THE CLIMATIC LIMITATIONS OF THE MEXICAN BEAN BEETLE.

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CONTENTS.

INTRODUCTION.

The phenomenal spread of the Mexican bean beetle, *Epilachna corrupta*, in the Eastern United States and its potentialities for destroying the bean crop are viewed with alarm by neighboring states now free of the beetle.

Many people believe the beetle can live almost anywhere and withstand great extremes of temperature. Metcalf and Flint state "further spread is sure to occur and in time its range will probably extend over almost the entire country." The Mexican bean beetle is still spreading into new territory, mostly in a northeasterly direction. This has been attributed by Thomas (1924) to winds, which come from the southwest. A study of the physical ecology of the beetle indicates that it has very definite requirements of moisture and temperature, the correct interpretation of which should enable us to map with some degree of accuracy the final limits of its distribution in the United States. Such a study should also enable us to determine those regions in which the insect may be expected to be of economic significance each season as well as the areas that will suffer occasionally, due to a series of favorable years.

LITERATURE.

Howard (1924) was the first to record the effect of the hot, dry period of 1921 at Birmingham, Alabama. He states, "Many thousands of pupæ gradually turned brown and died." The experimental effects of sunlight were also tested by Howard, and he states "An exposure to direct sunlight for two minutes was fatal to first instar larvæ one day old when shade temperatures registered 96° F." Since the bean beetle occurs in destructive numbers both in the arid west and the humid east, Graf (1925) concludes that the climatic factors of temperature and humidity are not important factors in limiting the distribution of this pest. In the season of 1925 a very severe drought in Tennessee almost wiped out the entire bean beetle population (Marcovitch, 1926). These observations led the author to make a study of the physical ecology of the beetle, which has been continued to date. Howard (1927) and Transeau (1927) made a study of the distribution of the bean beetle in Ohio, and they conclude that the beetle's environment corresponds to the area originally covered with the mixed mesophytic forest, such as is found in eastern and southern Ohio. In South Carolina, Eddy and McAlister observed that the hot, dry summers of 1925 and 1926 killed off great numbers of bean beetles and prevented the general establishment of the pest throughout the Piedmont section. During the heat waves of 1926 "All of the eggs, larvæ and pupæ, and some of the adults, were killed in many fields under observation." Sweetman (1929) summarizes the literature and shows that the western infestation in the United States is largely confined to areas where moisture is added to the fields through irrigation.

THE MEASURE OF DROUGHTINESS.

The Mexican bean beetle is undoubtedly affected by droughty periods, and the question arises how to measure the intensity of a drought. The simplest method is to record the amount of rainfall. This method is unreliable because of the large run-off that often takes place. The southeastern United States comprising Florida, the southern half of Alabama, Georgia, and South Carolina, with a high ratio of rainfall to evaporation is nevertheless subject to frequent droughts. The measure of precipitation in this area does not give an adequate idea of the environment. The rainfall comes in torrential storms which dissipate their water in surface run-off. As high as 80 per cent of a 2.5 inch rainfall falling in four hours may be lost by run-off (Chilcott, 1911). Columbia, Couth Carolina, with 47.55 inches of annual rainfall may have 62 drought periods in nine years whereas Ames, Iowa, with only 30.4 inches of rainfall may have but 23 drought periods (Williams, 1911). Thus the degree of temperature and the amount of rainfall required to produce a particular value of relative humidity will differ in the northern United States as contrasted with the southern.

Kincer (1919) maps those areas showing thirty consecutive days, or more without .25 inch of rainfall in 24 hours. These records point out that the central Appalachian district including Eastern Tennessee is least subject to droughts, which occur but one year in three. The plains sections are the most subject to droughts. Munger (1916) suggests that the intensity of a drought is most important and increases in a geometric relation to the length of the dry period. The single variable used is the length of the period without a 24-hour rainfall of .05 inch. The following formula is used viz.:

Severity of Drought = Length of Drought × ½ Length of the Drought.

Such a formula may approximate the actual conditions of the Pacific slope. East of the Rocky Mountains the summer rainfall is more abundant. The high temperatures that frequently prevail, however, also greatly lower the humidity of the air. The two factors are closely interdependent. In order to incorporate both temperature and rainfall, the following drought index appears to be a measure of the conditions during a droughty period in harmony with the climatic requirements of the bean beetle, in the eastern United States.

$$L \times \frac{L}{2} \times \left(\frac{100}{R}\right)^2$$

Where L = the total number of two or more consecutive days above 90°F. for the months of June, July, August, and September, and R = the total summer rainfall for the same months.

With this formula, the intensity of a drought is made to increase as the square of its duration, and includes both factors of temperature and precipitation. 100 is used in place of 1 in order to avoid decimals. A drought varies directly as the temperature, and inversely as the precipitation.

TABLE I.

Climatic index numbers, using the formula $L \times \frac{L}{2} \times \left(\frac{100}{R}\right)^2$ where L = the successive number of days above 90°F. and R = the summer rainfall.

Locality	$L \times \frac{L}{2}$	Summer Rainfall	$\frac{(100)}{(R)}$	$\left(\frac{100}{R}\right)^2$	Index Number
Birmingham, Ala.	164	16.5	6.0	36	5,904
Montgomery, Ala.	244	16.0	6.25	39	9,516
Centerville, Ala.	309	23.0	4.37	19.1	5,871
Yuma, Ariz.	3533	1.1	90.0	8100.	2,861,730
Little Rock, Ark.	173	15.0	6.66	44.35	7,612
Fort Smith, Ark.	160	14.58	6.85	46.92	7,504
San Francisco, Cal.	1	.5	200.	40,000	40,000
Denver, Colo.	11	6.5	15.38	237.1	2,607
Greeley, Colo.	64	5.7	17.54	306.2	19,584
Jacksonville, Fla.	96	26	3.84	14.74	1,421
Tampa, Fla.	292	32.77	3.05	9.3	2,715
Miami, Fla.	5	32.56	3.07	94.24	470
Orlando, Fla.	632	29	3.44	11.83	6,457
Atlanta, Ga.	33	16.3	6.13	37.57	1,237
Thomasville, Ga.	168	21.9	4.56	20.79	3,494
Springfield, Ill.	35	13.4	7.46	55.65	1,946
Vincennes, Ind.	205	15.5	6.45	41.60	8,528
Des Moines, Iowa	33	15.5	6.45	41.60	1,372
Lawrence, Kan.	96	17.7	5.64	31.80	3,052
Tribune, Kan.	132	8.6	11.62	134.5	16,758
Baton Rouge, La.	190	23	4.34	18.83	3,572
New Orleans, La.	211	23.09	4.33	18.74	3,945
Shreveport, La.	521	12.76	7.87	61.93	31,749
Mexico City, Mex.	1	16.7	5.98	35.76	36
Battle Creek, Mich.	19	13.4	7.46	55.65	1,056
St. Paul, Minn.	10	14.7	6.80	46.24	460
Jackson, Miss.	416	15.7	6.37	40.57	16,848
Columbia, Mo.	56	13.8	7.24	52.41	2,934
Helena, Mont.	4	4.9	20.4	416.1	1,664
Glasgow, Mont.	30	5.4	18.5	342.2	10,260
Boston, Mass.	6	13.5	7.40	54.76	328
North Platte, Nebr.	45	9.92	10.0	100	4,500
Bismark, N. D.	13	8.9	11.23	125.4	1,625
Agr. College, N. M.	862	5.3	18.86	353.4	304,286
Columbus, Ohio	18	12.7	7.87	61.93	1,114
Hamilton, Ohio	106	14.7	6.80	46.24	4,876
Oklahoma City, Okla.	500	12.6	7.93	62.88	31,400
Muskogee, Okla.	160	13.06	7.7	59.29	9,488
Portland, Ore.	10	4.9	20.40	416.1	4,160
State College, Pa.	7	15	6.66	44.3	310
Columbia, S. C.	88	17.9	5.58	31.13	2,728
Charleston, S. C.	34	17.7	5.64	31.80	1,079
Pierre, S. D.	49	9.2	10.86	116.6	5,684
Crossville, Tenn.	1	18.23	5.49	30.14	30
Knoxville, Tenn.	28	15.2	6.57	43.16	1,218
Knoxville, Tenn. (1925)	197	7.35	13.6	184.9	36,425
Nashville, Tenn.	50	15.01	6.66	44.35	2,217
Jackson, Tenn.	223	14.4	6.94	48.16	10,927
Wildersville, Tenn.	164	15.0	6.66	44.35	7,265

TABLE I—Continued.

Locality	$L \times \frac{L}{2}$	Summer Rain-fall	$\frac{(100)}{(R)}$	$\left(\frac{100}{R}\right)^2$	Index Number
Trenton, Tenn...........	326	13.6	7.35	54.02	17,604
Savannah, Tenn.........	470	13.5	7.40	54.76	25,709
Perryville, Tenn.........	342	13.5	7.40	54.76	18,810
Austin, Texas...........	1,512	10.6	9.43	88.92	134,416
Galveston, Texas........	32	19.15	5.23	27.35	873
St. George, Utah........	953	2.89	34.60	1,197	1,140,741
Moab, Utah.............	500	2.87	34.84	1,211	605,500
Roanoke, Va............	66	15.3	6.53	42.64	2,811
Diamond Sp., Va........	16	23.7	4.22	17.80	284
Fort Laramie, Wyo......	71	4.9	20.4	416.1	28,536
Border, Wyo............	5	4.7	21.3	453.6	2,268

THE CLIMATE OF TENNESSEE.

Tennessee has an average precipitation of 50 inches and an average temperature of 58° F. The rainfall type that characterizes Tennessee has a winter maximum and a well marked minimum in autumn. Due to its great length, a variety of climates exist. Eastern Tennessee is mountainous and includes the Great Smoky Mountains, a region abundantly favored with moisture. The annual precipitation in these mountains reaches 60 inches or more, while the mean temperature is but 45° F. Knoxville is located in a valley between the Smoky and the Cumberland mountains with a mean temperature of 56° F. and has 49 inches of rain. Middle Tennessee has a mean temperature of 58° F. and about the same amount of rainfall. West Tennessee is more or less flat, with a mean temperature of 60° F. and 50 inches of rain, and is adapted for cotton raising.

A study of the distribution of the insect in Tennessee clearly shows that the beetle reached East Tennessee first, gradually spreading to Middle Tennessee and spread very slowly towards the western third of the State. At first the absence of the bean beetle in West Tennessee proved puzzling, but the unprecedented drought of 1925 threw much light on the natural spread of the beetle as well as its capacity for destruction. The bean crops of 1923 and 1924 in Eastern Tennessee were almost completely ruined, due to a series of favorable years for the beetle, whereas in the drought period of 1925 the insect almost disappeared. The influence of such factors as temperature and moisture was clearly evident. Normally Eastern Tennessee is least affected by droughts during the growing seasons of June, July and August. The fact that the beetle is most consistently injurious in normal years indicates that East Tennessee possesses favorable conditions for multiplication. A drought such as occurred in 1925 is exceptional. The temperatures were greatly above normal and the rainfall amounted to 7.35 inches (see Fig. 1). The months of June, July, August and September registered 60 days above 90° F. and a drought index of 36,425, whereas normally but 23 such days occur and the index is 1218 (Table I).

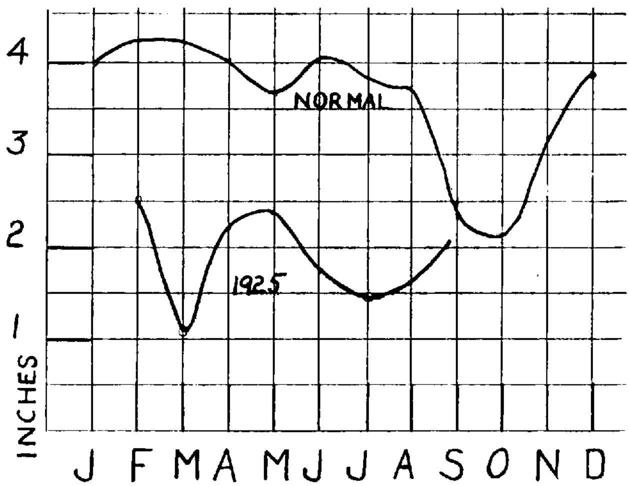

FIG. 1. Monthly precipitation at Knoxville, Tenn.

Nashville and Middle Tennessee show an index of 2217, and are somewhat less favorable for the beetle. Crossville, Tennessee, located on the Cumberland Plateau at an elevation of 1800 feet, shows a low index of 30, and suffers from beetle attacks accordingly. The years 1928 and 1929 in Knoxville were normal years, and the abundance of the bean beetle was evident.

In West Tennessee we find a somewhat lower summer rainfall than in East Tennessee and higher temperatures. Jackson averages 47 days or more above 90° F., and has an index of 10,927. When these values are plotted West Tennessee shows a curve approaching that of East Tennessee for 1925 (Fig. 2).

Although West Tennessee shows considerable uniformity, the eastern counties, such as Carroll and Henderson were the only ones to report serious damage by the bean beetle. A study of the temperature records of these counties shows that they are cooler than the adjacent counties such as Gibson and Madison. In West Tennessee, Carroll and Henderson counties are frequently referred to as "hill country." For Henderson County

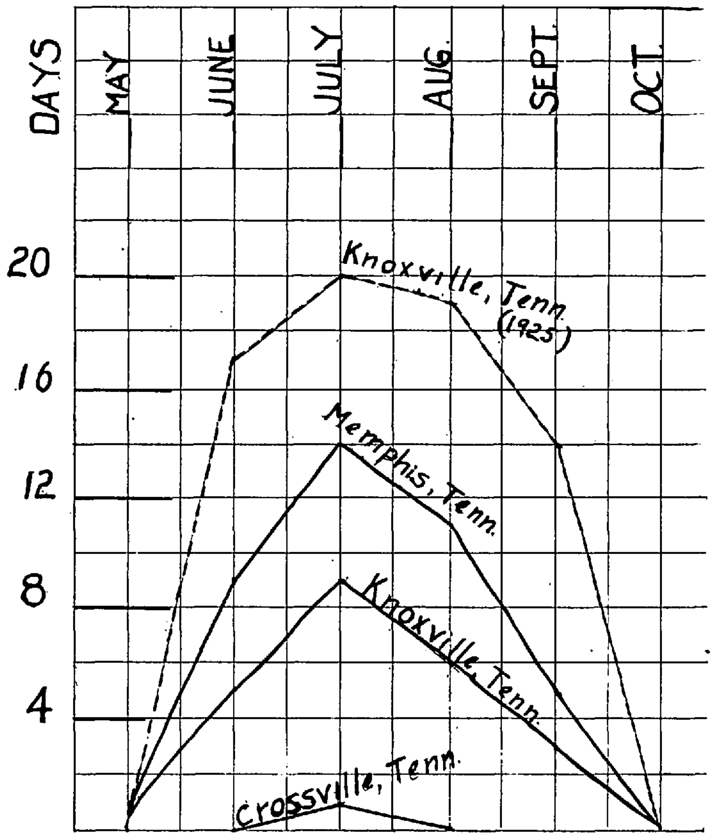

FIG. 2. Number of days above 90.

the only weather records available were for Wildersville which showed an index of 7,265. Jackson, only about 25 miles west shows an index of 10,927, while Gibson County shows an index of 17,604. West Tennessee is often spoken of as a unit, but these figures show that some towns are much hotter than others only 20 miles distant. In other words, West Tennessee, in average years appears unfavorable for the multiplication of the beetle. In favorable years such as 1928 and 1929 with abundant summer rainfall the beetle will spread further west, and show greater capacity for destruction. During unfavorable years the beetle may actually lose territory formerly occupied as occurred in South Carolina in 1925 (Eddy, 1927).

THE HUMID EAST FAVORABLE FOR THE BEETLE.

The climates of the eastern states, especially those bordering the Atlantic Ocean, are comparatively humid, and approach the marine type of climate. As a group, they represent a combination of temperature and moisture most suitable for the life of the bean beetle. The region in the vicinity of Norfolk, Virginia, shows a drought index of only 284. Injury by the beetle is known to be severe in this section. Other localities show equally favorable conditions, such as State College, Pennsylvania, with an idex of 310.

THE LIMITING FACTORS OF THE SOUTHERN PLAINS STATES.

The southern plains states, such as Kansas and Oklahoma, have a typically continental climate, characterized by wide extremes of temperature, with a good wind movement and high rate of evaporation. The occurrence of precipitation is irregular and droughts are relatively frequent. "Hot winds" are also characteristic, with temperatures ranging from 100° to 116° F., causing great injury to growing crops and even to the bark of trees. In the western half of the state great damage is often caused in a dry season in winter from high winds blowing the loose soil of wheat fields, leaving the roots of the plant bare.

It is quite evident that western Kansas is not only too hot for the bean beetle in summer, but offers very poor hibernating quarters in winter. The drought index for Tribune, Kansas, is 16,758, while that of Lawrence, Kansas, is 3,052. Assuming that the beetle can not exist in localities with an idex over 10,000, Lawrence possesses a favorable climate, while Tribune is highly unfavorable. Oklahoma is also unsuitable for the bean beetle, since Oklahoma City has an idex of 31,400. Texas, with the exception of the higher portions of the western part, and a narrow strip along the Gulf, is much too hot for the beetle. Austin, Texas, has the high drought index of 134,116.

DROUGHT CONDITIONS IN THE GULF STATES.

Although the Gulf states are favored by abundant precipitation, drought periods are frequent because of the irregularity of the rainfall and frequency of torrential rains which dissipate in surface run-off. Montgomery, Alabama, for example, although favored with a summer rainfall of over 16 inches, is subject to hot spells in summer time with a large number of days above 90° F. Its drought index is 9,516 which represents unfavorable climatic conditions for the beetle. A glance at the map showing the present distribution of the bean beetle indicates that the beetle has not spread south of Montgomery. Birmingham, about 100 miles north of Montgomery, is more favorable for the beetle with an index of 5,904. The insect was first introduced in the vicinity of Birmingham, and with a series of favorable years produced much injury to the bean crop. However, Birmingham is subject to droughts and in average years is not especially favorable for the development of the bean beetle. Because of the lack of beetles around Birmingham, the Bureau of Entomology found it necessary to move its laboratories to Ohio, where more specimens were available for experimentation. The southern third of Alabama seems to be too hot for the beetle. Centerville, however, with an index of 5,871 and the portion along the southern border appear favorable due no doubt to the influence of the Gulf of Mexico.

It is quite possible that the bean beetle could live in southern Alabama if it was capable of crossing the hot belt south of Montgomery.

Georgia presents conditions similar to Alabama. North Georgia is mountainous and very favorable for the beetle, while southern Georgia is too hot. It is of interest to note that an isolated infestation has been present around Thomasville for several years. Thomasville, with an index of 3,494, should be capable of supporting the beetle. The fact that the beetle has not spread from Thomasville indicates that the surrounding territory is not favorable.

THE WESTERN INFESTATION OF THE BEETLE.

Colorado and the neighboring states where the bean beetle has been present for 75 years is of special interest in the study of the distribution of the beetle. Considering the phenomenal spread of nearly 1000 miles in 10 years that took place in the eastern states, the comparatively static condition of the insect in the arid Rocky Mountains is striking. Graf (1925) believed that the beetle is adapted to the humid East and the dry West. Sweetman has shown that the western infestation is confined to the irrigated regions and that the beetle is not injurious in non-irrigated regions. Denver, Colorado, with an elevation of 5,283 feet and an index of 2,607 is fairly favorable for the bean beetle, while Greeley, Colorado, only a few miles east of Denver, but with an elevation of 4,649 shows an index of 19,584, and appears unfavorable. East of Greeley there are no mountain barriers to keep the beetle from spreading. List (1921) records the beetle from Greeley, and yet it has not spread east to any considerable extent. The eastern third of Colorado is the beginning of the hot arid plains which present an effectual barrier to the spread of the beetle eastward.

In the western states the Mexican bean beetle is known to be present in Arizona, New Mexico, Colorado, Wyoming, Texas and Utah, being confined to high elevations or irrigated regions. At present only the irrigated southeastern section of Wyoming is infested. Laramie shows an idex of 28,536 and without irrigation is not favorable. The arid conditions of the state of Wyoming appear to present an effectual barrier to the spread of the beetle into western Montana, where conditions are more favorable because of lower temperatures. West of the Rocky Mountains, the well known desert conditions offer an insurmountable barrier. While the summers are dry in the Rocky mountain states, the winters are still drier. January, 1928 at Greeley, Colorado, showed but .08 inch precipitation and maximum temperatures of 70° F. Such a combination produces an extremely dry atmosphere, which must be highly unfavorable for hibernation.

Tanner reports on the bean beetle at St. George, Washington County and Moab in Grand County, Utah. The weather records for St. George, Utah, show that this locality without irrigation is extremely unfavorable for the bean beetle, having a drought index of 1,140,741. Moab in eastern Utah is likewise unfavorable with an index of 605,500. It is likely that conditions in Utah are similar to those of Wyoming, where without irrigation the beetle could not exist. The infestation in Utah may ultimately spread along the Wasatch mountains into Idaho, western Wyoming and western Montana.

MEXICO, THE ORIGINAL HOME OF THE BEAN BEETLE.

Southern North America is believed to be the original home of the bean beetle. Since the bean beetle is a native destructive pest of Mexico at elevations above 4000 feet, a study of the climate of this country should be instructive. With the exception of the low coastal area most of Mexico is an elevated plateau ranging from 4000 to 8000 feet in height. The mean annual temperature is 60° F. and the rainfall is 30 inches,

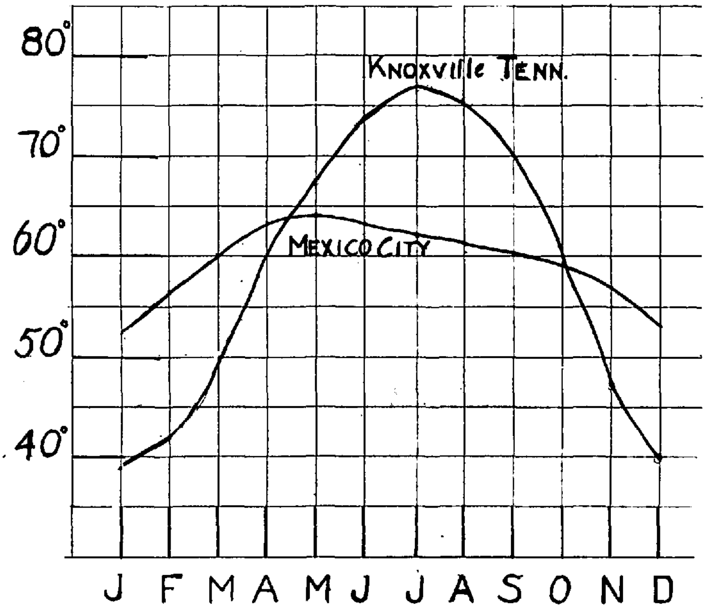

FIG. 3. Mean temperature.

most of which falls in the summer months (Fig. 3). During July and August, the months most favorable for bean growing, maximum temperatures of but 70° F. are reached in Mexico City (Hernandez, 1923). This presents a remarkable contrast considering that Mexico lies in the tropical zone. May, the hottest month in the year, has a maximum temperature of but 75° F. These comparatively low temperatures and the generous rainfall of 16 inches for the summer months, are the climatic conditions the bean beetle has been exposed to for numberless generations and undoubtedly present the optimum requirements for breeding.

Any wide departure from these combinations of temperature and rainfall may be regarded as unsuitable for the development of the insect. The drought index of Mexico City is 36. Crossville, Tennessee, on the Cumberland Plateau with an index of 30 is one of the few localities in the eastern United States that approximate the index number for Mexico. Since the Rocky Mountains extend into Mexico, there is every reason to believe that the beetle migrated from Mexico to Arizona along the elevated plateau and fed on the wild bean plants that are native to this region.

TEMPERATURE AND MOISTURE STUDIES UNDER CONTROLLED CONDITIONS.

The preceding study indicates that the beetle has definite requirements of temperature and moisture for best development, and that certain localities are more favoarable than others. There remains the gathering of experimental data under controlled conditions so as to determine the optimum temperature and moisture requirements in order to check the field observations.

STUDIES AT CONSTANT TEMPERATURES.

Methods Used in Rearing

The various stages of *E. corrupta* were reared in one-ounce tin salve boxes. The bottom of each box was covered with two or three pieces of blotting paper which were moistened each day in order to maintain the proper relative humidity.

The larvæ were secured by gathering egg masses from bean plants in the field and hatched under insectary conditions. Upon hatching the larvæ were placed in one-ounce tin boxes with moist paper and fresh bean leaves. Each day the boxes were examined and water and fresh food were added if necessary. After the larvæ entered the prepupal stage, just water was added to the boxes.

The Egg Stage

The egg stage was the only stage that was difficult to handle in this manner. If the box was too moist fungi would grow rapidly and prevent the eggs from hatching. For this reason sufficient data regarding the egg stage has not been secured to permit definite conclusions.

Incubation of eggs at various constant temperatures from limited data secured shows that both at 30° C. and at 25° C. the period of incubation was 6 days. At 15° C. the eggs hatched within 14.5 days.

The Larvæ Stage

The growth during the larval stage was marked with the usual feeding and molting. The length of the larval stage was considered terminated when the larvæ attached themselves to the leaf.

TABLE II.

Length of the Different Stages of the Bean Beetle Under Constant Temperatures.

Temperature	Number of Individuals	Duration in Days	Reciprocal
		Egg Stage	
15	....	14.5	.0689
20	....	10 (interpolated)	.1000
25	....	6	.1666
30	....	6	.1666
		Larval Stage	
15	23	43.66	.02293
20	58	23.30	.04291
25	75	16.02	.06250
30	13	12.93	.07751
		Prepupal Stage	
15	41	5.36	.1869
20	30	3.02	.3311
25	42	1.78	.5617
30	20	1.60	.6775
		Pupal Stage	
15	22	13.75	.0727
20	86	7.39	.1357
25	69	5.30	.1886
30	38	4.71	.2123
		Total	
15	23	77.27	.01295
20	61	43.71	.02288
25	69	29.10	.03436
30	12	25.34	.03952

Table No. II shows the average length of the different stages at constant temperatures. At temperatures ranging from 15 to 30° C. the larval stage varied from 14.5 to 49.4 days. At high temperatures such as 34° C. the young larvæ lived but a few days. With the low temperature of 15° C. the larvæ seemed contented but required a long period of time to complete their development. Less variation in relative humidity occurred in the boxes during this stage due to the presence of food.

The Prepupal Stage

No change was noticeable during this stage of development. The length of the prepupal stage was considered from the time the larvæ fastened themselves to the leaves until the larval skin was slipped back and exposed the pupæ. The prepupal stage averaged 1 to 5 days with the low temperature showing the greatest variation.

The Pupal Stage

Considerable variation occurred in this stage which required from 4 to 16 days. This stage was not greatly affected by the variable moisture conditions.

TOTAL LENGTH OF THE IMMATURE STAGES.

The total length of time for the development from the egg to the adult stage showed considerable variation. The average time to complete development at 30° C. required but 26.8 days while at 15° C. 83 days were consumed. At 25° C. the greatest percentage reached maturity, so that this temperature may be considered as the optimum. Practically no mortality occurred at 15° C., although the period of development was greatly prolonged. At 30° C. considerable mortality occurred with but a small percentage of larvæ reaching maturity, while at 34° C. the larvæ lived only 4 days.

THE EFFECT OF LOW TEMPERATURES ON THE COLOR OF THE BEAN BEETLE.

It may be of interest to call attention to the effect of temperature on the color of the beetle. At 25° C. and above, both the larvæ and pupæ are a bright yellow color. The larvæ take on a darker hue at 20° C. due to the black-tipped spines, while the pupæ show black lines on the wing pads. At 15° C. the larvæ assume a very dark appearance because the spines including their bases become black. The rest of the larval skin remains yellow. At the low temperatures the pupæ also become dark with practically no yellow color showing. The spots on the adults vary, although no markings were found characteristic of any one temperature. When the adults were reared at 15° C. the abdomen appeared quite dark. The dark color was not observed when the insects were reared at the higher temperatures.

MORTALITY IN A TEMPERATURE OF 100° F. AND VARIABLE HUMIDITIES.

Two temperature cabinets were regulated to keep a constant temperature of 100° F. In order to maintain a relative humidity of 80 per cent three large pans of water were placed in one cabinet and towels were hung in the water so that they formed a wick. This method gave a relative humidity of 80 per cent.

TABLE III.

Showing 50 Per Cent Mortality in Hours Produced by a Temperature of 100° F. and Variable Humidities.

	40 Per Cent R. H.	80 Per Cent R. H.	100 Per Cent R. H.
Small Larvæ..........	6.75	8	4.83
Full Grown............	13.75	22.5	12.5
Adults.................	10.64	25	12.5

The second cabinet was found to have a relative humidity of 40 per cent. The percentage of relative humidity was determined by using a stationary wet and dry bulb instrument manufactured by the Tycos Instrument Company.

For the production of 100 per cent relative humidity Ehrlenmeyer flasks were half filled with water and kept tightly stopped during the experiment. The insects were suspended in the space between the water and the stopper.

At 100° F. and a relative humidity of 80 per cent young larvæ lived but 8 hours, while full grown larvæ and adults lived 21 hours (Table III). Forty per cent relative humidity produced a kill in almost half the time. It is of interest to note that 100 per cent relative humidity is about as fatal as the dry atmosphere produced by 40 per cent. At 77° F. and relative humidities of 58 to 100 per cent, practically no mortality occurred, the insects living for several days.

Sweetman (1929) in his observations on the bean beetle in Wyoming considers moisture and precipitation as more important factors than temperature in the distribution of the insect.

The experimental work, however, indicates that temperature factor is the more potent in the life economy of the insect. Temperature and relative humidity are interdependent and vary inversely, high temperatures producing low humidities. The low humidities are fatal to the bean beetle only as the temperature is increased beyond the optimium of 77° F.

Above 100° F. the insects succumb rapidly. At 106° F. small larvæ lived but 7½ minutes, while at temperatures ranging from 108 to 112° F. full grown larvæ and adults lived 10–12 minutes.

A few experiments were also performed with larvæ crawling on heated soil in full sunlight. Surface temperatures ranged from 106 to 127° F. at the time shade temperatures were 90° F. When the soil temperature registered 106° F. small second instar larvæ lived 3½ minutes. At 115° F. they succumbed in one minute, while full grown larvæ lived for two to five minutes.

FUTURE SPREAD OF THE BEAN BEETLE. BASED ON CLIMATE.

In any study of the probable distribution of an insect, and its fitness to live in a new environment, a knowledge of the following aspects is important:

(1) Origin and history of the insect.
(2) Climate of the original locality of the insect.
(3) Optimum temperature and moisture requirements, determined by breeding.
(4) Conditions favoring optimum development of the host plant.
(5) Food availability.
(6) Ability to aestivate.

The first criterion is easy, for we know that the bean beetle originated on the table-lands of Mexico.

While Mexico is situated in the tropical zone, its table-lands are sufficiently elevated to have a temperate climate, and a few localities are even in the cold zone. The hottest months are characterized by maximum temperatures of 75° F. With 16 inches of rainfall during the summer months, the relative humidity is undoubtedly high.

In order to determine the most favorable temperature and moisture requirements for the development of the bean beetle, a number of the insects were reared under controlled conditions. The experimental data indicate that the largest percentage survived at constant temperatures of 77° F. and a relative humidity of 80 per cent. These figures undoubtedly represent the optimum conditions for breeding, and coincide in a striking manner with the climatic factors prevailing in the original breeding grounds of Mexico.

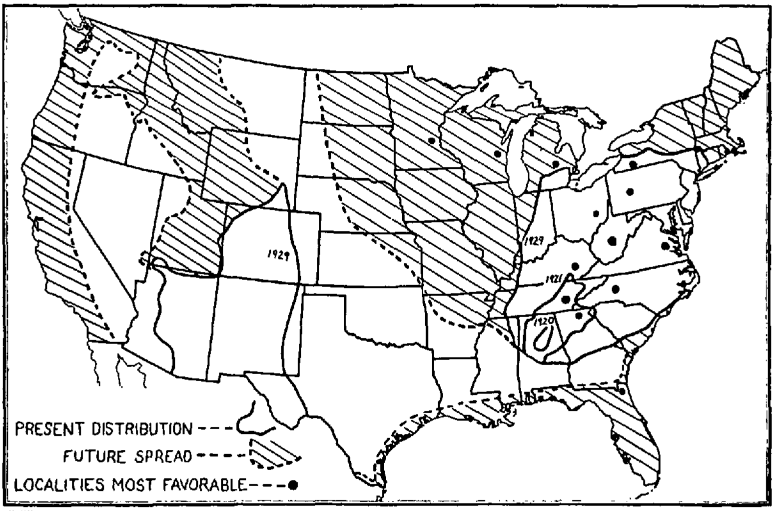

FIG. 4. Spread of the Mexican Bean Beetle.

The bean itself, the host plant of the beetle, requires cool nights, ample rainfall, and a comparatively high humidity. Cox and Pettigrove (1924) believe that these conditions are met with in eastern Michigan and account for the particular adaptation of a great part of Michigan land to bean production. In southern Michigan counties, the frequently prevailing hot weather of midsummer, which greatly favors the corn crop, prevents the suitable setting and filling of bean pods.

The conditions favoring the culture of the cultivated bean are also favorable for the breeding of the beetle, and it is safe to say that the abundance of garden beans in the East has been a factor of no small importance in the rapid spread of the beetle.

On the other hand, the inability of the bean beetle to tide over unfavorable conditions has been a handicap. Breitenbecher (1912) has shown that the potato beetle (*Leptinotarsa decemlineata*) has the power to desiccate itself when placed in an arid environment, ceases breeding and enters the ground to aestivate. With the approach of favorable temperature and moisture conditions, the beetle comes to the surface and begins breeding. In Tennessee, potato beetles are always abundant and destructive in the spring months, but are seldom noticed during the hot summer months. This accounts for the fact that we have but one full generation of potato bugs, even though there is time for four generations. The bean beetle, however, has not the power to cease breeding and the approach of hot weather is often harmful to the second or third generation. This is probably the principal reason that the potato beetle has been able to cross the hot plains and reach the Atlantic coast, while the bean beetle had to be transported to the humid east in order to reach the coast.

Knowing the climatic requirements of the bean beetle, and having determined those localities most favorable for its development, we are now in position to map the future distribution of this pest. With the aid of the formula $L \times \frac{L}{2} \times \left(\frac{100}{R}\right)^2$ as discussed previously, we can assign an index number to any locality desired. The Mexican bean beetle appears to thrive in those regions having an index of 2000 or less, and these may be considered the "normal" zone of occurrence (Cook, 1925). Regions with an index of 2000 to 6000 (See Table I) will be subject to periodic infestations, and may be considered areas of "occasional" abundance. In a series of favorable years these areas may suffer greatly from the ravages of the pest. Localities above 10,000 may be considered highly unfavorable for the development of the bean beetle.*

*Another severe drought occurred in 1930 over the Ohio valley, accompanied by a scarcity of bean beetles. Added confirmation of the conclusions reached in this paper is shown by the climatic index numbers that were reached at representative localities. Knoxville, Tennessee, for example, attained an index of 17,253. Up to September 6, 1930, the drought approached that of 1925 in severity. The last three weeks in September, 1930, cooled off sufficiently to favor the production of an hibernating generation. This did not occur in 1925. At Columbus, Ohio, the index number approached 24,000, whereas the normal is only 1,114.

After the index number of many representative localities was determined, a map showing the distribution of the Mexican bean beetle was constructed (Fig. 4). Those states that appear unusually favorable have been designated by a large black dot, and include East Tennessee, North Georgia, Kentucky, both Virginias, Pennsylvania, New York, the New England states, eastern Ohio, Michigan, Wisconsin, Minnesota, Iowa, and the northeastern part of Florida. To the north the beetle will migrate along the Great Lakes, and eventually reach Minnesota and Iowa.

In the South it will find a barrier of hot air in Central Alabama, Georgia, Mississippi, and northern Louisiana that will keep it from reaching the Gulf coast. The Atlantic coast seems to be favorable, and it is possible that the insect will travel along the eastern coast as far south as Jacksonville, and thence across to the Gulf coast and on to New Orleans. Just how the bean beetle will fare in Florida remains to be seen, as much will depend on suitable hibernation quarters and availability of host plants during the summer months.

The high temperatures of central and eastern Texas, Oklahoma, and western Kansas, and the meager summer rainfall of eastern Montana and eastern Wyoming, are factors that make these regions entirely unsuitable for the breeding of the beetle.

The western infestation of the bean beetle is at present confined to the irrigated or elevated regions of western Texas, New Mexico, Arizona, Colorado, Wyoming, and Utah. The hot, dry conditions prevailing in the desert regions west of Arizona and Utah will prevent the bean beetle from reaching the western coast. On the other hand, there are good possibilities of its spreading along the mountain ranges of Utah into Idaho, and thence to western Montana, where conditions are favorable. From Montana, it will be possible for the beetle to spread into Washington, western Oregon, and the irrigated regions of California.

SUMMARY AND CONCLUSIONS.

The phenomenal spread of the Mexican bean beetle in the East has been attributed to the prevailing wind. A study of the climatic requirements of this insect indicates that there are very definite limits of temperature and moisture that favor its development and determine its potentialities as a crop pest, as well as its ability to spread into new territory.

The original home of the Mexican bean beetle is the tablelands of Mexico and Central America. These elevated regions possess a uniform cool climate, with maximum temperatures of 75° F., to which the beetle is best adapted. The breeding work indicates that a temperature of 77° F. is most favorable for survival. Higher temperatures hasten development but produce greater mortality. At constant temperatures of 93° F., none of the larvæ were able to develop, while at 100° F. the small larvæ succumbed in 8 hours.

Observations during the past five years under out-door conditions show that the high temperatures prevailing in midsummer are often very unfavorable for the development of the insect. The following formula was used to measure the effects of a drought: $L \times \frac{L}{2} \times \left(\frac{100}{R}\right)^2$ where L is the successive number of days above 90° F. and R is the summer rainfall. With the aid of this formula, the climatic index number of representative localities was determined. Regions with an index number of 2000 or less appear favorable for the bean beetle. By the aid of these index numbers, a map was prepared showing the future spread of the bean beetle.

In time the beetle will reach Florida by the way of the Atlantic coast, and Minnesota by the way of the Great Lakes. The western infestation will spread along the Rocky Mountains to western Montana, and thence to the irrigated bean sections of the Pacific coast. Localities with extremely hot summers, like central Texas and Oklahoma, northern Louisiana and central Mississippi, will be exempt from bean beetle depredations. Cool humid regions, such as Eastern Tennessee, eastern Virginia, eastern Michigan, and Pennsylvania are most favorable for the beetle, and will suffer accordingly. Localities subject to droughts will often be free from the attacks of the pest except in a series of favorable years.

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