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By Harvey L. Sweetman and H. T. Fernald

Since 1921 the Mexican bean beetle has spread from its native habitat, the Southwest, over most of the East where it has also been very injurious to the bean crop. During 1929 it was found for the first time in Connecticut and Massachusetts. A study of temperature and moisture conditions necessary for the development of the insect is here used in an attempt to determine whether it is likely to become a serious pest under the climatic conditions prevailing in New England.

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AGRICULTURAL EXPERIMENT STATION,

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ECOLOGICAL STUDIES OF THE MEXICAN BEAN BEETLE

By Harvey L. Sweetman[1] and H. T. Fernald,

Professor of Entomology

The Mexican bean beetle, *Epilachna corrupta* Muls., is a native of southwestern North America. It has been a pest of beans in southwestern United States since about the middle of the last century. The beetle has spread over most of the East since 1921 and has been very injurious to the bean crop through most of its range. It was found in New England in 1929 in Connecticut and Massachusetts, having apparently spread from New York State. The insect is capable of becoming a very serious pest of the bean crop in New England if the environmental conditions prove to be favorable to its reproduction and spread. The data presented here are the results of a study of the influence of the physical environment upon the bean beetle.

Review of Ecological Literature

The ecological factors affecting the bean beetle have received very little attention from most workers. The discovery of the insect in Alabama in 1920 caused much speculation regarding the effects of climate on it.

Hinds (1920) stated that there were not any climatic or geographical barriers to prevent the pest from spreading, but later (1922) attributed the slow dispersal southward in Alabama to the prevailing winds. Montgomery (1920) thought that losses from the bean beetle were not great in the Southwest because of climatic and other conditions. This thought is somewhat misleading as serious injury is rather common in that territory. Howard (1922a) considered a temperature of 100° F. or over in dry weather to be very destructive, and found (1922b) that the larvae were killed in a few minutes when in direct sunlight if the temperature was above 90° F. Later (1924) death of the larvae was noted as occurring during heavy rains, but drouth was not thought to be injurious as long as the plants were green. Howard and English (1924) witnessed large numbers of the immature stages being destroyed during a hot, dry period, but this was due partially to lack of food and to exposure to direct sunlight. They found also that moist places were essential for successful hibernation and that the beetles migrated if the hibernating quarters became too dry. Howard (1922b, 1924) had emphasized the fact that the adults required moist, but well drained, places for successful overwintering. Later Howard (1927) in collaboration with Transeau (1927) found that the regions in which damage occurred in Ohio coincided with areas that were originally mixed mesophytic forest. The previous year De Long (1926) in Ohio had stated, "There is an ecological factor that is controlling very decidedly the distribution." Graf (1925) from a climatological study concluded that temperature and moisture were not important factors in limiting the distribution of the pest. Later (1928) he stated that low winter temperature alone could not be depended upon to control the pest. Eddy (1926) and Eddy and McAlister (1927) in South Carolina consider low humidity and high temperature very detrimental to the immature stages, and a

[1] Candidate for a graduate degree in Entomology.

high moisture environment beneficial. Eddy and Clarke (1929) note that warm, moist weather favors spring emergence from hibernation. Thomas (1924) in Alabama emphasized the importance of high moisture for hibernation and a temperature between 65° and 91° F. and relative humidity between 40 and 95 per cent for egg production. His records were not secured under controlled conditions. Pepper (1926) noted the destruction of immature stages in South Carolina during a heat wave. Marcovitch (1926) found that drouth destroyed the insect in Tennessee and was a more important limiting factor than cold. He considered the humid conditions of the East favorable to the pest. Douglas (1928) found that temperature alone would not cause emergence of the adults from hibernation quarters, but that moisture was essential and more important than temperature. Cecil (1928) stated that the beetle would successfully survive the winter temperatures prevailing in New York State. The writer (1929) demonstrated the necessity of humid conditions for the bean beetle to maintain itself in abundance, and showed that its distribution in the West, as well as the East, depended upon that factor.

All of the above conclusions are based upon outdoor observations where several possible factors may have been important in producing the results mentioned. A considerable difference of opinion between the various workers is evident, and some of the citations are decidedly misleading and contrary to fact, as will be brought out later. Accurate data of the physical factors affecting the immature stages are especially lacking.

Description of Stages and Injury

All stages,—eggs, larvae, pupae, and adults,—of the bean beetle are conspicuous in the field.

The eggs are pale or orange yellow in color, nearly elliptical in outline, and about twice as long as wide. They are attached at one end and laid irregularly in groups of about fifty on the under sides of the leaves.

The larvae have four instars, molting three times previous to the pupation molt. The newly hatched larvae are about 1.5 mm. long, pale greenish-yellow in color, with their bodies armed with spines. The developing and mature larvae are yellow, with six rows of spines which become strongly branched and black at the tips (Plate 1, B). When over half grown they appear to be "humped", the longest spines and thickest portion of the body being in the middle. The abdomen in all instars tapers to the anal segment which is produced to form a sucker-like apparatus by which the larvae are aided in clinging to the leaf, and by which they fasten themselves previous to molting.

The pupae are light yellow in color, spineless, and about the size of the adults. They hang head downward from the under surfaces of the leaves and are partly covered and protected by the shed larval skins, which are attached by the posterior end to the surface on which they are fastened.

The adults are robust, hemi-ovoid beetles with rather slender legs, and are about one-fourth of an inch in length and one-fifth of an inch wide. When newly emerged the color is yellow, gradually darkening with age to bronze or brownish. Each wing cover is usually marked with eight small black spots (Plate I, B).

Both the adult and larval stages are destructive (Plate I, B). The beetles cut irregular holes through the leaves, leaving portions of tissue and the larger veins. The larvae are voracious feeders, and do more harm than the adults. At first they feed in colonies near the old egg mass on the lower surface of the leaf, but soon become scattered as they crawl to other leaves in search of food. They consume the lower layers of the leaf, leaving the upper epidermis and large veins. The upper tissue soon dies and bleaches out, leaving a whitish skeletonized appearance (Plate I, A).

Seasonal History

The adults of the Mexican bean beetle emerge from hibernation in the spring after the advent of warm weather, and locate suitable food plants, principally beans. Egg-laying begins in about a week or ten days after their appearance, the eggs generally being attached to the under side of the leaves. Incubation of the eggs requires about ten days to two weeks. The larvae feed upon the leaves and pods for about three to five weeks, then attach themselves to the leaves and pupate; the adults emerge eight to twelve days later. The number of generations in a season is dependent upon the climatic conditions and length of season, varying from one to four in the different localities. The beetles enter hibernation in the fall in moist places, remaining dormant or semi-dormant, depending upon the region, until spring.

Food Plants

The bean beetle is primarily a bean pest, attacking by preference the common beans, including bush and pole varieties of snap beans, pinto, navy, lima, and tepary beans. It can subsist on a number of other plants and has severely injured cowpeas and soybeans in several states. Howard and English (1924) list the following plants as being attacked:

Common Name	*Scientific Name*
Tepary bean	*Phaseolus acutifolius*
Garden bean	*P. vulgaris*
Including navy, pinto, kidney, pole beans, etc.	
Lima bean	*P. lunatus*
Beggarweed	*Meibomia tortuosa,*
	M. canescens,
	M. viridiflora
Hyacinth bean	*Dolichos lablab*
Cowpea and Black-eyed Pea	*Vigna sinensis*
Soybean	*Glycine hispida*
Adsuki bean	*Phaseolus angularis*
Alfalfa	*Medicago sativa*
Sweet clover	*Melilotus alba*

Distribution

The bean beetle is a native of southwestern United States and Mexico. In the West it is now found in Wyoming, Utah, Colorado, Arizona, New Mexico, and Texas. It was discovered in Alabama in 1920 and has increased its range rapidly to the north and east since then. It spread to Georgia, Tennessee, North and South Carolina, and Kentucky in 1921; Virginia in 1922; West Vir-

PLATE I.

A. Bean Plant Injured by the Mexican Bean Beetle. B. Adult and Larval Stages and Feeding Injury on a Bean Leaf. (After Neale F. Howard, U. S. Bureau of Entomology).

ginia and Ohio in 1923; Pennsylvania, Indiana, and Mississippi in 1924; Maryland in 1926; New York, Michigan, and Ontario in 1927; Delaware and New Jersey in 1928; and Connecticut and Massachusetts in 1929. Unless some unusual climatic condition develops, the pest will probably reach eastern Massachusetts in the next two or three years.

Effects of Temperature and Moisture Under Controlled Laboratory Conditions

Biological Material.

Adults and Larvae. A stock cage of adults, feeding on growing plants, was kept in the greenhouse at all times. When experiments were started, beetles of about the same age and with similar previous history were used. The insects used in the original set of experiments were collected in late September and were of unknown ages and previous history. Care was used to proportion these beetles among the experimental cages according to the color, as the general body color becomes darker with age. The experimental cages were made of glass tubing about two inches in diameter, with the ends covered with cheese cloth, which permitted free access of air currents. The final method used for keeping the food fresh was to place the leaf petioles in a small vial of water. A grooved cork was used, to prevent evaporation from the vials affecting the cage conditions. By changing the leaves twice daily, the food was kept in excellent condition. Whenever the above method of handling the plants was not used, it is so stated when that experiment is considered. The larvae were cared for in a similar manner.

Eggs and Pupae. The eggs were handled by cutting away the surrounding leaf tissue and placing them in open vials. The drying of the leaf particles to which they were attached, and the consequent wrinkling sometimes injured a few eggs, and at times prevented some of the larvae from emerging, but this factor was considered when tabulating results. The pupae were treated similarly.

Physical Factors Involved.

Temperature is an extremely important factor in the life of the bean beetle. It is closely allied with moisture and does not affect the insect as a single factor except when approaching the high and low temperature limits. Moisture is as important to all stages of the insect as temperature, and in some stages is more so. It probably affects the insect principally through evaporation. The evaporation rate is in turn influenced by the temperature and air movement. The velocity of the air is extremely important, as the temperature and relative humidity about the plants approach a state of equilibrium with the environment away from the plants in direct proportion to the movement of the surrounding air. No direct effects of light on the bean beetle have been observed, but light is taken in indirectly through the food. It is extremely important to keep the insects supplied with fresh food. The larvae, especially, show signs of restlessness shortly after the plants begin to wilt.

Description of Apparatus.

A well-insulated cabinet containing six separate compartments was used. Each section was two feet by two feet by three feet in size. The top was made of glass so that the light intensity could be controlled from outside the cabinet. The doors, which were about two feet square, contained glass so that the insects and instruments could be observed without opening the compartments. The temperature was maintained with electrical heating units operated with thermostats, and cold running water, the two working against each other. Relative humidity was controlled by placing saturated salt solutions in wide pans, so as to have a large amount of surface exposed. In order to secure uniform conditions, fans were used to keep the air in motion. The fans were placed so that the air passed directly over the salt solutions. The experimental material was placed on wire shelves at about the middle of the compartment so that the air currents were directed through them, thus exposing the contents to the surrounding environment.

Environmental Conditions Obtained.

Temperature of any degree desired could be obtained, but relative humidity much below 32 per cent could not be secured. Generally a salt could be found that would give the approximate humidity sought above 32 per cent to nearly saturation of the atmosphere. All temperature records are in degrees centigrade, and moisture data in percentage of relative humidity.

These experiments were conducted as a part of the Mexican bean beetle project of the Wyoming Agricultural Experiment Station. Since the environments were controlled, the effects of temperature and moisture on the insect could not have been due to any geographical peculiarity in Wyoming.

Series of temperatures ranging from 17° to 37° at intervals of 5° were used. Moisture conditions varying from 32 to 93 per cent were maintained in the various temperature environments. Since it is impossible to discuss the effects of temperature on the Mexican bean beetle without taking into consideration the influence of moisture, the reactions of the insect to both factors are considered jointly.

Experiments with Adults.

Constant Conditions. A temperature of 37° was found to be above the maximum effective temperature regardless of the humidity that was maintained in the cabinets. Death resulted in every case in less than forty-eight hours, and the majority were killed in less than twenty-four hours (Table I, 37°). It is evident that the temperature alone was the major factor in destruction in this case, as death occurred in all humidity conditions used.

When a constant temperature of 32° was maintained, very interesting results were secured, as the interaction of both temperature and moisture are evident (Table I, 32°). Heavy egg production occurred in the dry environment, while the yield was exceedingly low in the moist conditions. The inhibitory action of a high humidity on oviposition was evident, as laying beetles in 92 per cent humidity discontinued deposition in the second week and all but one female was dead by the end of the third week. Non-laying beetles in 90 per cent humidity were not stimulated to egg production and all were dead by the end of the third week. All of the beetles were living at the end of five weeks in 32 per cent humidity. An earlier series with humidities of 40, 70, and 90 per cent gave results showing the same tendencies, but the data are not included in the table since the food was not kept fresh and starvation may have influenced the results in the dry environment. The amount of food consumed in 70 per cent humidity was much reduced, while very little food was consumed in the higher humidities in either series. Possibly the inability of the beetles to eliminate water in the high moisture environments was an important factor in producing death. These results show that a constant temperature of 32° can be very favorable to the oviposition rate and length of life of the bean beetle with a low humidity, and extremely unfavorable with a high humidity. When the beetles were varied between dry and wet environments, the number of eggs obtained was intermediate between the yields obtained in the constant conditions (Table I, 32° Moisture Varied). A calculation of the number of eggs to be expected according to the hours of exposure under regularly varied conditions of humidity, as determined by the results with constant humidity, gives figures which agree fairly closely with the actual number laid. Apparently the inhibitory action of 92 per cent humidity on egg production of the beetles was not carried over to any great extent into periods when the percentage of moisture was reduced to 32 per cent.

A temperature of 27° proved to be much more favorable to heavy egg production than 32° (Table I, 27° Moisture Constant). Three different series of experiments are given, but all of them show the same tendencies. The first series was made up of beetles of unknown ages collected in the field in September. Many of these beetles had been laying previous to exposure to the experimental conditions. Humidities of 60 per cent or above were favorable tc heavy oviposition, while a low humidity of 32 per cent showed a reduction of over one-half in the number of eggs deposited. A sufficient number of eggs was laid in the dry conditions for the bean beetle to maintain itself in numbers as far as egg production is concerned. A slight reduction in the egg yield occurred in 85 and 93 per cent humidity.

The varied moisture conditions gave results similar to the constant environments (Table I, 27° Moisture Varied). The beetles used in this series were collected in September after the natural oviposition period had ended. Many of the females had probably laid a large number of eggs previous to collection. A rather wide range of humidity appears to be suitable for good egg production at 27°, although a reduction in oviposition occurred in both high and low moisture environments. The two varied conditions in which the beetles were kept in 93 per cent humidity for sixteen hours show a markedly large reduction below the expected number of eggs, which is only partially accounted for by the death of a few of the beetles. This result indicates that this high humidity at 27° was slightly unfavorable to egg production.

The results secured at 22° were not as extensive as at 27°, but they are very similar in so far as they are comparable. Data from two experimental series are shown (Table I, 22°). One cage of beetles in the 40 per cent humidity showed a lowered egg production indicating a possible inhibitory effect in this low humidty. A similar decrease in egg production in the 90 per cent humidity cabinet indicated that this high moisture environment was still unfavorable, as was found with higher temperatures.

The results secured in the 17° environment with 50 per cent humidity are very important (Table I, 17°). Since this humidity is near a critical point between favorable and unfavorable moisture conditions for egg production at higher temperatures, care must be used in interpreting the data. It is quite probable that 17° is very close to the minimum effective temperature for oviposition of the bean beetle. This conclusion becomes more certain when the varied data are analyzed (Table II, 17°). The number of eggs laid appears

Table I.—The Effect of Moisture on the Adults of the Mexican Bean Beetle.

RELATIVE HUMIDITY—Per cent Daily exposure of 8 hrs.	16 hrs.	24 hrs.	Number of beetles ♂	♀	Number of beetles died ♂	♀	NUMBER OF EGGS 1st week	2d week	3d week	4th week	5th week	6th week	7th week	Total	Number of eggs expected
Temperature 37° C.—Moisture Constant															
	40		3	5	3	5	0							0	
	75		3	5	3	5	0							0	
	90		3	5	3	5	0							0	
Temperature 32° C.—Moisture Constant															
		32	2	5	0	0	219[2]	521	501	650	326[3]			2217	
		90	3	5	3	5	0	0	0	...	..			0	
		92	2	5	2	4	49[2]	129	0	0	0[3]			178	
Temperature 32° C.—Moisture Varied															
92	32		2	5	0	0	116[2]	414	545	294	179[3]			1548	1571
32	92		2	5	0	2	109[2]	112	173	202	144[3]			740	854
Temperature 27° C.—Moisture Constant															
		32	10	16[1]	0	2	27	214	111	61				413	
		60	10	16[1]	1	0	0	92	374	535				1001	
		72	10	16[1]	0	0	55	249	134	328				766	
		93	10	16[1]	0	0	0	175	236	442				853	
		32	5	8	0	0	0	55	217	266	381			919	
		60	5	8	0	0	0	264	261	691	933			2149	
		72	5	8	0	0	0	451	458	733	694			2336	
		93	5	8	0	0	234	458	601	561	295			2149	
		62	3	5	0	1	53	218	460	484	414	157	290	2076	
		80	2	5	0	0	0	374	563	738	494			2169	
		85	3	5	0	1	0	237	227	167	406	289	514	1840	

Temperature 27° C.—Moisture Varied													
32	60		10	16[1]	1	2	53	46	245	506		850	805
32	72		10	16[1]	2	1	139	112	134	345		730	648
32	93		10	16[1]	2	4	0	185	109	15		309	706
60	32		10	16[1]	3	2	101	125	123	179		528	609
60	72		10	16[1]	2	3	111	263	116	490		980	844
60	93		10	16[1]	0	2	47	54	227	165		493	902
93	32		10	16[1]	1	2	107	256	258	525		1146	560
93	60		10	16[1]	2	3	0	119	434	511		1064	952
93	72		10	16[1]	2	0	0	36	206	477		719	795
Temperature 22° C.—Moisture Constant													
		40	3	5	0	0	53	104	253	318	321	1049	
		60	3	5	0	1	0	161	300	335	271	1067	
		90	3	5	0	0	0	49	97	225	111	482	
		40	2	5[2]	0	0	0	115	243	346	231[3]	935	
		86	2	5[2]	0	0	285	658	655	539	320[3]	2457	
Temperature 17° C.—Moisture Constant													
		50	2	5	0	0	0	58	0	59	39	156	

[1] Beetles of unknown ages collected in September.

[2] Beetles four to six weeks old and laying at start of experiment.

[3] Beetles four to six weeks old and laying at start of experiment. Experiment closed in the middle of the fifth week.

to be in proportion to the number of hours the beetles were kept in the higher temperatures, indicating that very little, if any, stimulation to egg development occurred at 17°.

Varied Conditions. A number of experiments were planned to ascertain the effects of definitely varied conditions on egg yields. One factor, either temperature or moisture, was held constant, or approximately so, while the remaining one was varied. Temperature environments, which were easily controlled, ranged from 17° to 32° at intervals of 5° (Table II). Varied temperature conditions were obtained by transferring the experimental cages from one cabinet to another at definite intervals, a twenty-four hour day being divided into eight and sixteen hour periods. This process of alternation was continued day after day, so that each cage was in one environment for eight hours, another sixteen, then back to the eight hour condition, and so on, for the duration of the experiment. Moisture environments in two cabinets with different temperatures could not always be maintained with the same humidities, so that percentages of moisture as similar as possible were chosen. Thus combinations of high humidity percentages, as 86 and 92, 80 and 92, and 80 and 86, are considered approximately equal in their effects on egg production. Likewise combinations of low humidity percentages, as 32 and 40, and 40 and 50, can be considered as having similar effects on egg development. The one humidity combination of 32 and 50 per cent is considered as a varied moisture environment within the low humidity region. The experimental cages were transferred from one cabinet to another, as described above, when the effects of varied moisture conditions were sought. Data obtained from the cages that were kept in the constant environments are placed under each heading for comparative purposes. In each instance the beetles were taken from the same stock cages as those used in the varied surroundings. The data are arranged about the temperatures 32°, 27°, etc., so that a direct comparison can be made with the results from the constant conditions. This necessitates the repetition of some of the data in more than one place, but the discussion is not repeated unless necessary. An expected number of eggs was calculated from the data secured under constant conditions and placed in the last column of the table. These figures are based on the number of hours the beetles were kept in the respective temperatures and in high and low humidity, and serve as an aid in comparing the actual results obtained in the varied conditions with those secured in constant environments. A temperature of 37° was excluded from the varied experiments because of the disastrous results obtained under constant conditions.

The results obtained from varied temperature environments with 32° are given in Table II (32°). The humidity combinations, except 32-50 and 50-32, are considered as approximately constant. The total number of eggs laid by the beetles exceeded the expected number in every instance, but the excess was much greater in the high humidities. The reduced egg yield at 32° in the high moisture environments (Table I) seemed to be largely offset when the alternating temperature was reduced to 27° for sixteen hours daily, but was still evident with only eight hours' exposure daily at 27°. When 22° was used as the alternating temperature with 32°, the numbers of eggs laid were rather uniform in both high and low humidities. The results, 2057 to 2231 eggs, compared favorably with the number laid, 2217, in the 32° constant temperature cabinet with low humidity. When 17° was used as the alternating temperature in connection with low humidity, the number of eggs

Table II.—The Effects of Varied Temperature with Approximately Constant Humidity on the Adults of the Mexican Bean Beetle

TEMPERATURE °C. Daily exposure of			RELATIVE HUMILITY Per cent Daily exposure of			Number of beetles		Number of beetles died		NUMBER OF EGGS						Number of eggs expected
8 hrs.	16 hrs.	24 hrs.	8 hrs.	16 hrs.	24 hrs.	♂	♀	♂	♀	1st week	2d week	3d week	4th week	5th[1] week	Total	
										Basis of Comparison—32° C.						
		32			32	2	5	0	0	219	521	501	650	326	2217	
		32			92	2	5	2	4	49	129	0	0	0	178	
32	17		32	50		2	5	0	0	0	53	304	572	211	1140	843
17	32		50	32		2	5	0	0	0	298	564	439	399	1700	1530
22	32		40	32		2	5	0	0	354	530	629	412	201	2126	1790
32	22		32	40		2	5	0	0	0	499	724	615	393	2231	1362
22	32		86	92		2	5	0	0	169	568	403	635	282	2057	938
32	22		92	86		2	5	0	0	65	381	624	729	416	2215	1697
27	32		80	92		2	5	0	2	50	545	609	275	105	1584	842
32	27		92	80		2	5	0	0	104	506	575	694	236	2115	1505
										Basis of Comparison—27° C.						
		27			80	2	5	0	0	0	374	563	738	494	2169	
22	27		86	80		2	5	0	0	272	674	574	878	428	2826	2265
27	22		80	86		2	5	0	0	71	264	617	643	419	2014	2361
27	32		80	92		2	5	0	2	50	545	609	275	105	1584	842
32	27		92	80		2	5	0	0	104	506	575	694	236	2115	1505
										Basis of Comparison—22° C.						
		22			40	2	5	0	0	0	115	243	346	231	935	
		22			86	2	5	0	0	285	658	655	539	320	2457	
17	22		50	40		2	5	0	0	0	0	259	332	207	798	675
22	17		40	50		2	5	0	0	0	54	54	262	97	467	416
22	32		40	32		2	5	0	0	354	530	629	412	201	2126	1790
32	22		32	40		2	5	0	1	0	499	724	615	393	2231	1362
22	27		86	80		2	5	0	0	272	674	574	878	428	2826	2265
27	22		80	86		2	5	0	0	71	264	617	643	419	2014	2361
22	32		86	92		2	5	0	0	169	568	403	635	282	2057	938
32	22		92	86		2	5	0	0	65	381	624	729	416	2215	1697
										Basis of Comparison—17° C.						
		17			50	2	5	0	0	0	58	0	59	139	156	
17	22		50	40		2	5	0	0	0	0	259	332	207	798	675
22	17		40	50		2	5	0	0	0	54	54	262	97	467	416
17	32		50	32		2	5	0	0	0	298	564	439	399	1700	1530
32	17		32	50		2	5	0	0	0	53	304	572	211	1140	843

[1] Experiment closed in middle of fifth week.

deposited was in proportion to the hours of exposure at 32°, showing that very little development of the eggs, if any, occurred at the lower temperature.

The stimulating effect of a varied temperature over a constant one is well illustrated by comparing the actual number of eggs found with the expected result. The fact that a varied temperature is more stimulating to developmental processes than a constant one is not new to science, but very few papers can be found which actually give data that demonstrate this. This conclusion shows that results obtained from constant temperature studies are inaccurate when compared with field conditions, but not necessarily impractical, as a great deal of information can be gained from such studies with a large saving in time, labor, and equipment.

Results were obtained from varied temperature environments about 27° with high humidity only (Table II, 27°). The stimulation to heavy egg production caused by varied temperature conditions is readily seen. The expected egg yield was not reached in one test, the 27°-22° combination. This result is probably not significant as the actual number of eggs laid in all other varied environments in the table exceeded the calculated results. The yield was markedly reduced when the beetles were exposed to 32° for 16 hours.

Varied temperature environments about 22° were much more complete than at 27° (Table II, 22°). Heavy egg laying resulted in all combinations of temperature above 17°. The large number of eggs (25 per cent more than was expected) produced in the 22°-27° condition was much greater than with any other set of temperatures and suggests that the optimum temperature is somewhere between 22° and 27°. The reduction in the number of eggs laid at a constant temperature of 22° with 40 per cent humidity was offset under varied temperature conditions above 22°. The wide range of humidity that was suitable for good egg production at 27° was equally satisfactory at 22° in combination with higher temperatures.

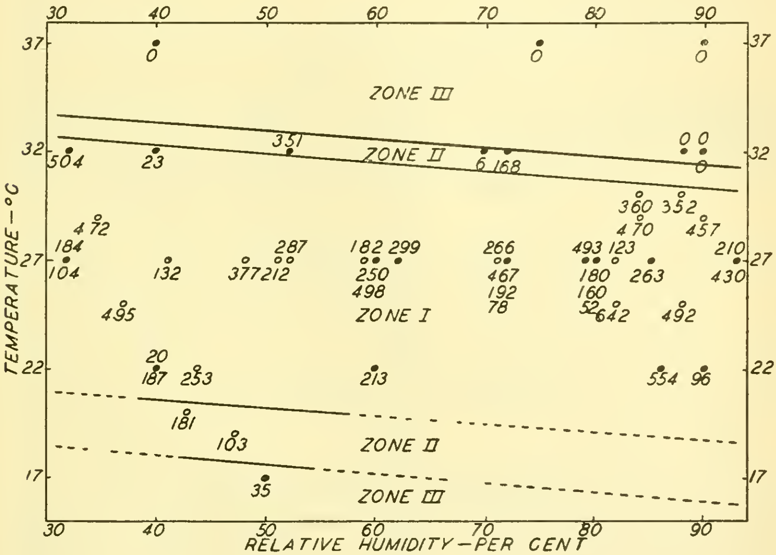
In Table I the minimum effective temperature was shown to be near 17°. When 17° was combined with higher temperatures good egg yields that exceeded expectations were found (Table II, 17°). It is evident that the bean beetle is capable of producing a sufficient number of eggs to maintain itself in numbers at low temperature between 17° and 22°, even when the humidity is below 50 per cent.

Constant and Varied Environments. The effects of temperature and moisture on the oviposition rate in both constant and varied environments can be further illustrated by plotting the data in Tables I and II (fig. 1). The figures represent the average number of eggs deposited per week in the various environments. More data are needed to determine accurately the limits in the low temperature and low humidity regions. However, general conclusions can be drawn from the data. Three zones are shown in the figure. The area marked "Zone I" probably covers the combinations of temperature and moisture in which the bean beetle is capable of producing a sufficient number of eggs to maintain itself in economic numbers, as far as egg production is concerned. Zone II represents the region where the insect probably will maintain itself, but not in economic numbers; while Zone III covers the conditions in which it will seldom be found. Keeping the beetles in variable environments enlarged the range of suitable temperature and moisture combinations over that obtained from constant conditions; but the results were essentially the same in other respects. The suitable temperature range for oviposition (about 12°) was quite narrow in comparison with the spread of favorable moisture conditions (about 60 per cent). It is apparent that it would require an extremely arid climate to lower the oviposition rates of the beetles sufficiently to reduce the numbers of the pest below that of economic importance. However, any reduction in oviposition, produced by arid conditions, would have an important influence on the total population if the conditions were dry enough to seriously affect larval development.

Summary. A temperature of 37° killed the adults in a few hours.

A temperature of 32° with high humidity was very destructive to the adults, but with low humidity was favorable to length of life and egg production. When alternated with lower temperatures the adverse effects were largely overcome below 27°, and partially offset at that temperature.

Figure 1. The Weekly Average Oviposition Rates of Beetles Maintained under Controlled Environments. ● —Constant Environments; ○—Varied Environments.



A temperature of 27° was favorable to length of life of the adults with all humidities used, and to egg production with moist conditions of 60 per cent or above. High moisture environments were more favorable than low humidity conditions, but the difference was not so great as with higher temperatures. When alternating temperatures were used with 27°, good egg production resulted with lower temperatures. Humidities of 93 per cent or above may be detrimental to egg production.

A temperature of 22° with humidities of 40 to 90 per cent was favorable to length of life of the adults and to egg production, although the number of eggs laid was reduced in the dry conditions. High egg yields with alternating temperatures resulted with all conditions above 17°.

A temperature of 17° was favorable to length of life of the adults but was near the minimum effective temperature for egg production. With alternating temperatures above 17°, the rate of oviposition was in proportion to the number of hours at the highest temperatures, the highest yields occurring in the 32° combinations with low humidity.

Experiments with Eggs.

Constant Environments. The results of incubating the eggs at 37° are given in Table III (37°). Three different humidity environments were used, but the eggs failed to hatch regardless of the moisture present, showing that a constant temperature of 37° is unsuitable for incubation of the eggs. The embryos not only failed to develop at this temperature but were killed, as later exposure to lower temperature conditions did not produce any development.

The incubation of the eggs at 32° gave results similar to those at 37° (Table III, 32°). Development failed to take place regardless of the humidity of the environment, showing that the failure to hatch was again due to the high temperature. An alternation of the eggs between wet and dry conditions did not change the results.

Table III.—The Effects of Moisture on the Eggs of the Mexican Bean Beetle.

RELATIVE HUMIDITY—Per Cent Daily exposure of 8 hrs.	16 hrs.	24 hrs.	Total number of eggs	Total number hatched	*Per cent hatched*	Days to hatch
		Temperature 37° C.—Moisture Constant				
		40	276	0	*0.0*	....
		75	246	0	*0.0*	....
		90	221	0	*0.0*	....
		Temperature 32° C.—Moisture Constant				
		32	411	0	*0.0*	....
		40	355	0	*0.0*	....
		70	477	0	*0.0*	....
		90	493	0	*0.0*	....
		92	353	0	*0.0*	....
		Temperature 32° C.—Moisture Varied				
32	92		371	0	*0.0*	....
92	32		395	0	*0.0*	....
		Temperature 27° C.—Moisture Constant				
		32	1700	0	*0.0*	....
		60	3175	773	*24.4*	6.0
		62	704	177	*25.0*	5.5
		72	3031	679	*22.4*	5.9
		79	1932	563	*29.3*	5.9
		80	335	34	*10.2*	5.5
		85	1059	155	*14.6*	5.8
		93	3195	953	*29.5*	5.7
		Temperature 22° C.—Moisture Constant				
		40	494	0	*0.0*	....
		60	485	13	*3.0*	7.3
		90	398	146	*37.0*	6.8
		40	304	107	*35.2*	7.8
		86	365	227	*62.2*	6.6
		Temperature 22° C.—Moisture Varied				
40	86		279	121	*43.4*	7.0
86	40		298	187	*62.8*	7.6
		Temperature 17° C.—Moisture Constant				
		50	484	213	*44.0*	12.4

When the eggs were incubated at 27°, entirely different results were obtained (Table III, 27°). Larvae were secured in all moisture environments from 60 to 93 per cent humidity. The failure to hatch any larvae from 1700 eggs incubated under the 32 per cent moisture condition emphasized the unfavorable effects of a dry atmosphere at this temperature. The hatching periods of the eggs in the medium to moist cabinets ranged from 5.5 to 6.0 days, showing a close similarity in all conditions. The number of larvae hatching in the 80 and 85 per cent humidity environments was much below those in the other conditions, but the 79 and 93 per cent surroundings produced the best hatches, thus indicating that a moisture environment of 60 per cent humidity, or higher, at 27° is favorable to incubation of the eggs. The unfavorable limit would fall somewhere between 32 and 60 per cent humidity.

The effects of moisture on incubation of two different series of eggs at 22° gave rather irregular results (Table III, 22°). Probably the first series—40, 60 and 90 per cent—shows a much lower percentage of hatching than is normal for these conditions. When this series is compared with the results in Table IV (22°), which are in agreement with the second series of this table, the probability of an abnormally low percentage of hatching is made doubly certain. A much better hatch was obtained in the cabinets with high humidity. The incubation period was about one day less in the high than in the low humidity chambers, but was about one and one-half days longer than was required at 27°. The percentage of eggs hatching under most conditions at 22° was considerably above that at 27°, indicating that the former is a more favorable temperature. The alternation of eggs between wet and dry environments gave results similar to those obtained under constant conditions (Table III, 22° Moisture Varied).

The influence of a temperature of 17° with 50 per cent humidity was favorable to hatching of the eggs (Table III, 17°). Good hatching resulted but the incubation period was nearly twice as long as at 22°.

Varied Environments. A discussion of these environments is given under this heading for the adult stage. A high temperature of 37° was excluded from the varied series, as none of the eggs had hatched at that temperature in the constant environments (Table III).

The results of alternations of temperature with 32° are given in Table IV (32°). Combinations of 32° with 17° and 27° failed to produce any larvae regardless of the humidity used. When 22° was used, sixteen hours of exposure at 32° killed the embryos in both high and low humidity, but when the exposure was reduced to eight hours at 32°, one egg hatched in the low and 21.5 per cent in the high humidity. The number of eggs hatching in both cases was low, but is significant for the high moisture environment. Eggs hatched in about half of the egg masses used in this moist condition. This shows that a high moisture environment is preferable to dry conditions and may indicate that 22° is near the optimum temperature for incubation of the eggs. The incubation period of the single individual emerging in the drier environment was more than twenty-four hours longer than the average for those in the wetter condition. The longest incubation period in the high humidity cabinet was eight days.

The eggs were incubated in the varied conditions about 27° with high humidity only (Table IV, 27°). Good hatches were obtained from the eggs in the temperature combination of 27° and 22°, while either eight or sixteen hours at 32° was sufficient to prevent hatching of the eggs. The percentage of eggs hatching in the control cabinet was probably abnormally low as can be seen by comparison with the results in Table III. The length of the incubation period was approximately a day and a half below that at 32°. The number of days required for development was slightly less than the calculated figures.

When temperatures were alternated about 22°, good hatches were secured with 27° and 17° (Table IV, 22°). The poorest hatches were obtained in the 32° combinations where the unfavorable effects of the high temperature, previously discussed, were not fully overcome by eight or sixteen hours' exposure at 22°. The percentage of eggs hatching in low humidity conditions was much less than in high humidity environments, especially when the moisture content of the cabinet was below 45 per cent. The stimulatory effect produced by varying the conditions is shown in the table.

The data secured from varied conditions about 17° with low humidity are not as extensive as with 22° (Table IV, 17°). All of the eggs failed to hatch when exposed to 32° for eight or sixteen hours. When alternated with 22°, the percentage of eggs hatching was low in the drier environment, while the combination with humidity above 45 per cent gave much better results.

Constant and Varied Environments. The effects of temperature and moisture on the eggs can be illustrated further by plotting the data in Tables III and IV (figs. 2 and 3). The percentage of eggs hatching is given in Figure 2, and the length of the incubation period in Figure 3. The two figures are discussed together.

Three general zones are rather sharply defined, although more data are needed in the low humidity region between 22° and 17°. Under field conditions the region that falls below 17° is automatically taken care of by the negligible number of eggs laid below this temperature (Tables I and II); but from a scientific viewpoint it would be well to conduct experiments with temperatures below 17°. A suitable, intermediate, and unfavorable zone is indicated for the two conditions,—percentage of hatch and length of incubation period. It is evident that Zones I of the two figures do not agree. Since both factors are vital in the life cycle of the bean beetle, a position favorable to both of the above factors must be selected. The temperature limits then would fall on the upper line of Zone I of Figure 2 for high temperature, and the lower line of Zone I of Figure 3 for low temperature. This gives a decidedly small temperature range (about 6°) that is favorable for incubation of the eggs, although it must be remembered that lower temperatures merely delay the time of hatching and do not kill the embryos. The moisture limits are in much closer agreement in the two figures. The upper limit is not determinable from the data at hand, although favorable results were obtained in 93 per cent humidity. The lower limit probably falls between 40 and 50 per cent humidity. Thus the incubation period is shown to be an extremely vital one in the economic distribution of the bean beetle, as both high temperatures and low humidity are very destructive. However, low temperature is not necessarily detrimental unless continued for prolonged periods. The physical conditions just described would need to occur among the growing bean plants in the field to affect the eggs of the bean beetle.

Summary. A temperature of 37° destroyed the embryos in both wet and dry environments.

A temperature of 32° gave similar results in constant conditions, but with varied temperatures a few larvae hatched in the moist environment at 22°.

Table IV.—The Effects of Varied Temperatures with Approximately Constant Moisture Conditions on the Eggs of the Mexican Bean Beetle

TEMPERATURE °C. Daily exposure of			RELATIVE HUMIDITY—Per cent Daily exposure of			Total number of eggs	Total number hatched	*Per cent hatched*	Days to hatch	Expected number of days to hatch
8 hrs.	16 hrs.	24 hs.	8 hrs.	16 hrs.	24 hrs.					
						Basis of Comparison—32° C.				
		32			32	411	0	*0.0*	....	....
		32			92	353	0	*0.0*	....	....
17	32		50	32		378	0	*0.0*	....	....
32	17		32	50		274	0	*0.0*	....	....
22	32		40	32		295	0	*0.0*	....	....
32	22		32	40		267	1	*0.4*	8.5	....
22	32		86	92		370	0	*0.0*	....	....
32	22		92	86		385	83	*21.5*	7.2	....
27	32		80	92		336	0	*0.0*	....	....
32	27		92	80		316	0	*0.0*	....	....
						Basis of Comparison—27° C.				
		27			80	335	34	*10.2*	5.5	....
22	27		86	80		414	228	*55.1*	5.7	5.9
27	22		80	86		411	324	*78.8*	6.1	6.2
27	32		80	92		336	0	*0.0*	....	....
32	27		92	80		316	0	*0.0*	....	....
						Basis of Comparison—22° C.				
		22			40	304	107	*35.2*	7.8	....
		22			86	365	227	*62.2*	6.6	....
17	22		50	40		315	87	*27.6*	8.9	9.3
22	17		40	50		413	258	*62.4*	10.2	10.9
32	22		32	40		267	1	*0.4*	8.5	....
22	32		40	32		295	0	*0.0*	....	....
22	27		86	80		414	228	*55.1*	5.7	5.9
27	22		80	86		411	324	*78.8*	6.1	6.2
22	32		86	92		370	0	*0.0*	....	....
32	22		92	86		385	83	*21.5*	7.2	....
						Basis of Comparison—17° C.				
		17			50	484	213	*44.0*	12.4	....
17	22		50	40		315	87	*27.6*	8.9	9.3
22	17		40	50		413	258	*62.4*	10.2	10.9
17	32		50	32		378	0	*0.0*	....	....
32	17		32	50		274	0	*0.0*	....	....

Figure 2. The Percentage of Eggs Hatching in Controlled Environments. ● —Constant Environments; o—Varied Environments.

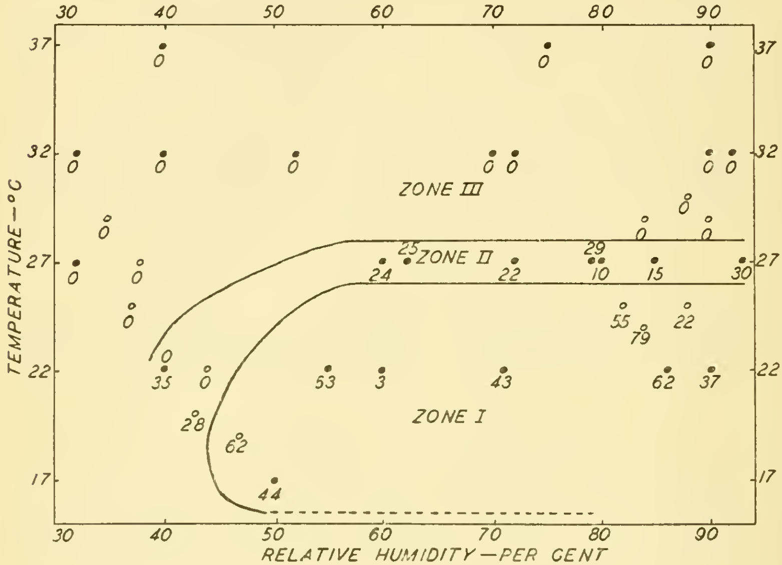
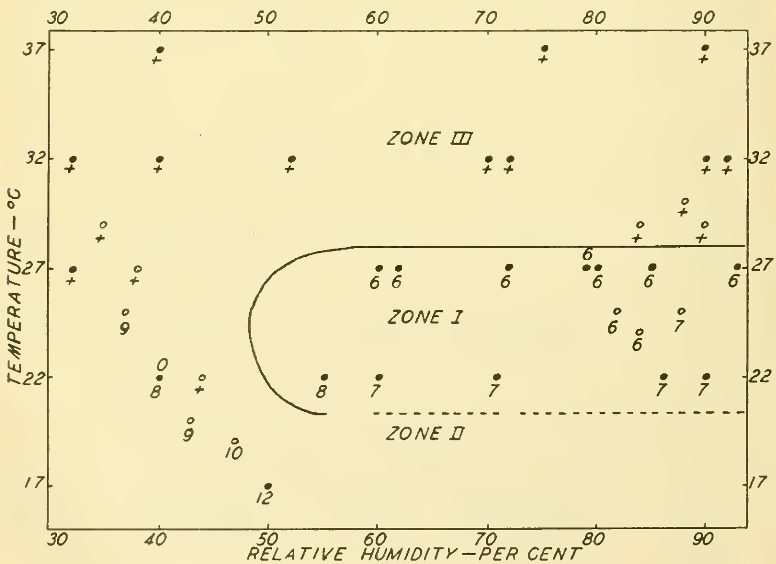


Figure 3. The Length of the Incubation Periods in Controlled Environments. ● —Constant Environments; o—Varied Environments.



A temperature of 27° produced a fair number of larvae in moist surroundings but none in dry conditions with constant environments. Good hatches were obtained in varied conditions with 22°, but not with 32°.

A temperature of 22° produced good hatches in moist environments and with temperature combinations below 32°.

A temperature of 17° was favorable to good hatching of the eggs with humidity above 45 per cent and with temperature combinations below 32°.

Experiments with Larvae and Pupae.

Constant Environments. A high temperature of 37° was as disastrous for the larvae as for the egg and adult stages of the bean beetle, regardless of the humidity used (Table V, 37°). It is evident that the temperature is the limiting factor.

The effect of moisture on the larvae was brought out very clearly in the 32° series (Table V, 32° Moisture Constant). The results of two lots of experiments are listed in the table. The larvae in the first lot were fed at 8 a.m., 4 p.m., and 10 p.m., but the leaf petioles were not placed in water to keep the leaves fresh. A low humidity of 32 per cent was sufficiently favorable to enable half of the larvae to complete development. When the humidity was increased to 92 per cent, a few of the larvae reached the pupal stage but failed to transform into adults. In the earlier series where the food was not kept fresh, the same tendencies can be seen, as a few larvae were able to reach the pupal stage in 40 per cent humidity but none completed the feeding stage in the higher humidities. Undoubtedly starvation was an important factor in the earlier series. This is indicated by the lengthened feeding period that was required. Alternation of the larvae between dry and wet conditions gave slightly more favorable results than high humidity alone as a few of the larvae developed to the pupal stage (Table V, 32° Moisture Varied). The pupae in the high humidity were about one-half below normal in size. The adults that emerged in these conditions were undersized, and all of them were crippled. Some of the individuals had distorted wings or elytra, or both, while about 50 per cent had disfigured abdomens. The shrunken condition of the abdomens was noticeable with some individuals while still in the pupal stage. Much of the distortion was great enough to prevent mating and reproduction. Probably the moisture problem for the larvae is to eliminate moisture, since they take in large quantities of water with their food. This elimination would occur through excretion, respiration, and evaporation through the body wall. Excretion and respiration are probably the important means of water elimination. Loss of water through respiration would be greatly reduced in high humidity environments, and the process possibly might be reversed. This may be the explanation for the deaths of the larvae in high humidity conditions at 32°.

At 27° the larvae developed well, and the majority completed growth as long as the food was kept fresh (Table V, 27°). The data from three different series of experiments are shown in the table. The larvae in the first series were fed at 8 a.m. and 8 p.m. during the first part of the experiment, and at 8 a.m., 4 p.m., and 10 p.m. during the latter part of the experiment, but the food became rather dry at times. Fresh food was given to the second series at 8 a.m., 4 p.m., and 10 p.m., but the frequent feedings were not sufficient to keep the food fresh in the drier environments. Ninety-three per

Table V.—The Effects of Moisture on the Larvae of the Mexican Bean Beetle.

RELATIVE HUMIDITY—Per cent Daily exposure of 8 hrs.	16 hrs.	24 hrs.	Total number of larvae	Number of days feeding	Number of days as prepupae	Number of days as pupae	Total number of days	PER CENT REARED Prepupae	Pupae	Adults
Temperature 37° C.—Moisture Constant										
		40	48	3	0	0	....	0.0	0.0	0.0
		75	28	2	0	0	....	0.0	0.0	0.0
		90	28	2	0	0	....	0.0	0.0	0.0
Temperature 32° C.—Moisture Constant										
		40	62	25.1	...	...	....	14.5	14.5	0.0
		70	15	...	...	0	0	0.0	0.0	0.0
		90	71	...	...	0	0	0.0	0.0	0.0
		32	16	16.8	1.7	4.7	23.2	62.5	62.5	50.0
		92	59	17.9	...	...	....	6.6	0.0	0.0
Temperature 32° C.—Moisture Varied										
32	92		24	21.0	2.0	...	....	16.7	8.3	0.0
92	32		28	17.0	1.5	...	....	7.1	7.1	0.0
Temperature 27° C.—Moisture Constant										
		32	100[1]	......		...	....	3.0	3.0	3.0[1]
		60	223	22.7		7.0	29.7	22.0	22.0	17.0
		72	120	23.5		6.9	30.4	16.0	16.0	10.0
		79	101	23.5		7.3	30.8	22.0	22.0	20.0
		93	87	17.7		7.0	24.7	39.0	39.0	38.0
		62	47	13.8		6.8	20.6	63.8	63.8	63.8
		85	37	13.7		6.1	19.8	73.0	73.0	73.0
		80	14	14.8	1.8	5.1	21.7	92.8	92.8	92.8

Temperature 22° C.—Moisture Constant										
		40	36	21.6	9.4		31.0	86.1	86.1	86.1
		60	36	19.7	8.9		28.6	66.6	66.6	66.6
		90	22	17.9	9.0		26.9	90.8	90.8	81.8
		40	13	20.0	2.6	6.7	29.3	92.3	92.3	92.3
		86	13	15.4	2.2	6.5	24.1	92.3	92.3	92.3
Temperature 22° C.—Moisture Varied										
40	86		25	18.4	2.7	6.8	27.9	88.0	88.0	(88.0)[2]
86	40		30	20.2	2.6	...[2]	...	83.4	(83.4)	(83.4)
Temperature 17° C.—Moisture Constant										
		50	8	30.4	3.9	11.1	45.4	87.5	87.5	87.5

[1] Approximate figures.

[2] Experiment closed before development was completed. Probable results in parentheses.

cent of the larvae in 80 per cent humidity, which were supplied with fresh food, completed development. The food was near normal field conditions in this case, although the water content of the leaves possibly may have been slightly increased. The second series of larvae showed as rapid development as the first, but the number maturing under these conditions was about 20 per cent less than with the third, indicating that the drying out of the food between feedings may have been detrimental. The first series had the greatest range of moisture environments. The detrimental influence of the drying out of the food was very noticeable, the length of the feeding periods being about 30 per cent longer and the percentage maturing greatly reduced when compared with the results where the food was suitable. Probably the results obtained in 32 per cent humidity were due largely to starvation rather than to the dry atmosphere. A part of the data from the larvae reared in 32 per cent humidity was lost, but the estimated figures given in the table are very close to the actual results obtained. A great majority of the adults reared at this temperature were normal in size and appearance.

Two different series of larvae were carried through the developmental cycle at 22° (Table V, 22° Moisture Constant). The effects of moisture are shown in the length of the growing periods, being several days less when the humidity was high. A greater percentage of the larvae reached maturity in both high and low moisture environments. It is evident that a temperature of 22° with humidity ranging from 40 to 90 per cent was favorable for larval development. The adults reared in these environments were normal in appearance, but those developing in the high humidity conditions averaged somewhat larger in size than those which reached maturity in low moisture environments. This result may have been produced by the better quality of the food in the moist cabinets. Alternation of the larvae between the dry and wet surroundings made very little change in the results (Table V, 22° Moisture Varied).

A temperature of 17° also was suitable for a large percentage of the larvae reaching maturity, but about 40 per cent more time was required for them to complete development (Table V, 17°). Only a few larvae were reared at this temperature, but a check lot of fifteen larvae had nearly completed the feeding stage when the experiment was closed, indicating that the results in the table are normal. The adults obtained were large in size and normal in appearance.

The larvae reared in the 17° environments became quite dark in color. During the feeding periods most of the spines were gray or black in color, but the body surface largely remained yellow. The pigmentation increased with age and did not seem to be lost in molting. The cast skins appeared to be clear and free from coloring matter. The pigment was retained by the pupae, the greater part of the body surface appearing as gray or black in color, but on transformation adults of the usual color pattern emerged. Thomas (1924) observed the same effect when the larvae were reared during the cooler part of the season. The black spots on the elytra of these beetles apparently were not any larger than those on specimens reared at higher temperatures. The accumulation of the pigment was probably caused by the low metabolic rate of the larvae when reared at 17° which was not sufficient to oxidize all of the melanin formed (Knight, 1924).

Varied Environments. Larvae were reared under varied conditions of temperature ranging from 17° to 32° and a moisture spread from 32 to 92 per cent humidity. The food was kept fresh in all conditions by placing the leaf petioles in water.

The influence of alternating temperatures with 32° and approximately constant moisture surroundings was more favorable for larval development than constant high temperature (Table VI, 32°). When 27° was alternated with 32°, sixteen hours of exposure daily in the higher temperature proved to be very severe on the pupae as well as on the larvae. Eight hours' exposure daily was largely overcome by the cooler condition, as only a few larvae were killed. The use of 22° as the alternating temperature with 32° when the moisture was high gave results indicating that the influence of the low temperature overcame the adverse effects of the high in proportion to the hours of exposure in each. When dry conditions were used, the data were similar to those obtained in the check environments. The humidities in the 17°-32° environments were 32 and 50 per cent, and while both are low, they cannot be considered as constant. Good rearings were secured in these conditions.

The adults reared in the 17°-32° alternating environments showed a high percentage of distortion, only about 30 per cent appearing to be normal, indicating that most of the development took place in the higher temperature. Abdominal disfigurement was evident in about half of these insects. A few of the beetles were reduced in size. When 22° was alternated with 32°, sixteen hours of exposure daily at 32° produced about 60 per cent of normal individuals in both high and low humidity, and eight hours of exposure daily developed 80 per cent of adults normal in size. The alternation of 32° and 27° produced 12 per cent of normal adults with sixteen hours of exposure daily at the high temperature, and 80 per cent of normal beetles with eight hours' treatment daily at this temperature. Many of the adults were reduced in size in this latter environment.

The results of alternations about 27° with high humidity were quite uniform and favorable to development of the larvae of the bean beetle with the exception of sixteen hours' exposure daily at 32°, which has been discussed previously (Table VI, 27°). The adults reared in 27°-22° temperature conditions were normal with eight hours' exposure daily to 27°, but about 40 per cent of them showed some distortion of the wings and elytra following sixteen hours' exposure daily to 27°.

The influence of alternating temperatures about 22° with approximately constant moisture environments is shown in Table VI, (22°). The unfavorable effects of both high temperature and low humidity are shown, fewer larvae reaching maturity with an increase in the number of hours at 32° and in the lower humidities. However, a sufficient number of larvae developed in all of the environments for the beetle to maintain itself in economic numbers. Most of the adults that developed were normal in size and contour in all conditions below 32°.

The data in Table VI (17°) show the influence of alternations in temperature about 17°. The lengthened developmental period shows that these environments were inferior to the 22° and 27° conditions for rapid growth, although the death rate was very low. The adults reared under the 17° constant temperature environment were large and normal in appearance, while many of the beetles reared in the 17°-32° temperature combinations were greatly distorted.

The melanism that occurred under constant exposure at 17° did not appear when the larvae were alternated between 17° and higher temperature en-

Table VI.—The Effects of Varied Temperature with Approximately Constant Moisture Conditions of the Larvae of the Mexican Bean Beetle.

Temperature °C. Daily exposure of 8 hrs.	Temperature °C. 16 hrs.	Temperature °C. 24 hrs.	Relative Humidity Per cent Daily exposure of 8 hrs.	Relative Humidity 16 hrs.	Relative Humidity 24 hrs.	Total number of larvae	Number of days feeding	Number of days as prepupae	Number of days as pupae	Total number of days	Per Cent Reared: Prepupae	Pupae	Adults
						Basis of Comparison—32° C.							
		32			32	16	16.8	1.7	4.7	23.2	62.5	62.5	50.0
		32			92	59	17.9	0.0	0.0	0.0	6.6	0.0	0.0
17	32		50	32		24	17.3	2.1	6.1	25.5	87.5	87.5	83.3
32	17		32	50		16	21.2	2.9	......[1]	.....	75.0	75.0	(75.0)
22	32		40	32		27	17.3[1]	1.8	5.1[1]	24.2	59.2	59.2	(59.2)
32	22		32	40		20	18.8	2.2	6.0	27.0	65.0	65.0	65.0
22	32		86	92		19	14.6	1.8	5.4	21.8	73.5	73.5	73.5
32	22		92	86		15	16.9	2.0	6.2	25.1	86.7	86.7	86.7
27	32		80	92		26	17.8	1.7	4.9	24.4	65.4	61.5	38.4
32	27		92	80		46	14.0	1.7	5.2	20.9	86.9	86.9	86.9
						Basis of Comparison—27° C.							
		27			80	14	14.8	1.8	5.1	21.7	92.8	92.8	92.8
22	27		86	80		37	14.1	2.2	5.3	21.6	91.9	91.9	91.9
27	22		80	86		25	17.6	2.0	6.0	25.6	88.0	88.0	88.0
32	27		92	80		46	14.0	1.7	5.2	20.9	86.9	86.9	86.9
27	32		80	92		26	17.8	1.7	4.9	24.4	65.4	61.5	38.4
						Basis of Comparison—22° C.							
		22			40	13	20.0	2.6	6.7	29.3	92.3	92.3	92.3
		22			86	13	15.4	2.2	6.5	24.1	92.3	92.3	92.3
22	17		40	50		12	25.0	3.2	......[1]	.	81.8	(81.8)	(81.8)
22	27		86	80		37	14.1	2.2	5.3	21.6	91.9	91.9	91.9
27	22		80	86		25	17.6	2.0	6.0	25.6	88.0	88.0	88.0
22	32		86	92		19	14.6	1.8	5.4	21.8	73.5	73.5	73.5
32	22		92	86		15	16.9	2.0	6.2	25.1	86.7	86.7	86.7
22	32		40	32		27	17.3	1.8	5.1	24.2	59.2	59.2	(59.2)
32	22		32	40		20	18.8	2.2	6.0	27.0	65.0	65.0	65.0
						Basis of Comparison—17° C.							
		17			50	8	30.4	3.9	11.1	45.4	87.5	87.5	87.5
22	17		40	50		12	25.0[2]	3.2	......[1]	.....	81.8	(81.8)	(81.8)
17	32		50	32		24	17.3	2.1	6.1	25.5	87.5	87.5	83.3
32	17		32	50		16	21.2	2.9	......[1]	.....	75.0	95.0	(75.0)

[1]Experiment closed before development was completed. Probable results enclosed in parentheses.
[2]One larva feeding when experiment was closed.

Figure 4. The Length of the Developmental Periods of the Larvae and Pupae Reared in Controlled Environments. ●—Constant Environments. o—Varied Environments.

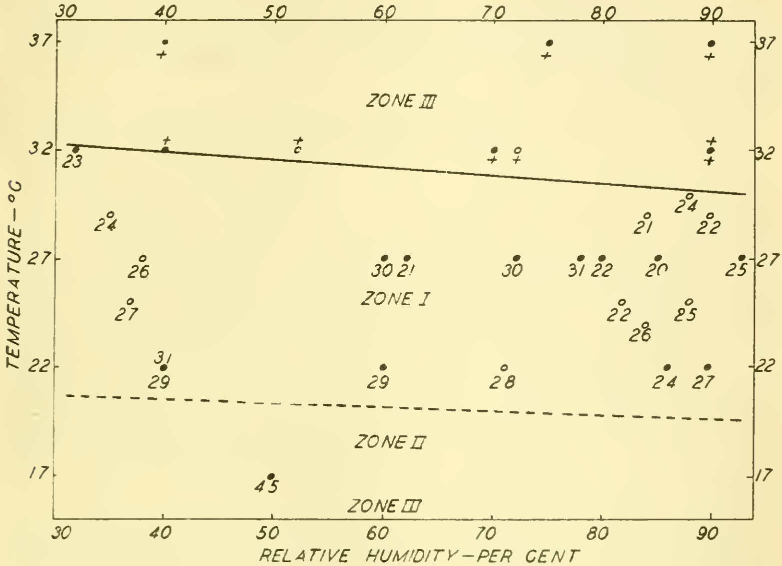
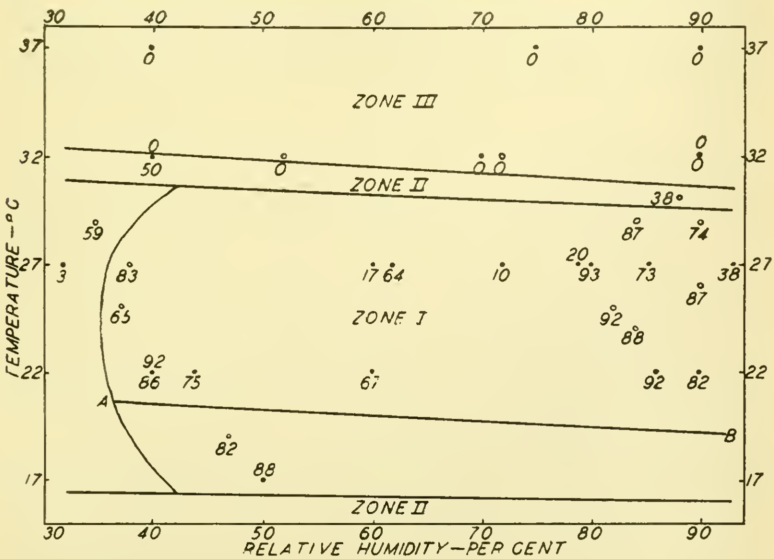


Figure 5. The Percentages of Larvae and Pupae Reaching Maturity in Controlled Environments. ●—Constant Environments. o—Varied Environments.



vironments. The increased metabolism occurring at temperatures above 17° was probably sufficient to oxidize the pigment.

Constant and Varied Environments. The effects of temperature and moisture on the larvae are shown graphically in Figures 4 and 5, which were constructed from the data in Tables V and VI. The length of the developmental periods was plotted in Figure 4 and the percentage of larvae reaching maturity in Figure 5.

The length of the developmental periods shows rather wide variations in environments that are very much alike. When development was completed at high temperatures, the time needed to reach maturity was favorable to the species. On the low temperature side the developmental period was greatly lengthened, indicating that a temperature below 20° would be rather unfavorable to the bean beetle. The average period was somewhat shorter when the humidity was high, but it is impossible to determine the limits of a suitable moisture range for length of developmental period from the data at hand. When the percentage of larvae reaching maturity is considered (fig. 5), the upper temperature limit of Zone I was one to two degrees below that in Figure 4, while the lower limit was still lower in comparison. The moisture limits are not indicated in Figure 4, but for the percentage of larvae reaching maturity (fig. 5) the lower limit was near 35 per cent. The moisture range, then, for favorable larval development lies between 35 and 95 per cent.

It is quite evident that neither the length of the developmental period nor the percentage maturing can be used as a criterion for determining the degree of favorableness for larval development necessary for the insect to maintain itself in economic numbers. Therefore a combination of Zones I of the two figures must be used. A high percentage of the larvae must complete development in a reasonably short time for the insect to maintain itself in abundance. Thus if a line is drawn from A to B (the lower limit of Zone I in Figure 4) in Figure 5, the resulting area of Zone I above this line would probably represent the combinations of temperature and moisture in which the bean beetle would become injurious in so far as larval development is concerned.

Summary. A temperature of 37° was very destructive to the larvae in all humidities used.

Half of the larvae completed development at a temperature of 32° when the humidity was low, while all of them succumbed in high moisture environments. The adults from larvae reared in these conditions were badly distorted. All of the larvae died in varied humidity at this temperature. The death rates were much reduced when the temperature was alternated, but most of the resulting adults were monstrosities.

A temperature of 27° was favorable for larval development with high humidity, while the death rate was very high in dry environments. Alternated environments with 32° were unfavorable.

A temperature of 22° was very favorable for larval development in all moisture conditions used. The number pupating was much reduced with 32° in the alternating temperature experiments.

A temperature of 17° was favorable for the larvae completing development, but growth was very slow. High percentages of the larvae matured in alternating conditions but the time necessary was greatly increased.

Suitability of the Climate of New England for the Bean Beetle

The practical value of the experimental data just presented can be estimated by a study of the climatological data for New England from the records of the United States Weather Bureau. Temperature and precipitation records from numerous places in this region have been secured for a number of years, and a few stations have been collecting relative humidity changes. The latter is more valuable in this study but, because of lack of sufficient material, precipitation records also will be used.

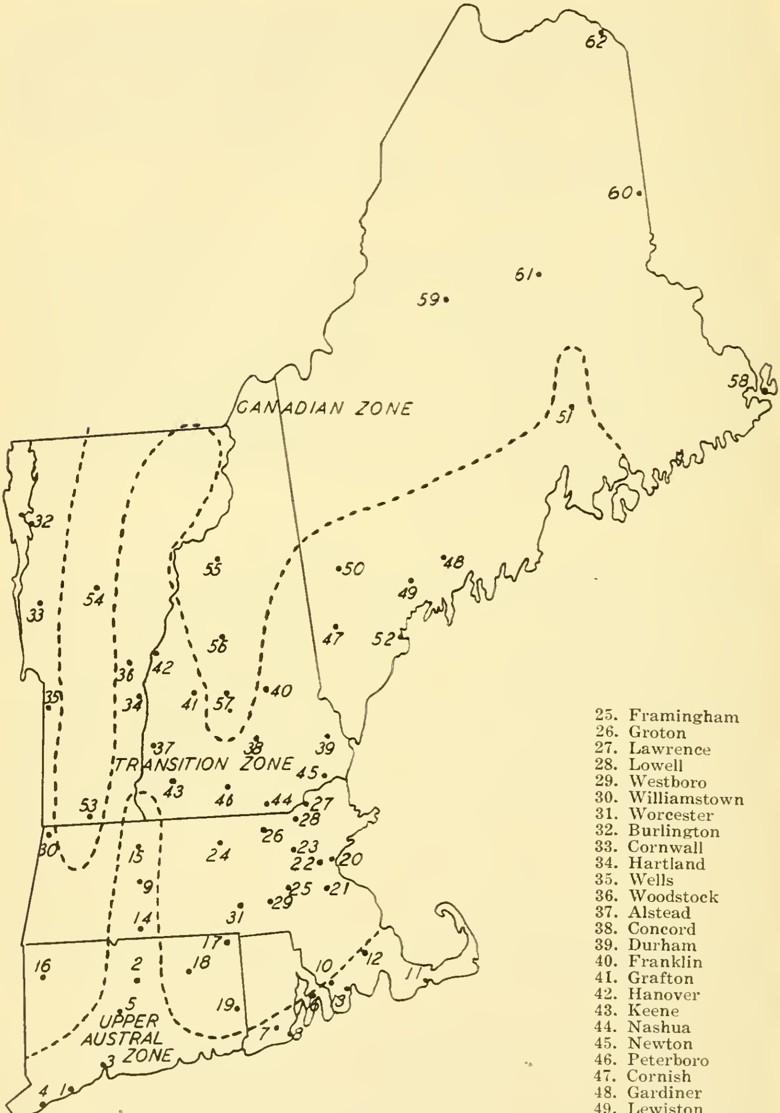
Faunal Zones of New England.

The faunal zones occurring in New England are the Canadian of the Boreal Region and Transition and Upper Austral of the Austral Region. These zones, as shown in the United States Biological Survey map of 1910 with modifications for New England by Fernald (1915 and later), are followed (Fig. 6). Meteorological data collected by the United States Weather Bureau stations within the various zones are used to determine the temperature and moisture conditions. Climatological data secured at places where the zones overlap are not used. Stations in the various zones selected as suitable for this study are shown in Figure 6.

Upper Austral Zone.—A composite climograph of temperature and moisture for the Upper Austral Zone is shown in Figure 7. The mean relative humidity is given in the climograph of Hartford, which is near the center of the Upper Austral Zone (fig. 8, Mean). The lowest humidity ordinarily occurs in the afternoon, and the 2 p.m. conditions plotted in Figure 8 (2 p.m.) approximate the driest part of the day. It is evident that the humidity is plentiful throughout the year, thus assuring suitable conditions for development of the eggs and larvae in summer and for hibernation of adults in winter. If the temperature becomes excessive during the summer months, the humid conditions would become unfavorable, but an examination of weather records shows that extreme temperatures are uncommon and of short duration. Maximum temperatures are ordinarily below 100° F. (37.8° C.) and, unless continuing for several successive days, the temperature among the plants fails to become injurious. Apparently conditions are favorable for the bean beetle to become a serious pest in the Austral Zone of Massachusetts, Connecticut, and Rhode Island. Beans are a rather common garden plant in this area. The insect is now found in this faunal division in southwestern Connecticut.

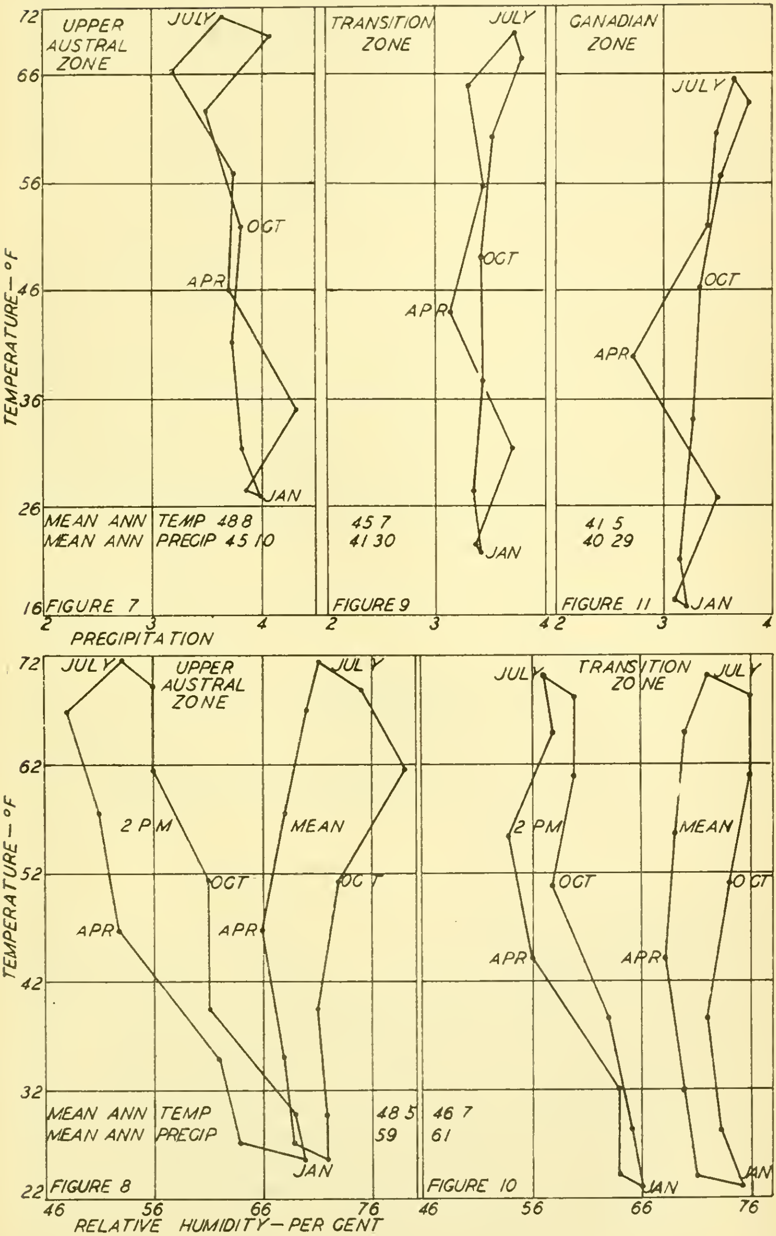
Transition Zone.—The mean temperature and precipitation are shown in the composite climograph for this Zone in Massachusetts, Connecticut, Vermont, New Hampshire, and Maine (fig. 9). A composite graph of the mean relative humidity and the 2 p.m. conditions of Boston, Portland, and Burlington are given in Figure 10 (Mean, 2 p.m.). The precipitation and relative humidity in Maine, Massachusetts, and Connecticut are very similar to that of the Upper Austral Zone just discussed. Since the temperature is slightly lower, less danger to the insect from the combination of high temperature and high moisture would exist. New Hampshire and Vermont are somewhat drier, but the heavier precipitation falls during the growing season and would be satisfactory for development of the immature stages. The winter months are sufficiently humid for successful hibernation of the adults.

Figure 6. The Faunal Zones of New England and Weather Bureau Stations in Each.



1. Bridgeport
2. Hartford
3. New Haven
4. Norwalk
5. Southington
6. Bristol
7. Kingston
8. Narragansett Pier
9. Amherst
10. Fall River
11. Hyannis
12. Middleboro
13. New Bedford
14. Springfield
15. Turners Falls
16. Cream Hill
17. No. Grosvenordale
18. Storrs
19. Voluntown
20. Boston
21. Blue Hill
22. Chestnut Hill
23. Concord
24. Fitchburg
25. Framingham
26. Groton
27. Lawrence
28. Lowell
29. Westboro
30. Williamstown
31. Worcester
32. Burlington
33. Cornwall
34. Hartland
35. Wells
36. Woodstock
37. Alstead
38. Concord
39. Durham
40. Franklin
41. Grafton
42. Hanover
43. Keene
44. Nashua
45. Newton
46. Peterboro
47. Cornish
48. Gardiner
49. Lewiston
50. No. Bridgton
51. Orono
52. Portland
53. Jacksonville
54. Northfield
55. Bethlehem
56. Plymouth
57. Sanbornton
58. Eastport
59. Greenville
60. Houlton
61. Millinocket
62. Van Buren

Figures 7, 8, 9, 10, 11. Composite Climographs of the Faunal Zones of New England.



Since the average temperature is somewhat lower than that of the Upper Austral, which ordinarily does not have excessive heat, it leaves the problem of determining if the temperature is high enough to favor reproduction. The mean monthly temperatures for July and August (fig. 9) for the Transition Zone are 69.7° F. (21° C.) and 67.4° F. (19.7° C.). These temperatures fall near the lower limits of suitability given in Figures 1-5 for the various stages. The beetle successfully overwinters in states that have as low temperatures as this area and apparently the bean beetle can be expected to become a pest over at least the southern part of the Transition Zone in so far as temperature and moisture are concerned, but may be restricted by lack of suitable food plants. As the northern limits of the Zone are approached, the injury will become less. The insect has recently been found in this faunal division in the Housatonic Valley of Connecticut and Massachusetts.

Canadian Zone. The climographs of temperature and precipitation for the portions of Maine, New Hampshire and Vermont in the Canadian Zone are given in Figure 11. The moisture of the environment appears to be satisfactory for the development of the immature stages. Very little danger to the pest would result from a combination of high temperature and high moisture conditions. However, the temperature alone would not encourage rapid development. The mean temperature of the warmest month, July, is 65.2° F. (18.5° C.). This means that the temperature would reach a favorable position for development for only a few hours daily and would not be sufficient for the beetle to become a pest. The insect may migrate into this area from the Transition Zone during the summer months and produce a limited amount of injury in local areas.

Discussion.

The conclusions that can be drawn from this study are based upon average conditions, and temporary variations from these will, of course, produce an environment either more or less favorable to the pest, depending upon the direction and duration of the variation. Local areas within the three zones may be found which do not have a temperature and moisture environment comparable to the surrounding region but such will not be sufficient to invalidate the general conclusions.

Food Availability in New England.

The principal food plant, beans, is common in Connecticut, Rhode Island, and eastern Massachusetts. This crop is localized in central and western Massachusetts and southern Maine, and is grown to a much less extent in New Hampshire and Vermont. Part of the Connecticut acreage is used for producing dry beans, but the growers in the remainder of New England market their product as string beans. The non-cultivated plants on which the bean beetle is known to develop belong to two genera, *Desmodium* (beggarweed) and *Crotolaria* (rattle-box), both closely related to beans (Thomas, 1924). One species of the latter, and at least seventeen of the former, are found in New England. Howard and English (1924) report *D. canescens,* a species found in New England, as being a suitable plant for larval development. These weeds may become important factors in the dispersal of the pest.

Conclusions

Adults. A temperature of 37° kills the beetles in a few hours; 32° is very unfavorable with high humidity and favorable with low humidity; 27° is suitable for heavy oviposition with humidity of 60 per cent or above and unfavorable with low humidity, but favorable for length of life with all humidities used; 22° is favorable with humidities of 40 per cent or above; and 17° with 50 per cent humidity is favorable for length of life but is very unfavorable for egg production.

Eggs.—A temperature of 37° kills the embryos; 32° is very destructive if reached for more than a few hours daily; 27° is suitable with humidities of 60 per cent or above and unfavorable with low humidity; 22° is very favorable with humidities of 60 per cent or above, but less favorable with low humidity; 17° with 50 per cent humidity is very favorable for good hatches, but development is very slow.

Larvae.—A temperature of 37° kills the larvae in a few hours; 32° is very unfavorable, especially with high humidity; 27° is favorable with high humidity and unfavorable with low humidity; 22° is very favorable with all humidities used; 17° with 50 per cent humidity is very favorable for a high percentage maturing, but development is exceedingly slow.

Climatic conditions in the Upper Austral Zone of Massachusetts, Connecticut and Rhode Island are favorable for the development of the Mexican bean beetle, and the insect may therefore be expected to become a serious pest. Conditions in the Transition Zone are less favorable, but the insect will probably become a pest in the lower portion of the Zone, with the injury becoming greatly reduced as the upper limits are approached. The Canadian Zone of New England does not have a physical environment suitable for the development of the beetle.

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