, at best, fragmentary and in need of research (see Ward *et al.* 1972).

Integrated Control

An integrated approach to controlling or managing these spider-mites should be the final desiderata. This is because no single artificial control technique can be expected to withstand the genetic counterattack to be anticipated from spider-mite populations when subjected to harsh selective pressure. Secondly, biological control cannot be expected to be fully developed nor appreciated for several years and, in the event of successful biological control, this balance can be readily disrupted by chemical measures applied for control of other primary pests and occasional pests. Hence, suitable selective artificial control measures need to be developed.

Some Directions for Future Research

Sophisticated pest-management tactics designed to stand the test of time should have as their foundation a thorough understanding of the ecology, particularly population dynamics, of the pests and their associates. It is not surprising that the practice of biological control, which can lead to permanent suppression of a pest, is firmly supported by ecological theory. However, these very principles and practices which pertain to population dynamics and biological control need examination in light of the grain sorghum agro-ecosystem⁴; and, if current concepts are of limited use, some new considerations are in order. It is particularly important to have a handle on theoretical ideas since, without them, we will not know precisely which parameters to measure, much less, how to measure them.

Population dynamics

Traditional approaches to the study of insect population dynamics generally involve a standard set of sequential operations. These can be listed as follows: (1) sampling of appropriate stages of the life cycle and of mortality factors associated with each stage; (2) construction of age-specific life tables from the census figures; (3) analysis of the life table data from several successive generations, usually via a key-factor analysis; (4) testing to determine if mortality is dependent or independent of host density; and (5) generation of a population model for explaining and predicting population events (Harcourt, 1969; Varley and Gradwell, 1970).

This approach to the study of insect population dynamics is not totally applicable to dynamics of insect-pest populations on grain sorghum. This is primarily because these methods are applicable to univoltine species (Luck, 1971; Ito, 1967), whereas

⁴Most of the remarks in this section deal with grain sorghum since there is sufficient knowledge available to speculate on insect-plant or mite-plant relationships in this crop. Most of the remarks probably apply to corn also.

most pests of grain sorghum are multivoltine; often the generations overlap such that age-specific life tables cannot be constructed. Also, the classical approaches (e.g., Varley and Gradwell, 1968) require that a population be studied in the same location for a number of years. A field of grain sorghum one year may be a field of cotton the next. In short, the approach is inapplicable not only to grain sorghum pests but also to pests of other temporary or annual agroecosystems, e.g., cotton, corn (see also Way, 1973).

In view of these circumstances, we should seek alternative methods of analysis and/or modify the existing methods to suit our needs.

For pests with overlapping generations (e.g., spider-mites, greenbug and other aphids) the methodology advanced by Hughes and Gilbert (1968) is useful. The approach entails gathering data (usually expressed in fecundity schedules) on aphids, their predators, parasites and hyperparasites and other parameters which markedly influence the system. In the end, a computer model is generated which, if the input data are realistic, can be used to predict population events.

For pest species with discrete generations (whether univoltine or multivoltine) on grain sorghum (e.g., *Heliothis*), perhaps a modification of existing methodology is in order. For example, age-specific life tables can be constructed for these populations and can be replicated in time and space. However, the analysis of the life-table data must take on a new dimension. Since the classical key factor analysis is of little value in this respect, a simple visual analysis of the life tables can aid in demonstrating any consistent features, such as a major loss of individuals between two successive stages. Also, the analysis of *intragenerational* processes as opposed to *inter-generational* processes may be of more value, especially from the utilitarian standpoint, since pests may be bivoltine or trivoltine and may cause economic loss in each generation. Modeling these sorts of relationships has not been exploited.

It is apparent that the study of insect population dynamics in temporary agro-ecosystems is a virgin field of applied ecology. The special theory and methodology underlying this discipline are lacking in many cases and it appears that those involved in research on grain sorghum pests (for example) are in a prime position to develop its basic principles. We cannot expect ecological theorists to do it. This, then, should be one major long-term research effort.

Classical biological control

The importation of exotic natural enemies to subjugate native or an exotic pest species is an established tactic in pest management. It is appropriate that workers in Oklahoma (e.g., Jackson *et al.*, 1971; Rogers *et al.*, 1972) are exploiting this technique, particularly since greenbug, corn leaf aphid and sorghum midge are exotic insects. However, such ap-

plied biological control should be given some special consideration in view of the temporal and spatial properties of the grain sorghum agro-ecosystem and the pests contained therein.

Lloyd (1960) noted that most successful cases of biological control occurred on pests of perennial plants (e.g., citrus, olive, coffee, eucalyptus, larch, etc.) and further indicated that the method may be limited to pests of such perennial or stable-crop agro-ecosystems. Newsom (1970) and Ridgway (1972) further document the fact that this apparent limitation to successful biological control is substantiated by the record of successful cases (see also Southwood and Way 1970). Hansberry (1968) further concludes that "it seems very unlikely that we can ever expect biological methods to control field and truck-crop pests."

Despite the fact that most of the attempts at and successes of biological control have involved pests of perennial crops, it should not be concluded, on an *a priori* basis, that the method is not suited for pests of temporary or annual agro-ecosystems. This is because no one has presented a valid theoretical reason why importation of exotic natural enemies for control or pests in such agro-ecosystems should not be attempted.

In this case, an underlying reason for the lack of a suitable explanation can be traced to the fact that the practice of importation of natural enemies has grossly preceded the theory. That is, present-day guidelines for importation of natural enemies of foreign pests have been largely established as a result of biological-control work in more permanent, perennial ecosystems. Thus, as in the case of population dynamics of insect pests in short-cycle agro-ecosystems, the theoretical guidelines for classical biological control in these situations seem deficient. We should not assume that the properties of a successful biological-control agent on olive or citrus will necessarily be coincident with an exotic enemy for a pest of grain sorghum.

In recent years, some theories of island biogeography put forth by MacArthur and Wilson (1967) have been used to enhance theoretical perspective with respect to non-insular habitats which are analogs of oceanic islands (i.e., habitat islands). Following the suggestion of MacArthur and Wilson (1967), several authors followed by relating principles of island biogeography to mountain tops (Brown 1971), host plants (Janzen 1968), individual oak trees (G. W. Grankie, personal communication), caves (Culver 1970), continental areas (Vuilleumier 1970) and geographic distribution of oaks (Opler 1974). Of the systems remaining, it may be of value to consider the geographical area occupied by a grain-sorghum field (for example) to be a habitat island or "functional island" (see Force, 1972).

MacArthur and Wilson (1967) emphasize two evolutionary strategies: K-strategy, in which a

species evolves toward more efficient utilization of environmental resources; and r-strategy, in which selection favors a rapid rate of population increase.

The temporary agro-ecosystem can be viewed as a functional island. That is, grain sorghum is planted, cultured and harvested in one season and the plant remains are plowed down at the end of the season. The following year, the same processes occur, often in another location. Thus, the pest species and their natural enemies may be forced to play a hide-and-seek game with their respective food source, and it follows that those species best adapted (pre-adapted) for this mode of existence (e.g., colonizing species) will be successful in exploiting such a temporary requisite.

Force (1972) noted that, in a disturbed ecosystem (e.g., agro-ecosystem), the r-strategist (or colonizing species) will be numerically dominant and further suggested importation of such enemies to effect biological control. Pianka (1970, 1972) and Price (1973) have given further details on identification of r-strategist species. Some major pests of grain sorghum in West Texas, namely, greenbug, corn leaf aphid and spider-mites, can perhaps be classed as r-strategists and it is suggested that future research be directed toward developing operational methods for identification of r-strategist enemies which, presumably, would be suitable agents for biological control of pests of grain sorghum.

In this regard, the following can be considered a working hypothesis: in a short-cycle crop such as grain sorghum, those natural enemies capable of colonization of the habitat and rapid exploitation of a temporary requisite (i.e., the prey) can be suitable biological-control agents. Some attributes of such enemies likely include: (1) competent dispersal (e.g., aphid parasitoids passively carried within the body of the alate aphid); (2) appropriate host or prey finding mechanisms once the enemy has arrived in the system; and (3) a comparatively high reproductive rate.

Recent evidence (Ehler *et al.*, 1973) from an analogous crop (cotton) gives added insight into how the strategy of rapid exploitation of cabbage looper [*Trichoplusia ni* (Hübner)] can be accomplished. In this case, polyembryony (a host-specific parasitoid), polyhedrosis (a nuclear polyhedrosis virus), and polyphagy⁵ (a complex of general predators) represent attributes enabling the given enemies to take advantage of a temporary requisite. Presumably, substantial biotic mortality is the result.

To summarize, we should question the concept that the necessary properties of a successful biological-control agent for a pest of a stable crop will be coincident with those of an agent for a pest of grain

sorghum. Second, we should attempt to delineate the properties of a suitable biological-control agent for pests of grain sorghum such that biological control can become a more predictive science.

Natural control of natural enemies

Varley (1970) urged the development of life tables for predators and parasites to enhance modeling of these agents and, by implication, to aid in explaining why certain enemies are not efficient. The studies of Hassell (1969a, b) apparently represent the first definitive explanation of the factors which contribute to population fluctuations in a natural enemy.

This line of research is particularly relevant to natural enemies of pests of grain sorghum in West Texas. For example, G.L. Teetes (unpublished data) demonstrated that when *Hippodamia convergens* Guer. adults and developmental stages were hand removed twice daily throughout the growing season, there were no significant increases in prey density (greenbug) over plots which retained the normal complement of this enemy. As a consequence, Kirby (1974) constructed life tables for the predator and demonstrated that, in general, 80-90 percent of the generation mortality occurred during the age interval comprised of eggs and first and second instar larvae. Kirby's results were consistent in time and space and can be used to aid in explaining why these beetles are seemingly inefficient predators.

Kirby also observed that a variable portion of the mortality of eggs was due to predation by other species [e.g., *Orius insidiosus* (Say)]. If this phenomenon becomes a predictable event and is of sufficient magnitude, it may be less profitable to seek those exotic aphid-feeding coccinellids whose ecological characteristics are similar to *H. convergens* since their ecological impact may be similarly affected. In this case, a parasitoid may be more suitable since certain natural enemies (hyperparasites) of these species exert their effect after the host (pest) has been parasitized and thus even high rates of hyperparasitization (e.g., Walker *et al.*, 1973; Frazer and van den Bosch, 1973) would not necessarily be conducive to disruption of biological control. It is suggested that these concepts be treated as working hypotheses and be the object of future research.

Manipulation of natural enemies

Apart from considering those factors which effect direct mortality of natural enemies in the agro-ecosystem, it may be expedient to investigate relationships within or outside of the system which, through intelligent manipulation, could enhance the impact of natural enemies. Such manipulation may involve providing an adequate supply of an alternate host during critical periods (e.g., Douth and Nakata, 1973) or providing artificial nutrients for enemies (e.g., Hagen and Tassan, 1970).

In the case of spider-mites on corn and grain sorghum, natural enemies often respond to mite outbreaks too late to exert sufficient control. In the El

⁵Although general predators may be of value in biological control programs, it is suggested that introduction of such agents be given critical scrutiny before establishment since these enemies could possibly disrupt established predator-prey systems (e.g., by preferentially feeding on other predators) and thus engender serious flarebacks.

Paso Valley, *S. atomus* is a case in point. This species shows a delayed reproductive response to increases in mite density. If adult beetles could be stored on alternate hosts nearby the crop, perhaps prompt immigration and more efficient predation would result. The writer has observed this species in the desert areas which surround the agricultural region in the valley, where it is closely associated with desert

spider-mite (*Tetranychus desertorum* Banks) on creosote bush. Since this inoculum of predators is spatially separated from corn and grain sorghum in the area, it is suggested that future research be directed toward bridging this gap, perhaps through planting suitable plants in the immediate vicinity of crops, so as to ultimately enhance the efficiency of the predators.

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