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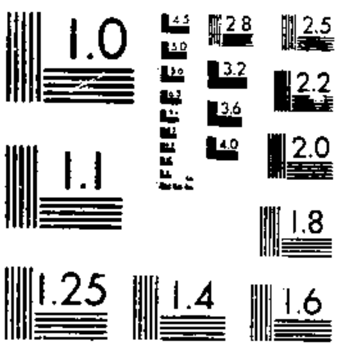

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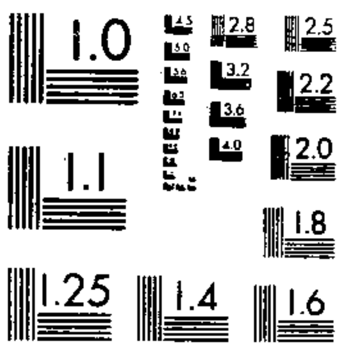

MICROCOPY RESOLUTION TEST CHART
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EFFECT of TEMPERATURE and HUMIDITY on DEVELOPMENT and POTENTIAL DISTRIBUTION of the MEXICAN FRUIT FLY in the UNITED STATES

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Effect of Temperature and Humidity on Development and Potential Distribution of the Mexican Fruit Fly in the United States

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The need for evaluating in the laboratory the effects of temperature, humidity, and light in their actual diurnal fluctuating patterns was recognized early in the ecological investigation of tephritid fruit flies occurring in Hawaii. Equipment, called bioclimatic cabinets, (fig. 1) was specifically designed to facilitate these and subsequent studies (Flitters and Messenger *7*, Flitters et al. *9*).[1]

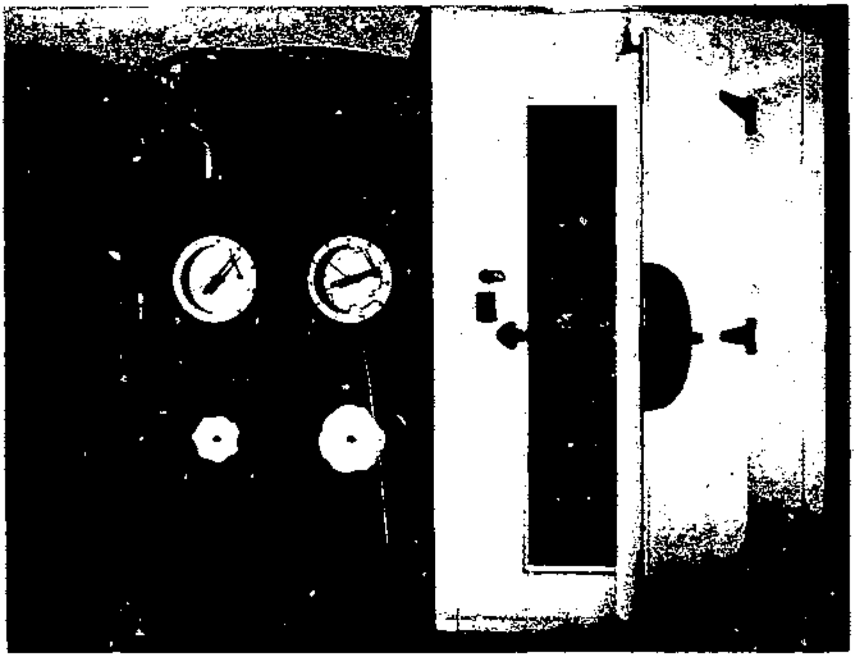


Figure 1.—Bioclimatic cabinet showing anteroom and transmitting and recording instruments.

[1] Italic numbers in parentheses refer to Literature Cited, p. 36.

Ecological studies on the Mexican fruit fly (*Anastrepha ludens* (Loew)) were undertaken in these cabinets upon conclusion of similar investigations on fruit flies in Hawaii. These studies were stimulated by the discovery in early 1954 of several specimens of the Mexican fruit fly at scattered points in northwestern Mexico in the vicinity of Tijuana, within a half mile of the international boundary, and later in the year by the discovery of an adult in one of a series of insect survey traps at San Ysidro in southwestern San Diego County, Calif. This insect had been known to occur in the United States only as a winter migrant in southern Texas. Consequently, the discovery of a specimen as far north as southern California created an urgent need for reliable information on the potential establishment and perpetuation of this economic pest in the important citrus and fruit-producing areas in California, Texas, Florida, and other important agricultural areas in the southern tier of States.

The research on the Mexican fruit fly at Mexico City, conducted by the U.S. Department of Agriculture, was expanded, and the California Agricultural Experiment Station entered into a cooperative research program that included bioclimatic investigations conducted at Brownsville, Tex. The results of this research are discussed in this bulletin. Preliminary reports of this work were published by Flitters and Messenger (*8*) and Messenger and Flitters (*16*).

DISTRIBUTION AND BIOLOGY OF THE MEXICAN FRUIT FLY

This insect is one of several fruit flies of economic importance in subtropical Mexico and Central America (fig. 2). Detailed study of the

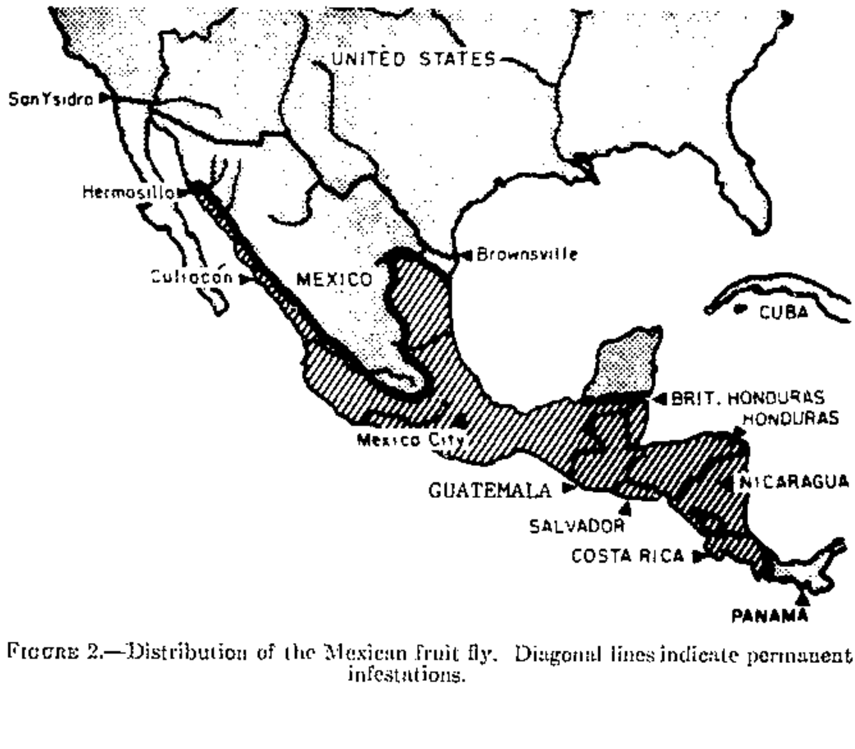


FIGURE 2.—Distribution of the Mexican fruit fly. Diagonal lines indicate permanent infestations.

specific localities in Mexico where it has been found indicates that it is able to tolerate several widely differing kinds of basic climates.

Based on the topographical and climatological maps of Tamayo (*20*) and the climatic and vegetational descriptions of Leopold (*13*), the Mexican fruit fly would appear to occur at elevations from sea level to about 5,000 feet in the southern central plateau and from the hot, arid deserts of Sonora to the humid tropical forests of southernmost Chiapas and Veracruz. The species is restricted in the northern half of Mexico to the States of Sonora, Sinaloa, Tamaulipas, and Nuevo León and to the seaward slopes and coastal plains of the two lateral cordilleras, which bound the high central plateau of Mexico, the Sierra Madre Occidental and the Sierra Madre Oriental. The pest also occurs in the States of Colima, Jalisco, Michoacán, Oaxaca, and Veracruz on both the northern and southern slopes of the transverse Cordillera Neo-Volcánica, which runs east and west at about the latitude of Mexico City.

To the south the distributional records show that the species occurs along the midelevation slopes of the Sierra Madre de Chiapas and in the central Chiapas highlands. Along the east coast the Mexican fruit fly is known from near sea level in the vicinity of Tampico, Tuxpan, and Veracruz and at the 4,000-foot level near Jalapa and Córdoba west of the city of Veracruz.

The climate and flora of these various areas differ widely. In addition, local agricultural and irrigation practices have altered the climatic conditions in many of these recorded sites. For example, the species is found in citrus at Hermosillo, Sonora, in essentially the middle of a hot, dry, subtropical desert, characterized regionally as a cactus desert interspersed with a mesquite-grassland vegetation. But at Hermosillo, local irrigation practices have converted the site near the Sonora River into a sort of tropical oasis. A similar situation occurs at Culiacán, Sinaloa, farther south along the west coast, where the gross vegetation is a characteristic semiarid thorn forest.

The region on the east coast in the States of Tamaulipas and Nuevo León is classed as a semiarid steppe, again with a predominantly mesquite-grassland vegetation. Here the fruit fly appears in such areas as Monterrey, Montemorelos, Linares, and Llera, where local irrigation practices have modified the climatic conditions and host fruit situation. Farther south on the gulf coast, where the species occurs in the State of Veracruz, conditions are much more moist, and the region is classed broadly as a hot, humid tropical savanna, with considerable rainfall, mostly in the summer and fall. The regional vegetation in this State varies in the extreme north from a drier thorn forest type to a tropical evergreen forest in the central part.

In the south-central plateau region at elevations from 4,000 to 6,000 feet and including valleys in the vicinity of Tequila, Guadalajara, and Ayo el Chico, State of Jalisco, the climate is temperate, with winter frosts and warm, wet summers. This climatic zone, to a varying degree, though without the frosts, includes the northern slopes of the Río de las Balsas basin in southern Mexico and areas in the vicinity of Cuernavaca, Morelos, and of Jungapeo and Uruapan, Michoacán.

In the far south in Chiapas State the Mexican fruit fly is known mostly at the higher elevations, though it has been found at Tapachula on the western slopes just north of the Guatemalan border at an elevation as low as 1,000 feet.

Although considerable numbers of wild and cultivated hosts occur in the true tropical rain forest environment of Mexico, this species does not appear there in large numbers, apparently because of the climate. In the tropical rain forests of southern Veracruz and in Tabasco, one of the dominant plant species is the fruit fly wild host *Achras zapota* L. The distributional records of the Mexican Fruit Fly Investigations laboratory of the U.S. Department of Agriculture at Mexico City more or less substantiate the claim of Stone (*19*) that this insect appears restricted south of Mexico to the higher elevations. The fact that it has not spread into tropical areas adjacent to its current limits of distribution in Central America, for example into Panama, also supports this contention.

Baker et al. (*1*) showed that adults of the Mexican fruit fly are able to tolerate repeated exposures to subfreezing temperatures and, most important, are able to do so without becoming permanently impaired reproductively. It is, therefore, interesting to compare the limits of distribution of the species with the limits of distribution of frost-free habitats in Mexico. Leopold (*13*), in his discussion of the physiographic regions of Mexico, provides a map of Mexico delimiting areas subject to winter frost ("temperate regions") from those known to be frost free ("tropical regions"). In the greater part of the range of habitats within which this insect is known to occur, particularly in the southern half of the country, it is seen on a regional basis to occupy frost-free areas. However, in the north in the States of Sonora on the west coast and in Tamaulipas and Nuevo León in the east, the fruit fly occupies habitats that have rather short periods of winter frost. This would indicate that such a climatic index as the presence of frost during the winter is insufficient to delimit potential distribution of the pest.

Crawford (*4*) and Hoidale (*12*) reported that this species occurred in Panama and northern South America, but their findings have not been verified in recent pest surveys.

Adult flies periodically extend their normal range by dispersal from northeast Mexico into the lower Rio Grande Valley of Texas. The first record of such an extension in range was made as early as 1903 (Sanderson *18*). The first known infestation by this pest of citrus in the Rio Grande Valley was called to the attention of entomologists in the U.S. Department of Agriculture in the spring of 1927.[2] The fruit fly has gradually extended its way northward along the west coast of Mexico, having reached Culiacán in 1933 (Baker et al. *1*) and Hermosillo, which is approximately 29° N. latitude, in about 1953 (Harper *10*). Beyond Hermosillo to the north there appears to be a dearth of potential host material. A large part of the area is desert, which is unfavorable for normal dispersal of the fly northward.

The Mexican fruit fly, a rather hardy subtropical species, produces several generations a year, but, like the Hawaiian species, has no cold-resistant overwintering stage that undergoes diapause or hibernation. Eggs are deposited by the female within selected fruits. After the eggs hatch, the larvae burrow within the fruit and so remain until fully developed (third instar). The mature larvae leave the fruit and enter the soil to pupate. Adults, upon emergence from the puparia, force their way upward through the soil to freedom.

[2] BERRY, N. O. HISTORY OF THE MEXICAN FRUIT FLY PROJECT, 1927–1943. 66 pp. U.S. Dept. Agr., Bur. Ent. and Plant Quar. 1943. [Unpublished.]

In the insectary at Brownsville, Tex., maintained at 75° to 80° F., eggs hatch after 3½ to 4½ days. The larval stage lasts from 10 to 12 days in an optimal dietary substrate, and the pupal period extends from 16 to 19 days. The adult preovipositional period ranges from 12 to 16 days for flies fed protein hydrolysate, sucrose, and orange juice concentrate, a near-optimal adult fly diet. The average adult longevity under insectary conditions is from 65 to 95 days. Under varying conditions of climate and with various ovipositional substrates, the incubation of eggs has been extended as much as 30 days, the larval and pupal periods beyond 100 days, and the adult preovipositional period well over 1 month.[3] The maximum longevity reported was 11 months for females and 16 months for males (Baker et al. *1*, Darby and Kapp *5*, McPhail and Bliss *14*).

The host range of the Mexican fruit fly includes citrus, other than lemon and sour lime, many deciduous fruits such as peach, pear, apple, and apricot, and many tropical fruits such as mango, guava, pomegranate, white sapote, and the Mexican or yellow chapote, which is considered to be the prime wild host. Many fruits are neither preferred nor very important insofar as the insect's abundance is concerned, and the degree to which a fruit becomes infested is not a true criterion by which to measure its importance. Numerous fruits, lightly infested and widely separated, can contribute more to the population buildup of an insect species than a few heavily infested fruits restricted in distribution.

The studies conducted with the fruit fly at Brownsville have pertained solely to the effect of climate on its development and perpetuation. Results indicating various degrees of fruit fly activity or reproductive capacity possible in certain simulated areas in the United States do not take into account other ecological factors such as host fruit availability, acceptability, abundance, and succession, nor the biotic factors such as parasites, predators, and disease, all of which are of vital importance to the establishment and population dynamics of the insect.

MATERIALS AND METHODS

Nine bioclimatic cabinets were used. Each cabinet, constructed similarly to a walk-in refrigerator, is provided with two insulated doors, separated by a vestibule measuring 4 by 4 by 7 feet high (fig. 1). These doors provide entry into a stainless-steel working space measuring 6 by 6 by 7 feet high. Built into the wall opposite the door is a window constructed of three pairs of glass panes, each pair with a dehydrated air space in between to hold heat transfer to a minimum and to provide a clear view of the cabinet interior. Attached to the exterior walls of the cabinet are various air-conditioning controls and instruments that permit the air circulating within the cabinets to be cooled or heated, dried or humidified.

A major advantage of the equipment is its capability of controlling temperatures and humidities in smoothly varying patterns such as occur naturally. Temperatures may be controlled to within ±1° F. over the range −5° to +125°. Humidities within this same temperature range may be controlled to within ±3-percent relative humidity over the range

[3] FLITTERS, N. E. DEVELOPMENTAL THRESHOLD FOR PREIMAGINAL DEVELOPMENT OF THE MEXICAN FRUIT FLY. 8 pp. U.S. Dept. Agr., Ent. Res. Div. 1959. [Unpublished.]

20 to 98 percent. Humidity can be controlled to levels as low as 10 percent when the temperature is above freezing. All cabinets have sufficient capacity to raise or lower the temperature 40° and to lower relative humidity 60 percent in 60 minutes. A lamp designed to give a wide spectral band of visible light provides daylight illumination requirements within the cabinets. These lights are automatically turned on and off by means of time clocks, the settings of which are periodically varied to simulate natural variations.

For studying the Mexican fruit fly within the bioclimatic cabinets, globular screen cages measuring 12 inches in diameter were constructed, consisting of frameworks of light sheet metal covered with 14-mesh wire screen (fig. 3). To facilitate the introduction and removal of host fruits, food, water, and flies, an 8-inch heavy zipper was attached to a plastic screen cover, which was clamped over a circular opening in the lower frame of the cage and served as its base. A hook attached to the top permitted the cage to be suspended within the cabinet work space.

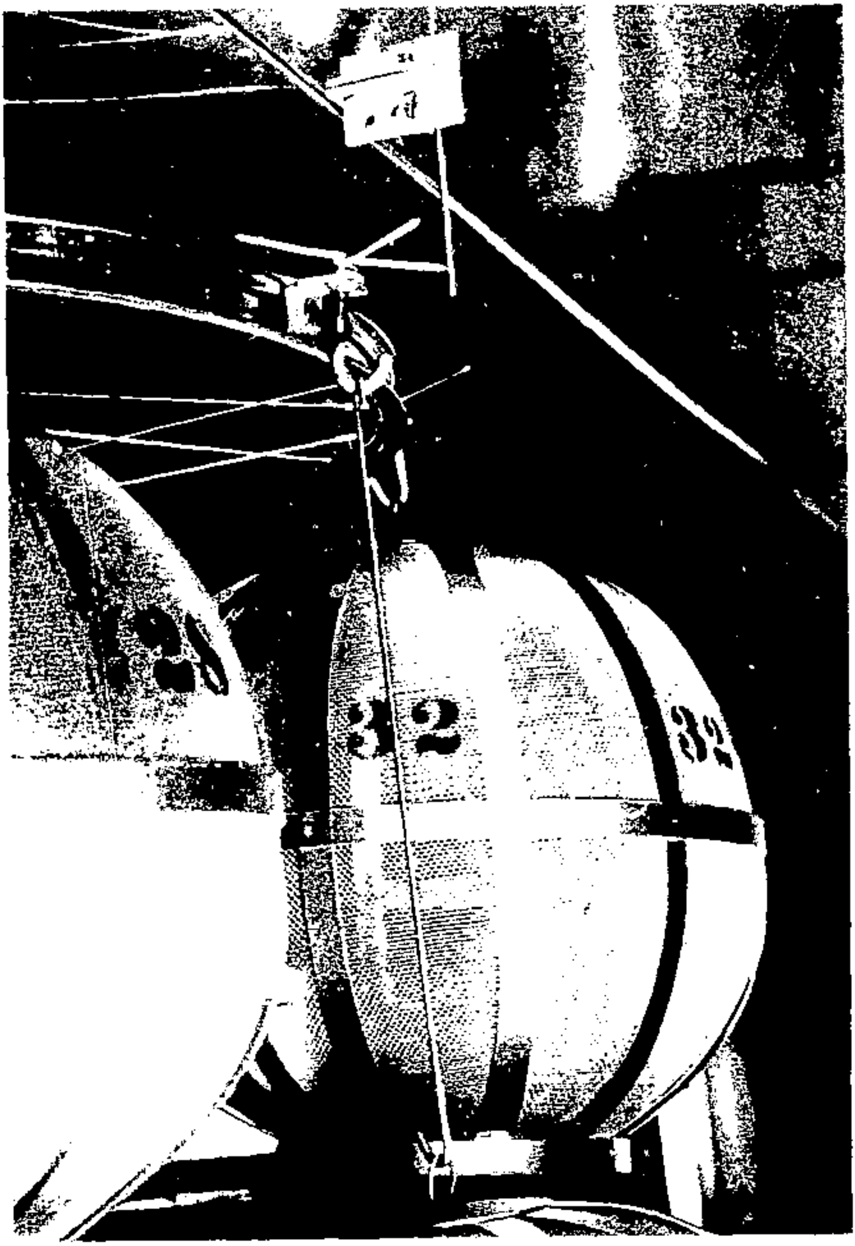
These globular cages were suspended from a bicycle wheel assembly, whose shaft in turn passed through the ceiling of the cabinet work space. The wheel, measuring 26 inches in diameter, permitted four globular cages to be suspended from its periphery, and, by using suspension hooks of varying lengths the wheel could carry 12 cages in all.

To minimize positional variation of the cages within the cabinet, the assembly was slowly rotated at a speed of one revolution per minute by a small electric motor mounted on top of the bioclimatic cabinet. The motor was connected to the bicycle wheel shaft by means of a gear-reduction box, pulleys, and belts. A slip clutch and bearing, mounted on the shaft of the wheel, were used to stop the cages for observation or manipulation of the fly samples without stopping the gear train or the motor.

To further reduce positional effects, the individual globular cages were also rotated intermittently on their own axes. Four trip rods on the suspension hooks of each cage engaged two stationary trip rods attached to the cabinet roof. As the main wheel assembly rotated through one turn, each cage rotated through two successive one-quarter turns. These actions served to expose the flies within a cage to all directions while at the same time the cage was slowly rotated about within the work space.

To measure oviposition and to permit reproduction of the fruit flies, grapefruit were exposed to the adults within the globular cages. After exposure, the grapefruit were placed singly in combination holding box and cage units. The box measured 4 inches wide, 8 inches long, and 2 inches deep, and a screen cage 6 inches high fitted over the top of the holding box. Within the holding box the grapefruit were placed on a layer of moist soil composed of peat moss, humus, and sand, which provided a place for the fully grown fruit fly larvae to pupate.

All fruit flies used in the cabinet experiments were cultured under standardized rearing techniques developed by the U.S. Department of Agriculture from insect rearing studies. Cultural procedures, including the use of carrot medium for larval rearing (Finney *6*), and other manipulation techniques were developed by the California Agricultural Experiment Station. The fruit fly culture was conducted in a special insectary used exclusively for this work. The laboratory techniques developed for the mass rearing of fruit flies in Hawaii were successfully



[illegible] flies were confined.

[illegible] Mexican fruit fly and needed only limited [illegible] requirements of this particular species, [illegible] producing experimental material to be used in the [illegible] oviposition shells, made of cheesecloth and paraffin (McPhail and Guiza *15*), were exposed in the early morning to gravid flies contained in standard rearing cages. After 4 hours the shells were removed and the eggs were washed from them with a light stream of distilled water. The eggs were collected in a beaker, and samples were transferred to a calibrated glass funnel and measured volumetrically into groups of 2,000 eggs. Each group of eggs was placed on a moist disk of organdy cloth, approximately 1½ inches in diameter, which was then placed in a petri dish. The egg dishes were stored in an incubation cabinet held at a constant 80° F. and 80-percent relative humidity.

Eggs under these conditions took approximately 4 days to hatch. At that time the pad, containing both eggs and newly hatched larvae, was transferred to a prepared larval medium consisting of finely ground carrots, dried brewer's yeast, butoben, sodium benzoate, and sufficient hydrochloric acid to bring the acidity to a pH of 3.5. Trays, holding the larval medium, were placed in the incubation cabinet. The larval development took 11 to 12 days in this medium, after which the larvae were washed free of the medium and counted volumetrically. One hundred larvae collected at random were weighed and the average weight was determined for each rearing batch.

Larvae, in groups of approximately 400, were transferred to small tin cans containing moist sandy soil. The cans were then placed in the rearing cages and held in the insectary at approximately 75° F. After penetrating the soil the larvae pupated, and under that thermal condition in the laboratory development was completed and adults emerged in approximately 18 days.

Flies to be used in the bioclimatic cabinets were transferred to a screened anesthetizing chamber, where they were immobilized with a combination of carbon dioxide and ether, counted by sexes, and transferred to the special globular screen cages. Another method of transfer was accomplished by aspirating the flies into a glass tube.

Experiments in the cabinets were designed to show the effect of different combinations of temperature and humidity on the various stages and on the life cycle as a whole of the test insect. Detailed observations and measurements were made on the preoviposition, sexual development, mating, reproduction, and longevity of fruit fly adults, development and recovery of the immature stages, and the rate and extent of buildup of progeny generations.

As a basis for comparing fruit fly activity and performance, a provisional life cycle was determined, based upon rearing results in the insectary. Under the constant conditions of temperature and relative humidity in the insectary, the life cycle took about 50 days, which may be divided approximately into the following intervals: Egg stage 4 days, larval stage 12 days, pupal stage 18 days, and adult preovipositional period 15 days. The normal adult longevity in the insectary was about 90 days, and adult reproduction was considered optimal when 2,000 to 3,000 eggs were laid by each female.

The suitability of specific simulated climates for supporting fruit fly populations was estimated by comparing the provisional life cycle with fruit fly performance and activity in the cabinet.

In each cabinet one globular cage was maintained with mature adult fruit flies from the insectary. These flies were provided with a diet of enzymatically hydrolyzed yeast and soybean, powdered orange juice concentrate, sucrose, and water. The hydrolyzed yeast and soybean provided the protein requirements for adult development to sexual maturity and for optimum adult fertility, productivity, and longevity. Food and water were replenished when necessary.

To this cage of mature fruit flies, grapefruit were exposed for 24-hour periods three times weekly. Then each fruit was placed in a combination holding box and cage, which was labeled with the globular cage number, the date of exposure, and the study site. The fruit fly eggs hatched within the fruit, and the resulting larvae fed until fully grown, whereon they crawled out of the fruit remains and into the soil beneath. Pupation occurred within the soil, and the eventual emergence of the progeny adults completed the immature development.

Mortality of the adult fruit flies in the parent cage was determined weekly, and the sample was replenished with identical numbers at that time.

A second globular cage containing adult fruit flies that were only 1 to 2 days old on introduction was maintained in each cabinet. These flies, fed the same diet as described for the mature flies, were held for study of the preoviposition period. After this cage of flies was in the cabinet for 8 days, oviposition shells were exposed for 24 hours every day until eggs were found. These eggs were placed on blackened filter paper soaked in a 2-percent benzoic acid solution or other comparable mold inhibitor and held in the insectary for hatching. Visual observation for copulation was made each evening. Oviposition indicated female maturity, and egg hatch indicated successful mating. The cage of immature flies was restocked only when each maturation study was completed.

A third cage of 1- to 2-day-old fruit flies, fed the same diet, was maintained in each cabinet to provide information on adult longevity. The mortality of these flies was measured weekly, and longevity was determined by the age of the last five survivors rather than by the sole individual survivor. This cage was replenished only at the completion of each longevity study.

Each globular cage of adult flies was stocked initially with 500 individuals, two-thirds of which were females.

Each day progeny of stock fruit flies were collected as they emerged, counted by sexes, placed in a fourth globular cage in each cabinet, and provided with the usual adult diet. The rate and extent of population buildup were noted. Eight days after a progeny generation began to emerge, grapefruit were exposed in the same manner as for the parent stocks, and the culturing of a second generation was commenced. Eventually several cages containing successive generations of the fruit fly were maintained within each cabinet.

In addition, auxiliary studies were conducted for each of the simulated climates. Immature stages of the insect, represented by eggs, infested fruit, and pupae, were removed from the culture room and introduced into the cabinets once weekly. The eclosion of eggs, larval development in the grapefruit, and pupal duration were all determined, and the differences in growth rate were correlated with the factors of climate.

RESULTS

The bioclimatic cabinet investigations of the Mexican fruit fly lasted just over 4 years. The study included simulation of 17 climatological sites, as shown in table 1. Progressive seasonal climatological changes and their effect on fruit fly development and perpetuation are summarized for each site simulated.

TABLE 1.—*Climatological sites simulated in bioclimatic studies*

Site	Approximate latitude	Altitude
	° N.	*Feet*
Tempe, Ariz.	33.5	1,159
Chula Vista, Calif.	32.5	9
Compton, Calif.	34.0	65
El Centro, Calif.	32.5	30
Riverside, Calif.	34.0	1,045
San Jose, Calif.	37.0	70
Sebastopol, Calif.	38.0	145
Orlando, Fla.	28.5	106
Athens, Ga.	34.0	798
Fort Valley, Ga	32.5	526
Houma, La.	29.5	13
Greenwood, Miss.	33.5	140
Malden, Mo.	36.5	290
Mesilla Park, N. Mex.	32.5	3,865
Charleston, S.C.	33.0	9
Memphis, Tenn.	35.0	263
Brownsville, Tex.	26.0	16

Tempe, Ariz.

A test simulating weather for Tempe, Ariz., in 1937 from October 5 through December 31 and January 1 through September 28 (run in that sequence) was carried out in 1956 and 1957. During this period 146 fruits were exposed to a parent stock of Mexican fruit flies. Temperatures and relative humidities for this study site are shown in figure 4.

Climatic conditions were favorable for the flies to successfully infest fruits from October through January, but no adults were recovered from the 362 pupae collected. The first infestation to result in the establishment of an F-1 generation occurred on February 21. Complete preimaginal development ranged from 82 to 90 days. A total of 38 pupae resulted from infestations during the month.

From March through May, when temperatures increased, both fruit infestations and preimaginal developmental rates increased. Nineteen fruits infested during this period yielded 2,238 pupae, from which 1,047 progeny flies emerged. Developmental rates ranged from 100 days for the earliest infestation to 43 days for the later ones.

June, July, and August had successive daily temperature peaks over 100° F. accompanied by particularly low relative humidities. Desiccation was very rapid, and the heat was lethal to most adult flies confined in the cabinet. These temperature and relative humidity extremes were also detrimental to host fruits, which quickly lost their moisture content and readily became light and mummified, a condition that definitely inhibited the preimaginal development of the fruit flies.

Although in September the climate was suitable for fruit fly activity, oviposition, and development, succeeding months were too cold for survival.

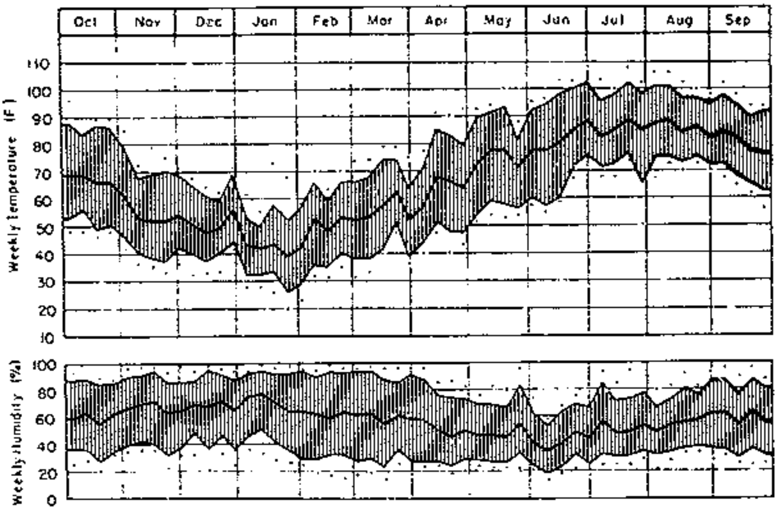


FIGURE 4.—Temperatures and relative humidities simulated for Tempe, Ariz., study, based on weather during 1937. Shaded bands indicate daily range of values throughout annual climatic cycle, as measured by weekly mean maxima and minima. Center curve represents weekly means. Points above and below each band indicate absolute maxima and minima for each week.

Summary.—The torrid summer temperatures at this site (mean 84°, mean maximum 98°) prevented fruit fly development and were lethal to adults. Climatic conditions during the early spring only were favorable for complete preimaginal development and fruit fly perpetuation. Therefore, it can be concluded that this site could support an infestation of the Mexican fruit fly only from late February through June and possibly for a short period in the fall.

Chula Vista, Calif.

A test simulating climatic conditions for Chula Vista, Calif., from March 19, 1953, through February 23, 1954, was carried out in 1954 and 1955, during which time 126 grapefruit were exposed to progeny flies. Temperatures and relative humidities for this study site are shown in figure 5.

The Chula Vista annual temperature was rather mild. Weekly mean temperatures rarely dropped below 60° F. or rose much above 80°. The proximity of this site to the ocean resulted in narrow diurnal fluctuations in temperature and relative humidity throughout the year.

Mexican fruit fly reproduction and development were comparatively heavy and continuous throughout the spring, summer, and fall. During the winter, reproduction was restricted, but preimaginal development, although retarded, continued uninterruptedly. An F–1 generation of fruit flies was established by early summer. This new generation began reproducing shortly thereafter, remaining active throughout the remainder of the summer and fall. An F–2 generation of fruit flies began and continued to emerge intermittently throughout the winter. It was determined that overwintering infestations exposed to a mean of 55.5° had a developmental cycle of 122 days.

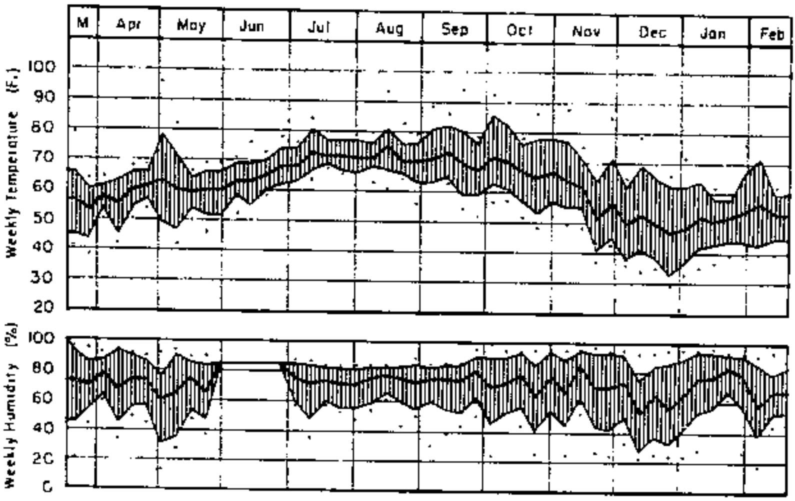


FIGURE 5.—Temperatures and relative humidities simulated for Chula Vista, Calif., study, based on weather between March 1953 and February 1954. For explanation, see legend for figure 4.

Total recovery of pupae from the F–1 generation amounted to 2,400, from which 1,695 flies emerged; 717 pupae from the F–2 population yielded 164 flies. Preimaginal development ranged from 43 to 122 days.

Summary.—Progeny flies were recovered every month of the year except January. The greatest emergence took place in September. Thus, insofar as climatic factors are concerned, the Mexican fruit fly would have little difficulty in becoming established in this site should an incipient infestation occur in any month of the year.

Compton, Calif.

The climate for Compton, Calif., from March 18, 1953, through March 28, 1954, was simulated in a bioclimatic cabinet in 1955 and 1956, during which time 143 grapefruit were exposed to a parent stock of Mexican fruit flies. Fifty fruits were exposed to the progeny of these flies, and 23 fruits were exposed to the resultant F–2 generation. Temperatures and relative humidities for this study site are shown in figure 6.

March and April were suitable for fruit fly activity, but no infestation of fruit occurred. Successive infestations followed in chronological order throughout the rest of the year.

Although the temperatures were amenable to fruit fly reproduction, they were sufficiently depressed to slow down preimaginal development. The minimum developmental period was 50 days (June–July) and the maximum 117 days (November–January).

In June, August, and September, infestations were heaviest. Despite a strong population of F–1 and F–2 flies, no third generation was realized. The recovery of adults from pupae resulting from the fruit infestations was rather high. Total flies representing the F–1 generation were 3,667, from which a second generation of 914 flies was established during the period of climate simulation.

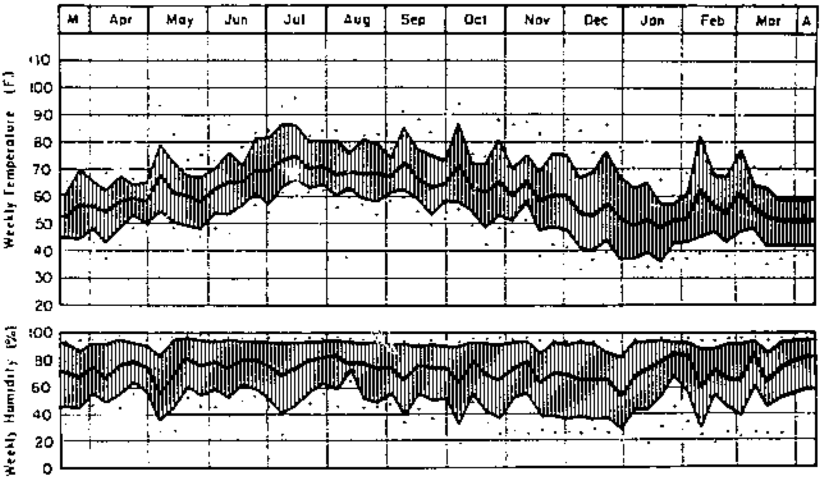


FIGURE 6.—Temperatures and relative humidities simulated for Compton, Calif., study, based on weather between March 1953 and April 1954. For explanation, see legend for figure 4.

Summary.—The high level of fruit infestation and the successive order in which successful oviposition took place from May through September indicated that the Mexican fruit fly could build up to strong populations during most of the year in climatic conditions comparable to those simulated in the Compton study.

El Centro, Calif.

Climatic conditions for El Centro, Calif., from October 25, 1951, through July 26, 1952, were simulated in 1954 and 1955. Temperatures and relative humidities for this study site are shown in figure 7.

No fruits introduced to the stock flies between October 25 and January 16 became infested. Pupae were collected from January through April, and the first progeny flies were recovered in April from fruits infested in January. Preimaginal development extended from 86 to 104 days. These infestations, which occurred under depressed thermal conditions, illustrated the extensible preimaginal developmental period that can be completed successfully by this particular fruit fly.

From May through July, day temperatures of over 100° F., accompanied by very low relative humidities, restricted fly activity and resulted in heavy adult mortality.

In studies at other sites, temperatures over 100° when accompanied by high relative humidities were soon lethal to adult fruit flies. However, in the El Centro study some adults survived the maximum of 112° and succumbed only after exposure to three consecutive daily peaks of around 110°. During these peaks relative humidity ranged from 20 to 30 percent. Adult flies congregated on the saturated cotton, which provided the water supply within each cage.

None of the fruits introduced to stock flies during June and July became infested, nor were there any progeny recovered from previous infestations. Progeny recovered for the simulated period totaled 206; these emerged from 559 pupae.

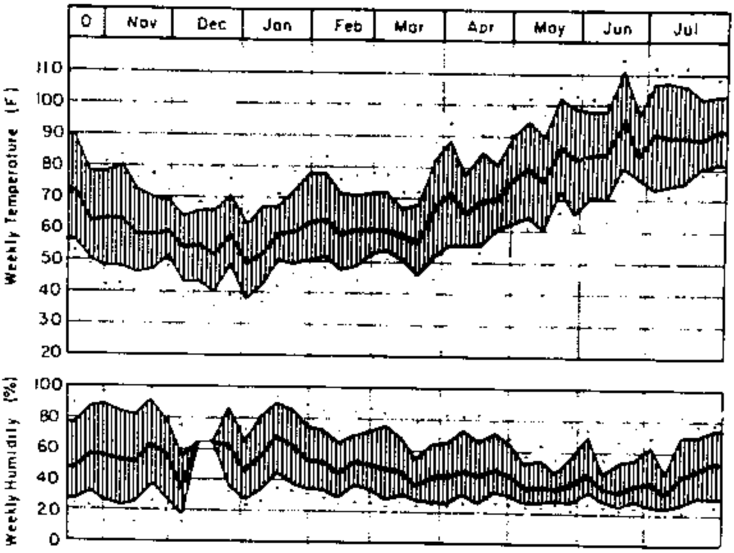


FIGURE 7.—Temperatures and relative humidities simulated for El Centro, Calif., study, based on weather between October 1951 and July 1952. For explanation, see legend for figure 4.

Summary.—The Mexican fruit fly would have difficulty surviving the high temperatures during much of the year in El Centro. It could probably survive and reproduce in the more favorable thermal conditions during the winter and early spring, provided acceptable host fruits were available.

Riverside, Calif.

A test simulating climatic conditions of Riverside, Calif., from April 4, 1949, through April 25, 1950, was conducted in the bioclimatic cabinets in 1954 and 1955. Temperatures and relative humidities for this study site are shown in figure 8.

From April through June 1949 temperatures were conducive to fruit fly reproduction. Peak temperatures often exceeded 100° F. and the minimum was rarely below 40°. Wide amplitudes of relative humidities prevailed every month.

First emergence of progeny flies occurred in June from April infestations. None of the 11 fruits introduced to F 1 flies between July 20 and August 26, 1949, became infested, and the increase in daily thermal peaks from mid-July to late September proved lethal to many stock flies and newly emerged progeny.

October, November, and December were progressively colder. Fruit fly activity was restricted and preimaginal development slow. There were nights with frost, and the lowest temperature, 20°, occurred in December. However, progeny flies were recovered each month.

January, February, and March 1950 were cool. Frost occurred on certain nights in January and February. The minimum temperature was 18°. No progeny flies were recovered during this period, but fruit became infested.

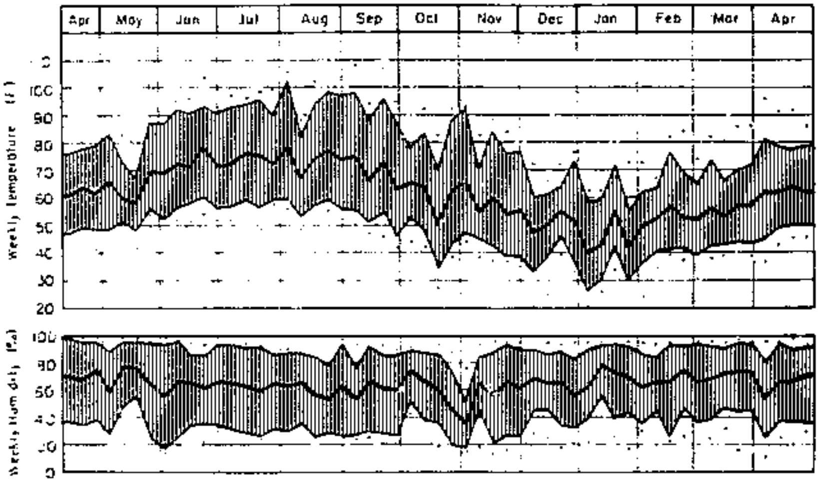


FIGURE 8.—Temperatures and relative humidities simulated for Riverside, Calif., study, based on weather between April 1949 and April 1950. For explanation, see legend for figure 4.

The recovery of five progeny flies in April indicated that preimaginal development can extend over 5 months for a Riverside winter, and normal-appearing adults can successfully complete their development. The grapefruit from which these five progeny flies were recovered became infested from November 7 through 18, and up to 125 days later larvae were observed still active in the fruit. Pupation began on March 12 and emergence on April 20. The pupal period was about 39 days. Thus, the total preimaginal developmental period for the first of the three infestations was 164 days.

During this study 1,146 pupae were recovered, and these yielded an F-1 generation totaling 651 flies.

Summary.—The Mexican fruit fly can successfully overwinter with means as low as 53° in the simulated climate of Riverside. It would appear that the metabolic activity of the larvae, although undoubtedly of a very low order during depressed temperatures, received the necessary stimulus for development from the daily thermal peaks.

San Jose, Calif.

Climatic conditions prevailing at San Jose, Calif., from August 29, 1951, through July 16, 1952, were simulated in 1954 and 1955 in the bioclimatic cabinets. Temperatures and relative humidities for this study site are shown in figure 9.

The few days of climate simulated for August and the entire month of September were conducive to both fruit fly activity and development. However, the depressed temperatures throughout the winter inhibited oviposition and preimaginal development. April and May were amenable to fruit fly reproduction, but the following months were not conducive to insect development.

During the entire study only 24 (19 percent) of 129 host fruits became infested, and from the resulting 804 pupae no adults emerged. Only in September, March, April, and May were fruits infested.

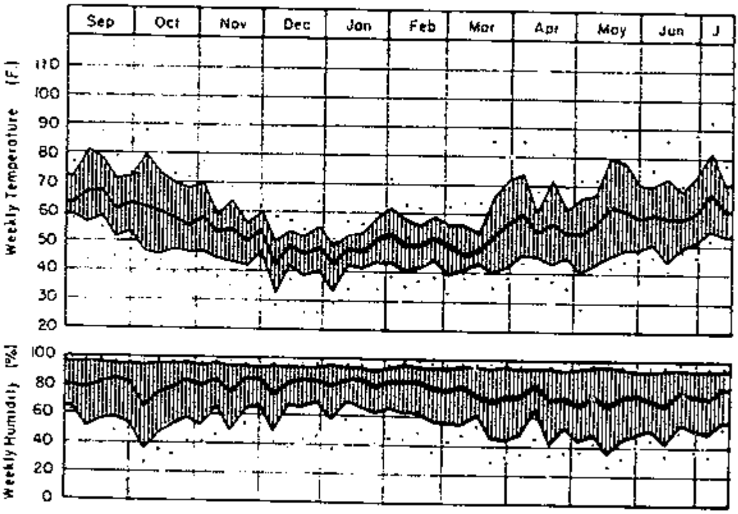


FIGURE 9.—Temperatures and relative humidities simulated for San Jose, Calif., study, based on weather between September 1951 and July 1952. For explanation, see legend for figure 4.

Summary.—The climate at this site was not suitable for the perpetuation of the Mexican fruit fly. The low temperatures, which prevailed during most of the climatological simulation, inhibited complete preimaginal development. Egg hatch, larval development, and pupation occurred in the fall and spring, but no progeny flies emerged.

Sebastopol, Calif.

The climate for Sebastopol, Calif., commencing in August 1953 was simulated for 13 consecutive months in the bioclimatic cabinets in 1956 and 1957. During this time 160 fruits were exposed to a parent stock of Mexican fruit flies and 11 fruits were exposed to their progeny. Temperatures and relative humidities for this study site are shown in figure 10.

From August through October 1953 the weather was conducive to uninterrupted fruit fly development. Fruit infestation took place each month, and the initial F 1 generation was established in late October after 80 days of preimaginal development.

Temperatures fell progressively from November through January (1954), restricting adult fly activity and extending preimaginal development. Progeny flies emerged in November and December, but their developmental period was from 108 to 129 days.

Only one fruit exposed to parent stocks of fruit flies became infested from February through April, and a single pupa was recovered from it. Temperatures were depressed and relative humidities remained high. No progeny flies were recovered.

From May through July temperatures were conducive to both adult fly activity and development of the immature stages. The F–1 progeny emerging in May took from 88 to 112 days to complete their development, the June recoveries from 61 to 97 days, and those emerging in July from 64 to 75 days.

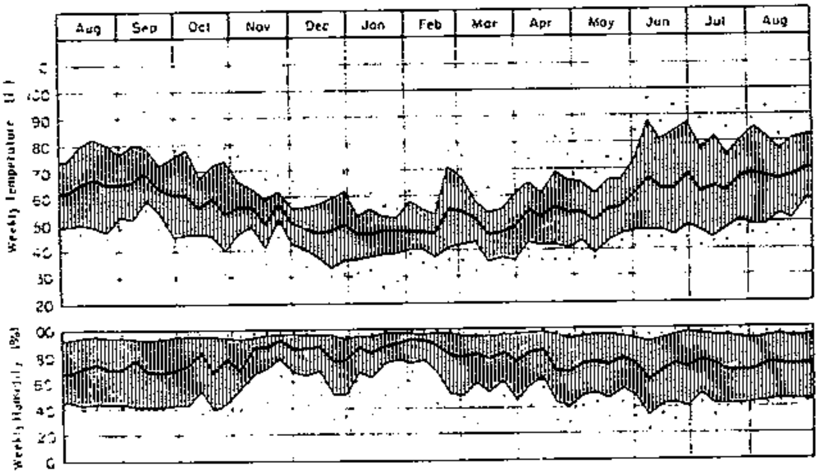


FIGURE 10.—Temperatures and relative humidities simulated for Sebastopol, Calif., study, based on weather between August 1953 and August 1954. For explanation, see legend for figure 4.

Weather conditions in August and September were suitable for all stages of fruit fly development, and recoveries of progeny flies were heavy. Between September 1 and 11, 264 progeny flies, representing the greatest number from any single infestation in this study, were recovered from a grapefruit infested in late June. During the entire study, 1,837 F-1 progeny flies emerged. Preimaginal development ranged from 61 to 129 days.

Summary.—Although the Mexican fruit fly could reproduce during the favorable months of late spring, summer, and to some extent early fall, progeny flies emerging in the late fall could not survive the winter in Sebastopol.

Orlando, Fla.

Climate for Orlando, Fla., from October 7, 1929, through September 29, 1930, was simulated in 1955 and 1956 in the bioclimatic cabinets. Temperatures and relative humidities for this study site are shown in figure 11.

From October through December 1929 the weather was not sufficiently cool (no frost until late December) to seriously retard fruit fly development, and fruit infestation took place each month. The first recovery of progeny flies was early in December. Developmental periods ranged from 46 to 66 days.

From January through March 1930 the weather was cool. However, there were enough days with peaks over 70° F. to permit fly activity and oviposition. February was the only month in which no progeny flies emerged. Flies emerging in January required 58 to 78 days to develop and those for March 106 to 117 days.

Climatic conditions from April through June were suitable for unrestricted development of all fruit fly stages. Preimaginal growth rates became accelerated. Flies emerging in April required 98 to 130 days to develop and those in June 41 to 72 days. No fruits exposed to the F-1 generation became infested.

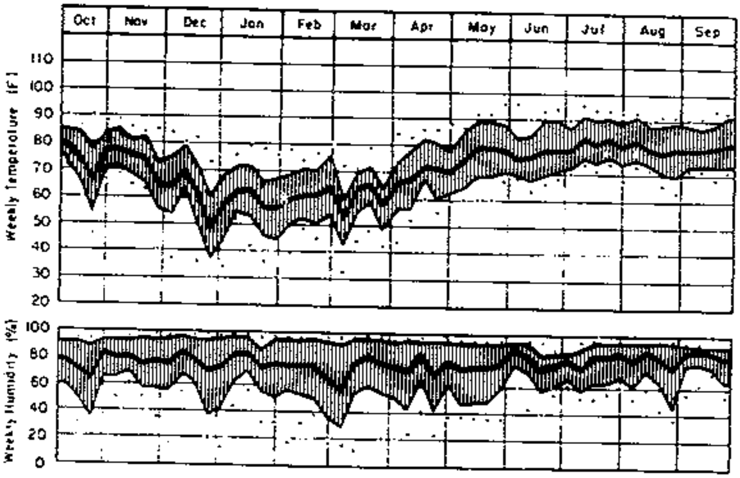


FIGURE 11.—Temperatures and relative humidities simulated for Orlando, Fla., study, based on weather between October 1929 and September 1930. For explanation, see legend for figure 4.

From July through September monthly means were approximately 80°. Fruit infestations were heavy. Progeny flies were recovered from infestations that had occurred from 40 to 67 days earlier. The emergence of six adults from fruits infested by progeny flies in July established an F-2 generation.

From 130 fruits exposed to parent stocks of fruit flies during this study, 2,606 F-1 flies were recovered, whereas from 17 fruits exposed to these progeny flies only 6 F-2 adults emerged.

Summary.—Results of this study indicate that the Mexican fruit fly could become established in the Orlando area should it be introduced there. This species was able to infest fruits during all simulated months of the study, and progeny emerged in all months except February.

Athens, Ga.

A test simulating weather for Athens, Ga., from November 1955 through November 1956 was carried out in 1956 and 1957 in the bioclimatic cabinets. Temperatures and relative humidities for this study site are shown in figure 12.

Weather from November 1955 through February 1956 inhibited fruit fly reproduction. Although daytime temperatures during certain weeks were amenable to fruit fly activity, thermal drops at sunset inhibited copulation.

The first infestation of fruit occurred on March 31, when the daytime temperature reached 70° F. Infestations became progressively more abundant during April and May. From June through August the weather was near optimal for fruit fly perpetuation; 30 of 39 fruits exposed to stock flies became infested. During this period a total of 1,600 F-1 flies emerged after preimaginal developmental periods of from 40 to 93 days. Emergence per infestation ranged from 1 to 141 flies, but this wide span is not uncommon in either natural or simulated climatic conditions because of variations in population density of parent stock, tem-

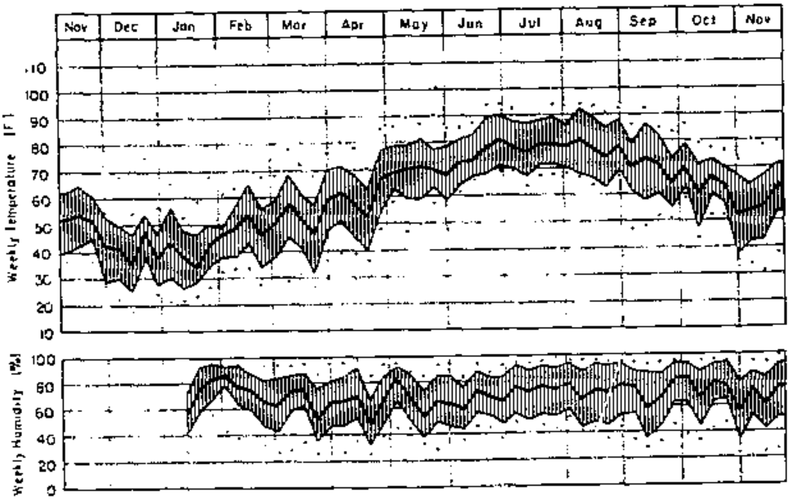


FIGURE 12.—Temperatures and relative humidities simulated for Athens, Ga., study, based on weather between November 1955 and November 1956. For explanation, see legend for figure 4.

perature, oviposition urge of females, and attractiveness of individual fruits to flies.

Although decreasing temperatures from September through November did not inhibit preimaginal development, progeny returns were less frequent and developmental periods were extended in some instances to 78 days. The initial F 2 generation (three flies), established in mid-September, was augmented in October with 266 flies and in November with 77 flies.

The highest yield of adults resulting from a single infested fruit was 141. The total F 1 population emanating from this study was 4,094 flies. The F 2 generation of 684 flies was established too late in the year to be of consequence.

Summary.—The simulated climate of Athens was suitable for the reproduction and development of Mexican fruit flies from April through September. The winter inhibited all stages of the fly's development.

Fort Valley, Ga.

The Fort Valley, Ga., climate for 12 months beginning on August 3, 1943, was simulated in the bioclimatic cabinets during 1955 and 1956. Temperatures and relative humidities for this study site are shown in figure 13.

Fort Valley, situated on a plateau about 500 feet above sea level and midway between the 32d and 33d parallel, was selected largely because of its favorable geographic location for the production of peaches, one of the most important hosts of the Mexican fruit fly. Sufficient seasonal variations there would indicate how far north or for what periods of the year the Mexican fruit fly could be expected to establish itself.

August, September, and October were conducive to fruit fly activity, development, and oviposition. The first F-1 fly emerged on October 31 after a preimaginal development period of 76 days.

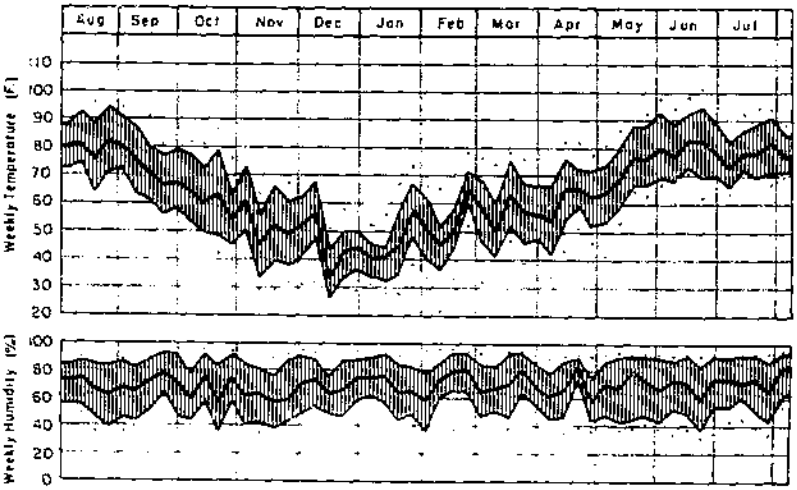


FIGURE 13. Temperatures and relative humidities simulated for Fort Valley, Ga., study, based on weather between August 1943 and July 1944. For explanation, see legend for figure 4.

From November through January (1944) freezing temperatures were evidenced each month, and a low of 19° F. occurred in December. No flies emerged during this quarter, and only two fruits became infested late in January.

With warming trends from February through April, fruit fly activity and oviposition increased. Larval development was ascertained to be taking place in fruits previously infested, but no progeny flies emerged during this period.

From June through early August the weather was conducive to uninterrupted fruit fly development, and at the close of the test both larvae and pupae were recovered.

From 133 grapefruits exposed to parent stocks of fruit flies during the study, 175 F 1 progeny flies were recovered, and about 98 percent of these emerged in May.

Summary. Infestations occurred in all months except November and December. A mean of 52° throughout the nonproductive period inhibited both adult survival and preimaginal development of the Mexican fruit fly. Thus, it would be improbable that this species could perpetuate itself at this site.

Houma, La.

In 1956–58, weather was simulated for Houma, La., in the bioclimatic cabinets for September 1949 through August 1950 and for September 1949 through March 1950. Temperatures and relative humidities for this study site are shown in figure 14. The annual climatic cycle was extended to obtain needed information on the reproductive capacity of the Mexican fruit fly and to determine the effect of depressed temperatures on a well-established, strong fruit fly population.

From September through November 1949 means were from 73° to 54° F. and relative humidities between 50 and 60 percent. Daily peak

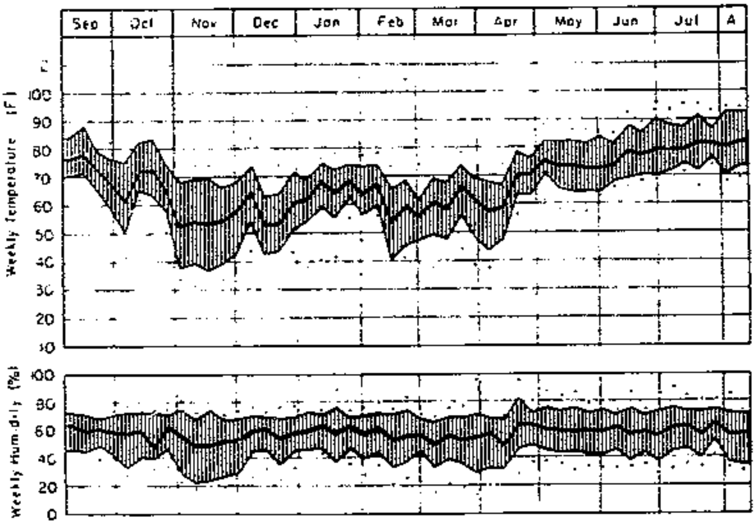


FIGURE 14.—Temperatures and relative humidities simulated for Houma, La., study, based on weather between September 1949 and August 1950. For explanation, see legend for figure 4.

temperatures were such that fruit fly oviposition took place each month, but the low night temperatures retarded preimaginal development.

Progeny flies first emerged in early December, having taken from 85 to 99 days to develop, and those emerging in January and February 1950 required from 84 to 105 days. Infestation was heavy in all fruits exposed to parent stock during these 3 months.

With monthly means from 60° to 73° from March through May, fruit fly reproduction progressed uninterruptedly. Preimaginal developmental periods for the progeny recovered ranged from 29 to 79 days.

In early June, F-2 flies commenced emerging from an April infestation. Monthly means for July and August were approximately 80°, which stimulated oviposition and accelerated insect development. Emergence of progeny flies was particularly heavy. In July, 1,255 F-1 flies emerged, 394 from a single infested fruit, and 251 F-2 progeny were recovered. During August, 201 F-3 flies emerged. Preimaginal development during the period took from 36 to 71 days.

Each progeny generation increased in number from September through November, and because of their population strength, no more stock flies were used in this study. Preimaginal development during this period required from 50 to 73 days, but fly activity slowed down as the weeks progressed.

From January through March, climatic conditions had little effect on fruit fly emergence, but they did extend the developmental cycle. An F-4 generation was established in January and was augmented by small numbers of flies emerging in the 2 following months. Ovipositional activity declined as the study terminated, and preimaginal development took over 100 days in many instances. But the perpetuation of the fruit fly generations proved that a high population density of Mexican fruit flies can survive during the winter at Houma.

During the study 149 fruits exposed to parent stock yielded 6,121 F-1 progeny, and from 239 fruits exposed to F-1, F-2, and F-3 generations, recoveries of flies were 1,580 F-2, 913 F-3, and 79 F-4.

Summary.—Climatewise, Houma was more favorable for the establishment and perpetuation of the Mexican fruit fly than any of the other sites in this investigation. Fruit fly activity was observed during all months of the study, and four progeny generations became established.

Greenwood, Miss.

Climate for Greenwood, Miss., was simulated for November 1, 1954, through July 7, 1956, in the bioclimatic cabinets only 2 weeks out of phase with the calendar dates. Temperatures and relative humidities for this study site are shown in figures 15 and 16.

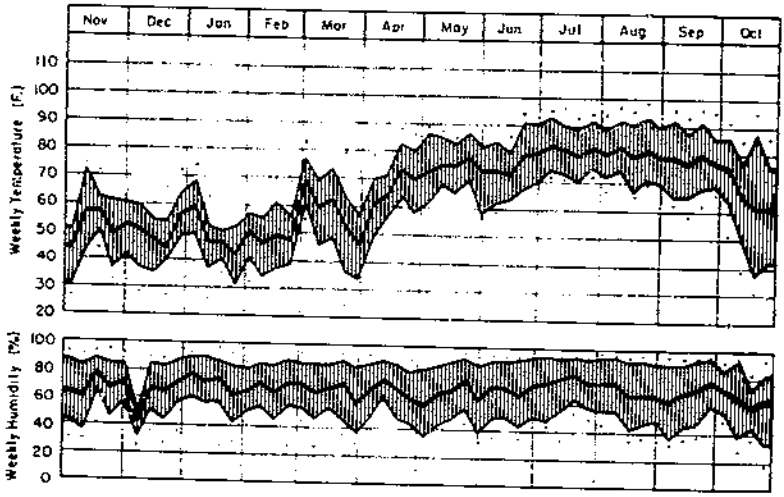


FIGURE 15.—Temperatures and relative humidities simulated for Greenwood, Miss., study, based on weather between November 1954 and October 1955. For explanation, see legend for figure 4.

From November through January, means from 52° to 48° F. were abortive to fruit fly survival and reproduction. Temperatures increased during the next 3 months. Fruit flies became active and oviposition took place in March and April.

From May through July the temperatures were favorable for all stages of fruit fly development, and fruits were successfully infested each month. The first F-1 flies emerged in June, having taken 41 to 56 days to develop. Fruits infested in May and June yielded adults in July. No progeny were recovered in August, but emergence took place in the 2 following months after developmental periods of from 42 to 65 days.

November 1955 commenced the second annual simulation period. No fruits became infested during this period, but a few progeny flies were recovered during November and December. From February through April sufficiently high daytime temperatures permitted fruit fly oviposition and preimaginal development. Temperatures from May through July were amenable to complete insect development. Progeny

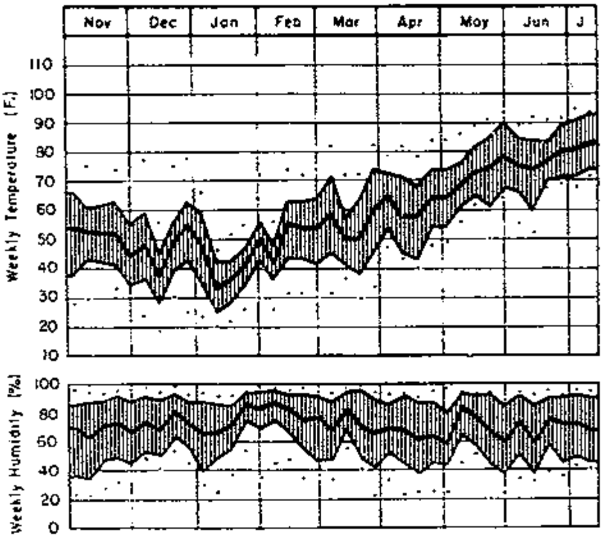


FIGURE 16.—Temperatures and relative humidities simulated for Greenwood, Miss., study, based on weather between November 1955 and July 1956. For explanation, see legend for figure 4.

flies emerged during each of these months; the greatest emergence occurred in June.

During the entire study 225 fruits were exposed to parent stocks of fruit flies; 71 (32 percent) became infested, and from 45 (63 percent) of these infestations, 1,279 progeny flies emerged.

Summary.—Mexican fruit flies were able to perpetuate themselves during most of the year at this simulated site, but in neither their adult nor preimaginal stages were they able to survive the severe midwinter.

Malden, Mo.

Climatic conditions were simulated for Malden, Mo., from October 13, 1955, through July 22, 1956, and again from November 11, 1956, through July 7, 1957. The studies were conducted in the bioclimatic cabinets 3 weeks out of phase with these dates. Temperatures and relative humidities for this study site are shown in figures 17 and 18.

October, November, and December 1955, with means from 59° to 36° F., were too cold for fruit fly development, and many adults succumbed during the freezing temperatures in December. From January through March it was too cold for insect activity and development. Little feeding occurred until a warming trend in March. From April through July fruit fly activity increased as the temperature rose, and the initial F–1 fly progeny were established in June.

Ninety-eight fruits were exposed to stock flies during this phase of the study. Sixteen fruits became infested, and from 3 of these infestations, 198 F–1 flies emerged. Preimaginal developmental periods ranged from 52 to 60 days.

During the second phase of this study commencing in November 1956 there was little respite from the cold days and freezing night tempera-

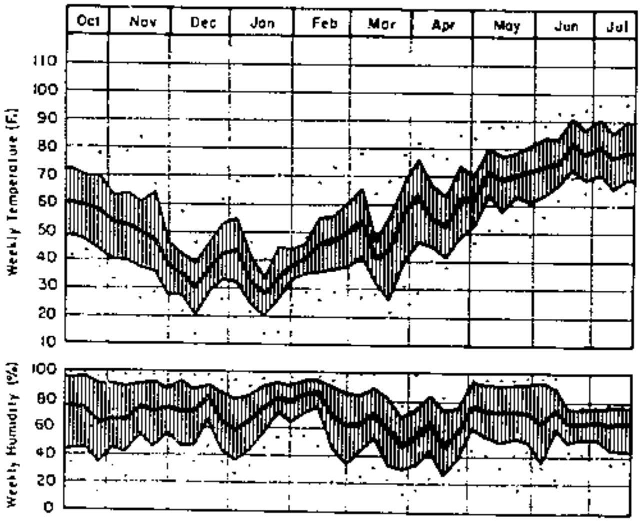


FIGURE 17.—Temperatures and relative humidities simulated for Malden, Mo., study, based on weather between October 1955 and July 1956. For explanation, see legend for figure 4.

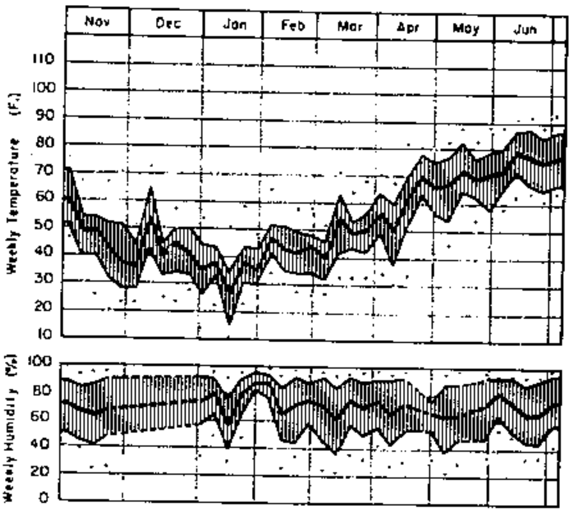


FIGURE 18.—Temperatures and relative humidities simulated for Malden, Mo., study, based on weather between November 1956 and June 1957. For explanation, see legend for figure 4.

tures until April, when the monthly mean reached 60°, and thermal peaks of 80° were frequent. Flies successfully infested 11 of 13 fruits during the month. Means from May through July 1957 were from 69° to 79°. During the combined periods of the Malden study, 880 progeny flies were recovered, and all of these emerged during June.

Summary.—Although the Mexican fruit fly could be expected to have little difficulty in becoming established at this site during spring and early summer if sufficient acceptable host material were available, subsequent populations would succumb during the prolonged winter.

Mesilla Park, N. Mex.

Climate for Mesilla Park, N. Mex., from March 1948 through February 1949, was simulated in the bioclimatic cabinets in 1957 and 1958. Temperatures and relative humidities for this study site are shown in figure 19. Relative humidities for the entire period were particularly low.

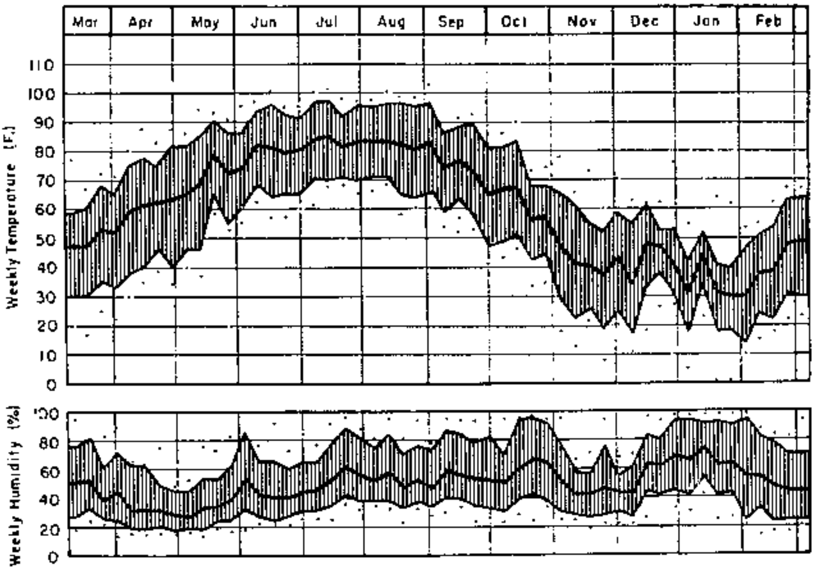


FIGURE 19.—Temperatures and relative humidities simulated for Mesilla Park, N. Mex., study, based on weather between March 1948 and February 1949. For explanation, see legend for figure 4.

From March through May the temperatures were amenable to fruit fly reproduction and development. Progeny flies began to emerge in early June, and recoveries were made almost daily throughout June and July. The initial F-2 generation was established in August. None of the infestations after August 30 produced progeny flies.

Although progeny flies continued to be recovered from September through November, temperatures as low as 8° F. during occasional nights in November killed the adult flies. Subfreezing weather from December through March inhibited fruit fly development and was often lethal to adult flies.

During the entire study, 70 of 127 fruits (55 percent) became infested and 2,213 F-1 flies emerged. Of 29 fruits exposed to these flies, 12 (41 percent) became infested, and 93 F-2 progeny emerged. Preimaginal development for the F-1 generation ranged from 89 days in the spring to 37 days in the summer. Second-generation flies required from 43 to 75 days to complete their development.

Summary.—Low relative humidity throughout the year at this site apparently did little to depress fruit fly activity. Optimal development occurred in the summer, and consequently a second generation became established. However, the winter temperatures nullified any possibility of the population's overwintering. Therefore, fruit fly perpetuation in Mesilla Park would be improbable.

Charleston, S.C.

Climatic conditions of Charleston, S.C., from April 1939 through May 1940 were simulated in the bioclimatic cabinets during 1956 and 1957. Temperatures and relative humidities for this study are shown in figure 20.

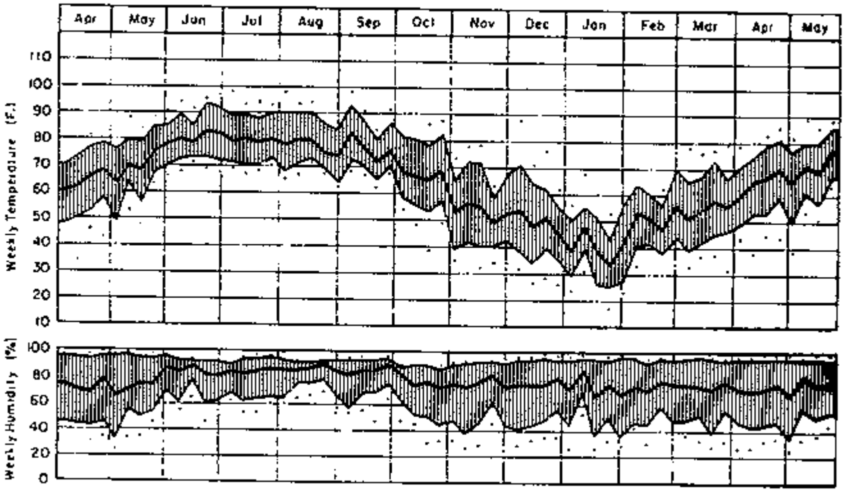


FIGURE 20.—Temperatures and relative humidities simulated for Charleston, S.C., study, based on weather between April 1939 and May 1940. For explanation, see legend for figure 4.

The humid coastal area where Charleston is situated affected both insect activity and host fruit keeping qualities. Temperatures from April through June, with means from 64° to 80° F., were conducive to fruit fly development, and preimaginal growth was accelerated, with recoveries of the F–1 generation in June.

From July through September the temperatures were conducive to preimaginal development, but during daytime peak temperatures, adult activity was restricted and longevity adversely affected. F–1 progeny flies emerged each month. One fly recovered in August required 112 days to develop.

Although from November through January (1940), means were from 53° to 40°, sufficiently high daytime peaks stimulated oviposition. Relative humidity only slightly affected adult fly activity but profoundly affected the deterioration rate of infested fruits. To what extent this variable manifests itself on population buildup is difficult to determine, but its existence as a potential limiting factor cannot be overlooked. Preimaginal development of flies emerging during this period extended from 48 to 93 days.

From February through May the means were from 50° to 70°. No fruits were introduced to stock flies after March 27, but 12 of the 24 fruits introduced during February and March became infested. Preimaginal developmental periods ranged from 57 to 106 days.

Of 152 fruits exposed to stock flies for the entire study, 77 (51 percent) became infested, and 1,648 progeny flies were recovered.

Summary.—Conditions conducive to fruit fly oviposition at this site began early in February and continued through September. Emergences occurred throughout most of the year. However, flies that emerged during the winter succumbed quickly to the cold.

Memphis, Tenn.

A test simulating weather for Memphis, Tenn., for 15 months commencing in November 1955 was conducted in the bioclimatic cabinets during 1956 and 1957. Temperatures and relative humidities for this study are shown in figure 21.

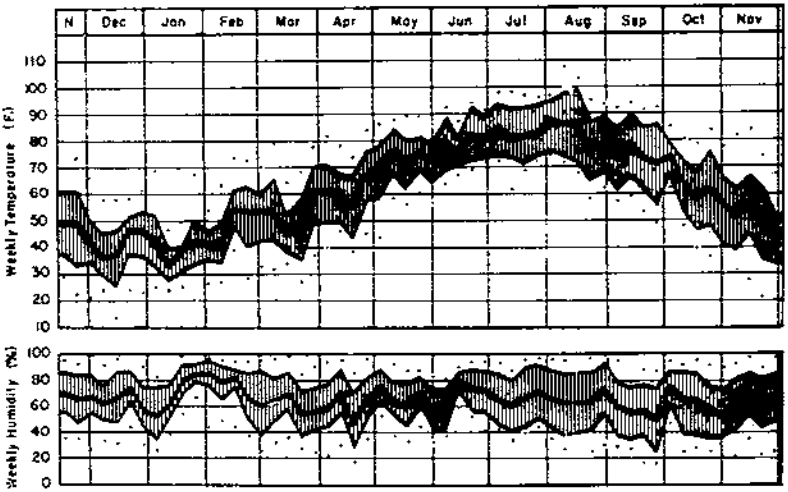


FIGURE 21.—Temperatures and relative humidities simulated for the Memphis, Tenn., study, based on weather between November 1955 and November 1956. For explanation, see legend for figure 4.

From November through January, temperatures were below the threshold for oviposition, with means from 51.7° to 39° F. Fly activity increased from February through April. Light infestations occurred in February and March, and all fruits introduced to stock flies in April became infested. May and June temperatures were conducive to all stages of fruit fly development. F–1 flies began to emerge early in June, and recoveries per infested fruit were particularly heavy, ranging from 200 to 382 individuals. A total of 1,504 F–1 flies emerged during June.

Temperatures for July and August were nearly optimal for fruit fly development. The last infestation to yield adults in this study occurred late in August. September and October temperatures were conducive to continued fruit fly development. Progeny flies were recovered each month, and because of the high population density of the F–1 generation, the study was continued through November and December 1955 and January 1956. Only two flies emerged in November, these from an infestation in mid-August, 80 days earlier. No fruits became infested during December and January.

Only 67 (37 percent) of the 182 fruits exposed to parent stocks of fruit flies became infested, and from these infestations 2,465 F–1 progeny emerged. Of 24 fruits exposed to this latter generation, 3 became infested and 19 pupae were recovered.

Summary.—The climate of Memphis would be favorable for Mexican fruit fly establishment from spring through late summer, but the winters would be lethal to established adult populations and inhibitive to preimaginal stages.

Brownsville, Tex.

A test simulating weather for Brownsville, Tex., between September 1954 and September 1955 was conducted in the bioclimatic cabinets during the same years. Temperatures and relative humidities for this study site are shown in figure 22.

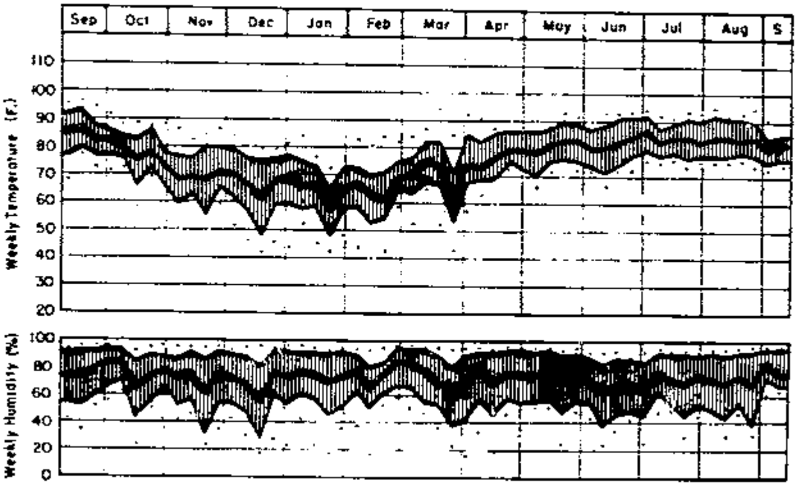


FIGURE 22.—Temperatures and relative humidities simulated for Brownsville, Tex., study, based on weather between September 1954 and September 1955. For explanation, see legend for figure 4.

The means for September through November were 84° to 69° F. Temperatures never fell below 55° at sunset, the copulatory threshold of the Mexican fruit fly. Consequently, oviposition took place in fruits exposed during the entire period. The initial progeny fly emerged in November from a September infestation.

Temperatures for December through February, with means about 65°, were conducive to fruit fly activity and development. Progeny flies emerged each month.

March's wide temperature vacillations resulted in a mean of 72°. April and May had means of 76° and 80°, which were ideal for preimaginal development but detrimental to adult longevity. The 500 F–1 flies that emerged in April accounted for 67 percent of the progeny recovered during the entire study. The last infestations to produce progeny flies occurred in mid-May.

Between May 20 and the end of the study on September 1, 11 of 43 fruits became infested, from which 345 pupae were recovered. Weekly peak temperatures for this nonproductive period ranged between 90° and 95°, lows averaged 74°, and the mean was 83°. That these high temperatures adversely affected adult longevity was evidenced by daily mortality counts. However, it was ascertained that limited oviposition had taken place in some fruits exposed in the last weeks of this test.

From 123 fruits exposed to stock flies, 745 progeny flies were recovered.

Summary.—Infestations occurred throughout the year at this site, but pupae were recovered only from summer infestations, when the mean was 83°. The winter and spring were favorable for fruit fly activity, but high summer temperatures had a deleterious effect on adult longevity.

DISCUSSION

Effect of Climate on Fruit Fly Development

The effect of climate on the normal biological processes of the fruit flies was determined by the following criteria: The number of months, the specific season, and the extent to which successful infestation of fruits took place; and the number of successive generations of progeny in a single year, their population size and reproductive capacity, and the extent to which their life cycle differed from that established for the insectary-reared flies.

Results of this study indicated that temperature exerted a greater effect on the development of fruit flies than did humidity. This is partially attributable to the fact that the egg and larval stages are spent within the host fruit where sufficient moisture is generally present. Although both arid and saturated soils had deleterious effects on the insect during its subterranean sojourn, temperature ameliorated or enhanced these effects.

The rate of preimaginal development was definitely affected by temperature. Each distinctive stage had an optimal thermal range within the larger optimal range for the complete life cycle of the insect. High temperatures, lethal to adults, only accelerated larval development in fruit and adult emergence from puparia buried in the soil. On the other hand, winter conditions typical of certain sites simulated in southern California extended development in many instances up to 5 months, whereas in these and other sites during early or late summer, growth was accelerated and the complete preimaginal developmental period was reduced to approximately 40 days.

The activity of adult fruit flies is not affected solely by external temperature (Uvarov *21*, Bodenheimer *2*). Generally insect activity is depressed by low humidity. Headlee (*11*), Breitenbrecher (*3*), Robinson (*17*), and others working with various insects reported that the rate of reproduction is affected by humidity. High humidity in the simulation site of Charleston, S.C., restricted adult activity and caused rapid decay of host fruits, which in turn affected larval development and limited progeny buildup.

Climatological data pertinent to the response of the fruit fly and limited to the months simulated for each site are presented in table 2. Mean and mean maximum temperatures indicate the general level and the extent of fluctuation at each study site investigated. Mean maximum temperatures during the winter indicate whether oviposition could occur, since it was established that females would oviposit when the day temperatures reached or exceeded 55° F. Days with maximum temperatures above 95° restricted all adult activity, interfered with reproduction, and materially reduced adult longevity.

The threshold for copulation was approximately 55° F. The entire preimaginal developmental cycle could be completed under diurnally fluctuating temperatures and relative humidities at a mean as low as 53°, with a diurnal amplitude of about 20°. Preimaginal development was inhibited when the overall mean was 52° or lower. The longest developmental period under simulated conditions of climate was at Riverside, Calif., from November to April, when at a mean of 53° complete development from egg to adult required 164 days. However, various other combinations of temperatures with greater diurnal amplitudes but resulting in the same mean temperature could further affect the developmental cycle of the insect.

The seasonal reactions of the fruit fly to the simulated climates are summarized in table 3. The reproductive periods covering both fruit infestation and adult emergence are included in figure 23. In table 3, a normal response (++) is indicated when adult feeding, mating, and oviposition occur rather regularly. Depressed responses (+) are indicated when adults are only able to mate or to infest grapefruit intermittently, although feeding may continue and longevity may be extended. For the immature stages, normal responses are shown when the developmental periods are optimal (40–90 days). "Extended" indicates that preimaginal growth was extended more than 90 days because of unfavorable temperatures, and "arrested" indicates that preimaginal development was arrested in the larval or pupal stage.

The lowest daytime temperature (55° F.) at which fruit flies infested grapefruit occurred during February in the Fort Valley study. Several infestations originated at 56° to 58° in the Riverside (January–February), Greenwood (March), and Malden (November) studies.

In certain studies the immature forms were observed to overwinter; i.e., eggs laid in the fall resulted in adult emergence the following spring. The low temperatures extended development. Overwintering infestations were observed in the studies of Riverside (mean 53° F., 164 days), Chula Vista (mean 55.5°, 130 days), Compton (mean 59°, 117 days), and Orlando (mean 61°, 130 days).

Eggs subjected to short periods of freezing survived, but embryogenesis was extended on occasion to more than 30 days. Larvae within fruits completed their development and pupated at very low temperatures in approximately 125 days, and pupae survived similar conditions for about 90 days.

TABLE 2.—*Temperature data for each study site*

Site	Winter (December–February)			Spring (March–May)		Summer (June–August)			Autumn (September–November)	
	Mean	Mean maximum	Nights below 32° F.	Mean	Mean maximum	Mean	Mean maximum	Days above 95° F.	Mean	Mean maximum
	°F.	*°F.*	*Number*	*°F.*	*°F.*	*°F.*	*°F.*	*Number*	*°F.*	*°F.*
Tempe, Ariz	48	61	18	64	79	84	98	66	68	85
Chula Vista, Calif	52	63	3	58	66	69	75	0	66	77
Compton, Calif	54	67	0	58	67	68	79	1	64	76
El Centro, Calif [1]	57	70	1	71	85	89	103	55	60	74
Riverside, Calif	50	65	17	60	75	73	93	37	63	85
San Jose, Calif [2]	48	55	10	55	66	62	73	0	59	70
Sebastopol, Calif	48	57	8	51	62	63	79	1	60	71
Orlando, Fla	60	71	3	68	78	79	89	3	75	84
Athens, Ga	43	52	33	61	71	76	87	0	63	73
Fort Valley, Ga	48	56	16	63	73	79	90	12	62	74
Houma, La	61	69	2	65	74	78	88	0	65	76
Greenwood, Miss	49	57	13	66	76	79	90	9	65	76
	46	54	26	63	73	80	90	7	---	---
Malden, Mo [3]	38	46	51	58	69	78	88	2	55	64
	41	51	48	59	68	77	85	0	---	---
Mesilla Park, N. Mex	39	52	62	60	75	81	94	32	60	75
Charleston, S.C	47	58	30	63	75	79	89	3	65	77
Memphis, Tenn	43	50	44	62	70	81	91	18	64	75
Brownsville, Tex	65	74	0	75	84	83	90	0	77	85

[1] June and July only simulated for summer and November for autumn.
[2] Summer includes only June and 2 weeks of July.
[3] For first study, only June and July simulated for summer and October and November for autumn.

TABLE 3.—*Seasonal responses of Mexican fruit fly in its adult and immature stages to simulated climatological sites*

Site	Reproductive behavior of adults [1]				Preimaginal development of immature stages			
	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter
Tempe, Ariz	++	0	+	0	Normal	Arrested	Arrested [2]	None.
Chula Vista, Calif	+	++	+	0	Extended [2]	Normal	Normal	Extended.
Compton, Calif	+	++	+	0	Normal [2]	do	Extended	Arrested.
El Centro, Calif	+	0	0	+	do	Arrested	None [2]	Extended.
Riverside, Calif	+	+	+	+	do [2]	Normal	Normal	Do.
San Jose, Calif	+	0	+	0	Arrested	None	Arrested [2]	None.
Sebastopol, Calif	+	++	+	0	Extended	Normal [2]	do	Arrested.
Orlando, Fla	++	++	++	+	Normal	do	Normal [2]	Extended.
Athens, Ga	++	++	+	0	do	do	do [2]	None.
Fort Valley, Ga	+	+	+	0	do	do [2]	Arrested	Arrested.
Houma, La	++	++	+	++	do	do	Extended [2]	Extended.
Greenwood, Miss	+	+	-----	0	do	do	None [2]	None.
	++	-----	+	+	do	-----	Normal [2]	Extended.
Malden, Mo	+	0	0	0	do	Arrested	Arrested [2]	None.
	+	0	0	0	do	None	do [2]	Do.
Mesilla Park, N. Mex	++	++	+	0	do [2]	Normal	do	Do.
Charleston, S.C	+	++	+	+	do [2]	do	Normal	Extended.
Memphis, Tenn	++	++	0	0	do	do	Arrested [2]	Do.
Brownsville, Tex	+	+	+	++	do	Arrested	Normal [2]	Normal.

[1] ++ = normal response; + = depressed response. (See text for explanation.)
[2] Exposures to climate started in this season.

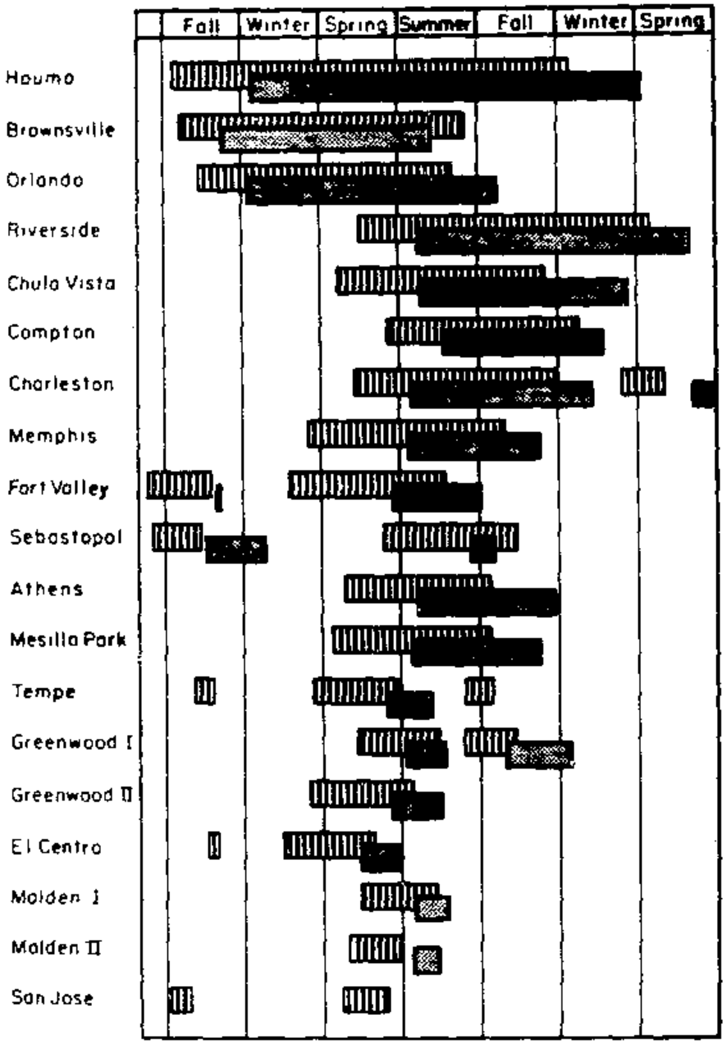


FIGURE 23.—Periods during study when Mexican fruit fly adults infested fruits (vertical lines) and when progeny flies emerged (stipple). Sites are listed in order of decreasing adult reproductive periods.

Effect of Climate on Potential Distribution

Results of the bioclimatic cabinet study indicated that the Mexican fruit fly would be able to breed and perpetuate itself in climates similar to those of Orlando, Fla., Houma, La., and Brownsville, Tex. In climates such as at Chula Vista and Compton, Calif., where winter reproduction was prevented, or Riverside, Calif., where it was much reduced, fruit fly populations could probably maintain themselves because of overwintering preimaginal forms.

High thermal conditions representative of Brownsville, Tex., Tempe, Ariz., and El Centro and Riverside, Calif., caused high mortalities, and in many instances newly emerged adults succumbed before reaching sexual maturity. Although immature forms seem much more resistant to heat, continuous establishment throughout the summer would probably depend on large spring populations and abundant fruit infestations.

In contrast to the lethal summer conditions at these sites, climate in the coastal areas of southern California would appear conducive to prolonged periods of normal adult activity and immature development. With the combination of uninterrupted breeding during the spring, summer, and fall and the overwintering of the resulting preimaginal forms, continuous populations could probably be maintained in these coastal areas. The adults might annually disperse into the interior valleys each fall and winter. However, summer temperatures would probably kill such infestations or drive the adults back to the coastal areas or into the foothills.

Permanent populations of this fruit fly could no doubt also develop along the coast of the Gulf of Mexico and over most of Florida. Adults from these areas might disperse northward into the Mississippi River Valley and along the southeastern seaboard, for short distances at least, during the spring and summer. However, cold winter temperatures would probably annihilate or drive them southward.

The areas of infestation in the Southern and Southeastern United States would probably fluctuate, depending on whether it was warmer or cooler than normal. Cooler weather in the Florida or Gulf Coast areas would depress existing populations in a southerly direction, whereas warmer than normal winters would disperse populations northward. Fluctuations in population size with climate would no doubt be more closely correlated with cooler than normal summers in the southwestern areas (Texas to Arizona).

No climatic factor we studied would preclude the initial establishment of the Mexican fruit fly in any area of the United States during certain favorable months of the year, particularly if large populations were introduced. However, in most such areas, winter conditions would eliminate such temporary infestations. In the southwestern areas of the Nation, summer heat would limit establishment of infestations.

Effect of Other Factors on Distribution

In prognosticating areas in which the Mexican fruit fly could establish and maintain itself, other factors besides climate should be considered. One basic requirement, not studied in this work, is that of suitable host food supplies for the fruit fly. Suitability, abundance, and sequence of the host must be considered (Baker et al. *1*). In the temperate regions of the United States it is improbable that any given suitable host will be present continuously throughout most of the year. Hence, it will be necessary that several suitable and abundant hosts appear in succession, with little more than a 2- or 3-month gap between peak fruit abundances, depending on the severity of the weather.

In addition, orchard fruit hosts that might provide the necessary food requirements for the Mexican fruit fly would probably be treated with insecticides to control other insect pest species and thus would affect both its initial establishment and continued propagation. In many cases the early harvesting of crops might interfere with the successful permanent establishment of the fruit fly.

In the Southern United States the possible effects of natural control factors should be mentioned. Where the climate is suitable, initial establishment of the Mexican fruit fly will most probably occur in the absence of its normal Mexican parasites, predators, and diseases. Subsequent fruit fly populations would probably become larger than in the natural habitat of the species if the weather is favorable. On the other hand, general or nonspecific predators, such as ants and carnivorous beetles that might interfere with the initial establishment of the fruit fly in spite of favorable weather, would undoubtedly occur in the potentially inhabitable areas.

Darby and Kapp (5) studied the differential effects of temperature and humidity on the Mexican fruit fly and one of its most effective parasites in Mexico, *Opius crawfordi* Vier. They found that the immature forms of the parasite have temperature-tolerance limits slightly narrower than those of the host insect, and that low humidities are excessively deleterious to the longevity of parasite adults relative to that of fruit fly adults. Based on these findings, *Opius crawfordi* would appear to be less effective in those dry areas where the Mexican fruit fly could be expected to survive throughout the year, such as Riverside, Calif., or Brownsville, Tex.

SUMMARY

Natural temperature and humidity patterns representative of important agricultural localities, particularly in the southern tier of States, have been simulated in bioclimatic cabinets for the purpose of estimating the potential distribution and establishment of the Mexican fruit fly (*Anastrepha ludens* (Loew)) in the United States as governed by climate.

The Mexican fruit fly was able to perpetuate itself throughout the year under the simulated climatic conditions of Houma, La., Orlando, Fla., and Brownsville, Tex. Preimaginal stages of development were able to overwinter in conditions representing Chula Vista, Riverside, and Compton, Calif. The hot summer temperatures caused excessive adult mortalities in the simulated sites of Brownsville, Tex., Tempe, Ariz., and El Centro, Calif., and to a less extent at Riverside, Calif.

During a simulation period of 1 year, three generations of flies were produced in the Houma, La., study site, two generations at the sites of Athens, Ga., Chula Vista and Compton, Calif., Orlando, Fla., and Mesilla Park, N. Mex., and one generation at each of the other sites except San Jose, Calif., where no progeny fly population became established.

Permanent populations of this fruit fly could no doubt develop along the southern coast of California, along the coast of the Gulf of Mexico, and in the greater part of Florida. Dispersal from these centers of permanent infestation might then occur each fall and winter into the interior valleys of southern California and each spring and summer northward into the lower Mississippi River Valley and along the southeastern seaboard.

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