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Effect of Sorghum Midge on Grain Sorghum Production in the San Joaquin Valley Relative to Date of Planting and Plant Spacing

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Populations of the sorghum midge, *Contarinia sorghicola* (Coquillett), are maintained at low levels in johnsongrass, *Sorghum halepense* (L.) Pers., from late spring to mid-summer. A slow buildup occurs on grain sorghum, *S. bicolor* (L.) Moench, during early August, and numbers capable of causing severe yield reductions are reached after ca. 20 August. Fields planted prior to 15 June will likely escape midge damage. Those planted between 15 and 22 June may or may not escape damage, depending on the season. Virtually all plantings made after 22 June risk severe midge infestations and yield reductions.

Plant population appears to have little influence on ultimate yield. The yields in plots thinned to 13 and 26 plants per meter were not significantly different from those thinned to 39 plants per meter, although the midge infestation in heads from the low plant population was more than double that in heads from the high plant population. Plants in the low population produced larger heads and were able to tolerate a much higher level of infestation without suffering a yield reduction.

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Effect of Sorghum Midge on Grain Sorghum Production in the San Joaquin Valley Relative to Date of Planting and Plant Spacing¹

INTRODUCTION

THE SORGHUM MIDGE, *Contarinia sorghicola* (Coquillett), is the most cosmopolitan pest of grain sorghum, *Sorghum bicolor* (L.) Moench, and occurs in nearly all regions of the world where the crop is grown (Young, 1970). The sorghum midge was first recorded in the U. S. (Alabama) in 1895 (Dean, 1911; Walter, 1941), and is now distributed throughout most of the major sorghum-growing regions of the United States. *Contarinia sorghicola* was first reported from California (Tulare County) in 1960 (Lange et al., 1961) but was probably present several years prior to its discovery. Its present distribution in the state is shown in Fig. 1.

Damage is caused by the larvae feeding on the internal contents of the developing ovary. The damaged ovary fails to develop, resulting in an empty spikelet. This condition is called "blast" or "blight" of the spikelet, and severely damaged heads produce little or no grain (Fig. 2). Although as many as seven larvae may infest a single spikelet, only one usually matures; but this is sufficient to prevent grain development (Bowden, 1965). Huddleston et al. (1972) reported losses due to sorghum midge of \$10 million on the Texas High Plains. Losses from individual California counties where the midge

occurs are not known, but, based on a survey of 25 fields, we estimated that the loss in Tulare County in 1973 exceeded one-half million dollars.

Although chemical control of this pest is possible (Huddleston et al., 1972), several factors make it impractical in California (Summers et al., 1975). To minimize midge damage, chemicals must be applied during bloom (Stanford, Huddleston, and Ward, 1972). The heterogeneous soils of many California fields results in an uneven and protracted period of bloom that may last for 4 weeks in an individual field. Under such conditions, up to four insecticide applications may be required for control to be effective, and this is both economically and environmentally unrealistic. Chemical treatments pose a danger to the great numbers of honeybees, *Apis mellifera* L., which collect sorghum pollen during bloom. Such treatments also interfere with the naturally occurring biological control of the greenbug, *Schizaphis graminum* (Rondani), and corn leaf aphid, *Rhopalosiphum maidis* (Fitch), (Summers, unpublished observations).

In Texas, the practice of an early planting date has been shown to minimize damage and losses caused by the sorghum midge (Bottrell, 1971). If

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Fig. 1. Distribution of sorghum midge in relationship to the principal sorghum-growing counties in California. Outline map © Rand McNally & Company, R.L. 75-Y-42.

planted prior to 25 May, all grain sorghum hybrids, regardless of maturity class, generally complete blooming, the stage susceptible to midge attack, before midge populations reach damaging numbers. Planting later than mid-June usually results in severe economic loss. However, much of the grain sorghum in California, and nearly all of that planted in the counties where the midge is present, is grown as a double crop following winter wheat or barley. Thus, the time at which sorghum can be planted depends to a great extent on how rapidly the preceding cereal crop matures and can be harvested and the length of time required to prepare the soil for the subsequent sorghum crop. In most years, 1 June is the earliest that double-cropped sorghum can be planted in the southern San Joaquin Valley and was used as the starting date in our investigations.

This paper reports the results of trials conducted to determine the "midge-free planting date." This date we have defined as the last day on which double-cropped sorghum can be planted without serious risk of significant yield

Fig. 2. Damage caused by sorghum midge. Severely blasted head on right, undamaged head on left.

loss due to severe midge infestation. Data on plant population as it influences midge populations and yield are also presented.

MATERIALS AND METHODS

Field plots were established with the medium maturity grain sorghum hybrid Amak R-10 at the Kearney Horticultural Field Station (KHFS), Parlier (Fresno County), California, in 1972, 1973, and 1974. Ammonium sulfate at the rate of 168 kg of N per ha was broadcast prior to planting and incorporated to a depth of 15 cm with a disk. Plots were arranged in a randomized complete block design with four replications. Each plot consisted of four single rows 7.6 m in length, each planted on beds with 76-cm centers. All plots were planted with a single-row Planet Jr.[®] seeder, and were hand-thinned to the desired plant population 5 to 7 days after seedling emergence. In 1972, plantings were made on 15,

22, 29 June and 6 July with 26 plants per meter (344,300 plants per ha). In 1973, plantings were made on 1, 8, 15, 22, 29 June and 6 July with 13 and 39 plants per meter (172,100 and 516,500 plants per ha). In 1974, plantings were made on 1, 15, 29 June and 13 July, and plant populations of 13, 26, and 39 plants per meter were evaluated. Yields were determined by hand harvesting heads in the two center rows of each plot when the moisture level in the grain was ca. 20 percent. Heads were threshed in an Ames[®] single-head thresher, and a 100-g subsample was taken for moisture determination. Yields were then adjusted to 15 percent moisture. Except for the hand harvest and threshing, all cultural practices

Fig. 3. Emergence container used to determine the number of adult midges per head.

were typical for grain sorghum grown in the San Joaquin Valley.

The level of midge infestation per head was determined by counting the number of adults that emerged from 30 randomly selected heads from each plot. Doering and Randolph (1963) showed that adult emergence begins 10–12 days

after head exertion, and, unless otherwise stated, all heads used in this study were in this age category.

Heads were placed in gallon ice-cream cartons (five heads per carton) into which a 4-dr screw-cap vial had been inserted (Fig. 3). The cartons were then placed in the greenhouse, and midge counts were made from the vials every 2 to 3 days until emergence ceased. The cartons were then opened, and any trapped midges counted. All midges were counted and sexed under 25 $\times$ magnification. We also monitored midge populations in johnsongrass, *S. halepense* (L.) Pers., growing along a canal ca. 150 m from the plots, to determine its role in midge buildup. One hundred heads were sampled weekly from 5 June to 1 August. These were placed in emergence cartons (25 per carton), and counts were made as previously described.

RESULTS AND DISCUSSION

Midge populations

1972. The midge population was relatively low (Fig. 4), with a maximum of 25 adults emerging from heads blooming² 10 September (planted 6 July). Such a low infestation in sorghum blooming this late in the season is unusual; however, several factors appear to have contributed significantly to the reduced population level. The midge overwinters as a cocooned larva, a state of diapause in which it is extremely resistant to cold (Walter, 1941; Passlow, 1965). Naked larvae, those failing to form cocoons, and pupae are killed by short exposures to subfreezing temperatures (Walter, 1941). Although a small percentage of the larvae from each generation enter diapause, the majority of diapausing larvae develop in late October and early November, prob-

Fig. 4. Number of adult sorghum midges emerging per head in relationship to planting and flowering dates, 1972.

² Blooming as used in this paper refers to 50% bloom, i.e. the distal one-half of most heads showing yellow flowers. Blooming and flowering are used interchangeably.

Fig. 5. Portion of the total midge population comprised of females in 1972–1974.

ably in response to decreasing temperatures (Walter, 1941; Summers, unpublished observations). From 30 October to 9 November, 1971, a severe cold spell resulted in nighttime temperatures at or below freezing for 11 consecutive days, including one -5°C reading. This sudden cold probably killed a high percentage of the larvae before they completed development into the resistant cocooned stage. Termination of diapause requires a combination of warm temperatures (16 to 32°C) and high humidity (98 to 100 percent) or periodic rainfall (Walter, 1941; Passlow, 1954, 1965). In the absence of such conditions, the larvae may remain in diapause for 2 to 3 years (Walter, 1941; Passlow, 1965). Since the humidity rarely reaches such levels for a sustained length of time in the San Joa-

Fig. 6. Number of adult sorghum midges emerging per head in relationship to planting and flowering dates, 1973.

quin Valley, rainfall is the most critical prerequisite for diapause termination. However, only 0.35 cm of rain were recorded at KHFS from 6 February to 6 June, 1972. On 7–8 June, 1.19 cm of rain fell; but, after such a dry winter and spring, this amount was not sufficient to initiate a mass emergence, and most of the larvae remained in diapause. We feel that the combination of the sudden freeze in the fall of 1971 and the dry winter and spring of 1972 were the principal factors contributing to the low population level in 1972.

Another possible contributing factor was the low percentage of females during 1972. Females usually outnumber males by ca. 2:1 (Dean, 1911; Walter, 1941; Passlow, 1965). Summers (1975) showed that although the sex ratio is near 1:1 early in the season, by mid-August, the ratio shifts significantly in favor of the females. In 1972, however, males significantly outnumbered fe-

males (except on 14 August when the ratio was 1:1) throughout the entire season (Fig. 5). Such a low percentage of females throughout the season probably also contributed to maintaining the population at a lowered level for the year.

1973. Midge populations are indicated in Fig. 6. The infestation was minimal in heads blooming prior to 12 August, but began increasing slowly in heads blooming later in the season. No substantial increase in numbers occurred, however, until after 1 September (in plots planted on 6 July). Slightly more adults emerged from heads in plots thinned to 13 plants per meter, but the difference was significant ($P = 0.05$) for the 11 September bloom date only. Although the plant population $\times$ number of midges emerging per head interaction was highly significant ($P = 0.01$), the difference in numbers emerging from heads blooming 10–11 September (planted 6 July) was the most important factor contributing to this significant interaction. When counts from the 6 July planting date were excluded from the factorial analysis, the mean squares for both plant population and interaction were nonsignificant ($P = 0.05$). The sex ratio (Fig. 5) in 1973 was more typical of the midge. Females comprised 50 percent of the population emerging from heads that bloomed during early August, and nearly 60 percent of the midges emerging from heads blooming in early September.

1974. As in 1973, the infestation was relatively low in heads blooming prior to mid-August (Fig. 7). The number emerging per head increased sharply in late August, with the most abrupt increase occurring in heads blooming after 1 September. Significantly ($P = 0.05$) more adults emerged from heads in plots thinned to 13 and 26 plants per meter than from plots with 39 plants per meter, blooming on 15

Fig. 7. Number of adult sorghum midges emerging per head in relationship to planting and flowering dates, 1974.

September (planted 13 July). All other differences in plant populations were nonsignificant. There was no significant interaction between the number of midges emerging per head and plant populations in this range. The sex ratio was nearly identical to that observed in 1973, with females comprising slightly less than 50 percent of the population emerging from heads blooming in early August, but increasing to 60 percent by mid-September (Fig. 5).

The only differences in the number of adults emerging per head from plots blooming on any given date were from those plots blooming after 1 September in 1973 and 1974, when the level of infestation was extremely high. These differences were due mainly to the physical size of the head, and thus the availability of suitable oviposition sites. Grimes and Musick (1959) showed that

TABLE 1

GRAIN YIELDS AND NUMBER OF ADULT MIDGES PER HEAD FROM FOUR PLANTING DATES. KEARNEY HORTICULTURAL FIELD STATION. FRESNO COUNTY, CALIFORNIA. 1972.

Planting date	Date of 50% bloom ^a	No. plants per meter	No. adult midges per head	Yield kg per ha ^b
15 June	10 Aug.	26	1.2	4608 a
22 June	22 Aug.	26	4.6	4019 a
29 June	27 Aug.	26	19.3	3832 a
6 July	10 Sept.	26	25.2	3803 a

^a Distal one-half of most heads showing yellow flowers.

^b Means followed by the same letter are not significantly different at the 5% level of probability. Duncan's multiple range test.

Fig. 8. Relation between number of adult sorghum midges emerging per head and grain sorghum production in 1972.

head size is determined by the area available to each individual plant. They obtained three times the quantity of grain per head with 723 cm² per plant as with 181 cm² per plant. Pendery (unpublished data) found that doubling the number of plants per meter reduced the number of spikelets per head by 40 percent. Although head size affects the length of time for flowering to spread over an individual head (Doggett, 1970), and thus the length of time it is susceptible to oviposition, we observed no differences in the number of days required to complete flowering in any of the plant populations. As far as midge infestation is concerned, the length of time the entire field is in bloom is more important than the single-head flowering time (Thomas, 1969).

Midge populations followed the same general trend in all three years of this study. Infestation levels were extremely low in sorghum blooming in early August and increased slowly as flowering occurred later in the season. The sharp increase in numbers occurred after the 27 to 29 August bloom dates, and maximum infestation levels were reached in heads blooming during September. Harding (1965a), Thomas (1969), and Huddleston et al. (1972) reported a similar pattern of midge buildup in Texas, and observed the highest populations in heads blooming in late August through September.

Grain production

1972. Yield decreased slightly as planting date was delayed. However, differences in yield over the four planting dates examined were not significant at $P = 0.05$ (Table 1). The relationship between the number of midges emerging per head and yield is shown in Fig. 8. The regression coefficient expresses the kg per ha decrease in yield for each increase of one midge per head. Yield decreased significantly in relationship to the increasing midge infestation. The amount of damage caused by infestation levels of 25 per head or less was not severe enough, however, to result in an overall yield reduction for the four planting dates. Although delays in planting are known to affect the yielding ability of certain hybrids

TABLE 2
GRAIN YIELDS AND NUMBER OF ADULT MIDGES PER HEAD FROM SIX
PLANTING DATES AND TWO PLANT POPULATIONS.
KEARNEY HORTICULTURAL FIELD STATION.
FRESNO COUNTY, CALIFORNIA. 1973.

Planting date	Date of 50% bloom ^a	No. plants per meter	No. adult midges per head	Yield kg per ha ^b
1 June	4 Aug.	13	3.4	5797 a
	5 Aug.	39	2.4	5845 a
8 June	6 Aug.	13	3.2	5652 a
	6 Aug.	39	6.7	5857 a
15 June	12 Aug.	13	26.3	6413 a
	13 Aug.	39	17.0	6231 a
22 June	20 Aug.	13	40.7	6399 a
	21 Aug.	39	33.7	5962 a
29 June	29 Aug.	13	56.4	4855 b
	30 Aug.	39	59.4	4505 b
6 July	11 Sept.	13	641.8	1592 c
	10 Sept.	39	261.9	2007 c

^a Distal one-half of most heads showing yellow flowers.

^b Means followed by the same letter(s) are not significantly different at the 5% level of probability. Duncan's multiple range test.

Plant population N.S. $P = 0.05$

Plant population $\times$ planting date N.S. $P = 0.05$

(Worker, 1975), our data indicate that a delay of up to 3 weeks in planting did not cause significant yield reduction with the hybrid Amak R-10 under conditions in the San Joaquin Valley. Similar results from June plant-

ings were reported by Newman (1961) with the hybrid RS-610. That low levels of midge infestation do not cause significant yield losses has been shown by Huddleston et al. (1972), who failed to obtain significant yield decreases in

Fig. 9. Relationship between number of adult sorghum midges emerging per head and grain sorghum production in 1973. Numbers in parentheses are plant populations.

Fig. 10. Relationship between number of adult sorghum midges emerging per head and grain production of individual heads in 1973. Numbers in parentheses are plant populations.

plots where midge infestation ranged from 6 to 15 adults per head.

1973. Plant populations of 13 and 39 plants per meter and 6 planting dates were evaluated. Yields were not affected by plant population or the interaction between planting date and plant population (Table 2). Yield decreased significantly in both plant populations as midge infestation increased (Fig. 9). The data presented in Table 2 appear to be somewhat in conflict with the proposed hypothesis that increasing levels of midge infestation cause decreased yield. Such is not the case, however. Yields for the first three planting dates, although increasing slightly on 8 and 15 June, were not significantly higher than those from the 1 June planting date. Also, the possibility of a curvilinear regression between yield and both planting date and midge infestation was examined using the techniques described by Snedecor (1956) and found to be nonsignificant ($P = 0.05$). Harding (1965b) concluded that the number of midges per head at light infestation levels was not necessarily correlated with yield. Significant

yield losses did not occur until the midge infestation level exceeded 40 adults per head in plots planted on 29 June and blooming on 29–30 August. Maximum losses occurred in plots planted 6 July, and flowering on 10–11 September. There was no significant difference in yield between the high and low plant populations, although the midge infestation in the low plant population was $2\frac{1}{2}$ times that in the high population. An examination of the two regression coefficients (Fig. 9) shows that the yield loss per unit increase in midge numbers at 39 plants per meter was $2\frac{1}{4}$ times that at 13 plants per meter. This indicates that lower plant populations can produce the same amount of grain as higher populations despite the increased severity of midge attack.

This concept is more easily understood by examining the relationship between midge infestation and the amount of grain produced by individual heads (Fig. 10). The larger heads in the low plant population plots produced nearly twice the amount of grain as did the small heads in the high population plots,

TABLE 3
GRAIN YIELDS AND NUMBER OF ADULT MIDGES PER HEAD FROM FOUR
PLANTING DATES AND THREE PLANT POPULATIONS.
KEARNEY HORTICULTURAL FIELD STATION.
FRESNO COUNTY, CALIFORNIA. 1974.

Planting date	Date of 50% bloom ^a	No. plants per meter	No. adult midges per head	Yield kg per ha ^b
1 June	8 Aug.	13	5.0	5645 abc
	9 Aug.	26	5.0	6156 ab
	9 Aug.	39	3.2	6521 a
15 June	15 Aug.	13	12.4	5074 bc
	15 Aug.	26	13.5	5300 bc
	16 Aug.	39	12.8	5711 abc
29 June	27 Aug.	13	63.2	4042 d
	27 Aug.	26	42.3	3670 d
	28 Aug.	39	33.3	4180 d
13 July	15 Sept.	13	170.9	2109 e
	16 Sept.	26	163.8	2348 e
	16 Sept.	39	73.1	2560 e

^a Distal one-half of most heads showing yellow flowers.

^b Means followed by the same letter (s) are not significantly different at the 5% level of probability. Duncan's multiple range test.

Plant population N.S. $P = 0.05$

Plant population $\times$ planting date N.S. $P = 0.05$

when midge numbers were near zero and thus not influencing yield. As midge infestation increased, the yield per head in the high population plots decreased by 48 mg per head per midge, whereas the decrease in the low popula-

tion plots was only 25 mg per head per midge. This indicates that the larger heads produced in the low population plots were better able to tolerate high levels of midge infestation without suffering a commensurate yield reduction.

Fig. 11. Relationship between number of adult sorghum midges emerging per head and grain sorghum production in 1974. Numbers in parentheses are plant populations.

Fig. 12. Relationship between number of adult sorghum midges emerging per head and grain production of individual heads in 1974. Numbers in parentheses are plant populations.

1974. Populations of 13, 26, and 39 plants per meter were evaluated on four planting dates. As in 1973, yields were not affected by plant population (Table 3). Likewise, there was no significant interaction between planting date and plant population. The relationship between midge infestation and yield is shown in Fig. 11. As in previous years, yield decreased as the number of adults emerging per head increased. However, significant yield losses did not occur until midge infestation exceeded 33 adults per head in plots blooming ca. 28–29 August (planted 29 June). Maximum losses occurred in plots flowering in mid-September (planted 13 July). Losses in relationship to midge infestation in the low and middle plant populations plots were nearly identical, each losing ca. 20 kg per ha for each additional midge per head, based on the regression coefficient in Fig. 11. As in 1973, however, the yield loss in the high population plots was more than twice that in the low population plots, and also twice that in the middle population plots. Reference to the relationship be-

tween midge infestation and grain production by individual heads (Fig. 12) shows the loss per increase of one midge per head in the high population was twice that in the low population, and $2\frac{1}{2}$ times that in the middle population. Again, larger heads were better able to tolerate increased midge infestation levels without a loss in yield. Plots blooming on 27–28 August (planted 29 June) and thinned to 13 and 26 plants per meter yielded as well as plots thinned to 39 plants per meter despite twice the midge infestation (Table 3). Similar results were obtained from plots flowering on 15–16 September (planted 13 July).

That midge infestation was the most important factor affecting yield during 1973 and 1974 is shown by the general multiple regression model,

$$Y = a \pm b_1X_1 \pm b_2X_2 \pm b_3X_3$$

where

X_1 = No. midges per head

X_2 = Plant population

X_3 = No. midges per head $\times$ plant population interaction

Y = Yield

b_1, b_2, b_3 = Regression coefficients for X_1, X_2, X_3

a = Y intercept

In both years, only b_1 (regression coefficient for the number of midges per head) was significant ($P = 0.05$), indicating that neither plant population nor the interaction explained any significant variation in yields.

Role of wild hosts

Several weed species have been shown to support populations of sorghum midge (Bottrell, 1971; Huddleston et al., 1972; Randolph and Montoya, 1964). In California, however, johnsongrass appears to be the only wild host of importance. Midge populations are main-

Fig. 13. Emergence of adult sorghum midges from johnsongrass in 1973.

tained at low levels in this species until double-cropped sorghum begins blooming ca. 1 August (Fig. 13). The increase in numbers to levels ultimately causing damage then occurs in the sorghum fields rather than in johnsongrass.

GENERAL DISCUSSION AND SUMMARY

The buildup of sorghum midge populations in the San Joaquin Valley is similar to that reported from various sorghum-growing regions of Texas (Harding, 1965a; Thomas, 1969; Bottrell, 1971; Huddleston et al., 1972). Diapause is terminated in late May, provided suitable conditions exist, and populations are maintained at low levels on johnsongrass throughout June and July. When sorghum begins blooming in early August, midge populations begin a slow increase to levels capable of reducing yield by late August. It is difficult, if not impossible, to determine the exact infestation level at which a significant yield reduction occurs. Yields may vary significantly from year to year using the same hybrids grown at the same location, with planting date, fertilization, and other cultural practices held constant (Worker, 1975). It is not surprising then that yields varied from year to year under nearly identi-

cal midge infestation pressure (Tables 2 and 3).

Infestation levels of 0 to 25 midges per head had no significant impact on ultimate yield. However, infestation levels of 50+ per head resulted in significant yield reductions. The impact of infestation levels between these ranges appears questionable, and factors other than midge probably play an important role. In 1973, 34 adults per head in the high population plots (39 per meter) did not cause the yield to drop significantly from that of plots blooming the previous week, in which the infestation level was 17 per head (Table 2). In 1974, however, the identical infestation level at the same plant population did result in a significantly reduced yield (Table 3).

In all three years, the infestation levels in plots flowering prior to 16 August (planted 15 June or before) failed to reach 25 adults per head, and no sig-

nificant yield losses occurred. The infestation level in those plots blooming 27 August or later often exceeded 50 adults per head, resulting in significant yield reductions.

Sorghum blooming between mid and late August may escape damaging levels of midge infestation, as was the case in 1973 (Table 2). Every day's delay in planting after 15 June increases the risk of severe loss from sorghum midge, and fields planted later than 22 June will likely suffer severe midge damage and yield loss.

We obtained a significant negative linear regression of yield on the number of adults emerging per head in all plant populations. Similar results were obtained by Harris (1961), who used the number of infested spikelets as the

independent variable. The yield loss per increase of one midge per head in plots thinned to 39 plants per meter was more than double that occurring in plots thinned to 13 plants per meter. The loss in plots thinned to 26 plants per meter in 1974 was nearly identical to that in plots thinned to 13 plants per meter. Total yield per ha, however, was not affected, and there was no significant difference between plant populations. Grimes and Musick (1960) failed to obtain yield differences with plant populations ranging from 138,300 to 553,300 plants per ha and concluded that a large variation in plant population can exist without seriously affecting yield. This indicates that maximum yields can be obtained with a plant population of 13 to 26 plants per meter.

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Portions of the state map in Fig. 1 were reproduced with the permission of Rand McNally & Company.

LITERATURE CITED

BOTTRELL, D. G.

1971. Entomological advances in sorghum production. Tex. Agri. Exp. Sta. PR-2940; 28-40.

BOWDEN, J.

1965. Sorghum midge, *Contarinia sorghicola* (Coq.), and other causes of grain-sorghum loss in Ghana. Bull. Entomol. Res. 56: 169-189.

DEAN, W. H.

1911. The sorghum midge. USDA Bull. 85, part IV; 39-59.

DOERING, G. W., and N. M. RANDOLPH

1963. Habits and control of the sorghum midge, *Contarinia sorghicola*, on grain sorghum. J. Econ. Entomol. 56: 454-459.

DOGGETT, H.

1970. Sorghum. Longmans, Green and Co. Ltd., London. 403 p.

GRIMES, D. W., and J. T. MUSICK

1959. How plant spacing, fertility, and irrigation affect grain sorghum production in Southwestern Kansas. Kansas Agri. Exp. Sta. Bull. 414: 1-17.

1960. Effect of plant spacing, fertility, and irrigation management on grain sorghum production. Agron. J. 52: 647-650.

- HARDING, J. A.
1965a. Ecological and biological factors concerning the sorghum midge during 1964. Tex. Agri. Exp. Sta. Bull. MP-773. 10 p.
1965b. Evaluation of insecticides for sorghum midge control. Tex. Agri. Exp. Sta. PR-2352: 1-7.
- HARRIS, K. M.
1961. The sorghum midge, *Contarinia sorghicola* (Coq.), in Nigeria. Bull. Entomol. Res. 52: 129-46.
- HUDDLESTON, E. W., D. ASHDOWN, B. MAUNDER, C. R. WARD, G. WILDE, and C. E. FOREHAND
1972. Biology and control of the sorghum midge. 1. Chemical and cultural control studies in West Texas. J. Econ. Entomol. 65: 851-55.
- LONG, W. H., V. L. MARBLE, W. E. PENDERY, and V. E. BURTON
1961. New California pest, sorghum midge, found in San Joaquin Valley. Calif. Agri. 15(1): 7-9.
- NEWMAN, J. S.
1961. Effect of planting dates on the yield of grain sorghum hybrids in different maturity groups on the High Plains, 1960. Tex. Agri. Exp. Sta. PR-2198: 1-7.
- PASSLOW, T.
1954. The sorghum midge diapause. Nature 174: 656.
1965. Bionomics of sorghum midge (*Contarinia sorghicola* (Coq.)) in Queensland, with particular reference to diapause. Queensland J. Agri. and Anim. Sci. 22: 149-167.
- RANDOLPH, N. M., and E. L. MONTOYA
1964. Ecology, biology, and control of sorghum midge on the Texas South Plains. Tex. Agri. Exp. Sta. PR-2304: 1-10.
- SNEDECOR, G. W.
1956. Statistical methods. Iowa State Univ. Press, Ames, Iowa. 534 p.
- STANFORD, R. L., E. W. HUDDLESTON, and C. R. WARD
1972. Biology and control of the sorghum midge. 3. Importance of stage of bloom and effective residual of selected insecticides. J. Econ. Entomol. 65: 796-99.
- SUMMERS, C. G.
1975. Daily adult emergence in the sorghum midge, *Contarinia sorghicola*. Environ. Entomol. 4: 495-8.
- SUMMERS, C. G., R. L. COVIELLO, W. E. PENDERY, and R. W. BUSHING
1975. Sorghum midge pest management in the San Joaquin Valley. Calif. Agri. 29(9): 4-5.
- THOMAS, J. G.
1969. The sorghum midge and its control. Tex. Agri. Exp. Sta. L-842: 1-4.
- WALTER, E. V.
1941. The biology and control of the sorghum midge. USDA Tech. Bull. 778: 1-26.
- WORKER, G. F.
1975. Hybrid grain sorghum trials. Calif. Agri. 29(1): 8-9.
- YOUNG, W. R.
1970. Sorghum insects, p. 235-87, in J. S. Wall and W. M. Ross [eds.], Sorghum production and utilization. AVI Pub. Co., Inc., Westport, Conn. 702 p.

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