quently the influence of each borer of population on the percentage of transportation of food material is correspondingly less as the size of plant increases and as a result, the smaller stalk varieties suffer greater damage.

CONCLUSION. In planning this project it was hoped that by ascertaining the ratio existing between borer population and reduction in yield, the damage occurring within any field could be readily computed after determining the borer population. However, the results of the investigations reported here indicate that there is not likely to be established a specific formula, based upon borer population per stalk alone, for measuring damage that will apply to all varieties, soils, planting dates, seeding rates, crop rotations and weather conditions. The writers believe that the same populations established on the varieties presented here would not produce identical results another year because of the above mentioned factors. Nevertheless the amount of damage per average borer of population can be correlated in a general way with the nature of the variety according to the scale given in Table 6.

THE EFFECT OF TEMPERATURE, RELATIVE HUMIDITY AND EXPOSURE TO SUNLIGHT UPON THE MEXICAN BEAN BEETLE

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ABSTRACT

This series of laboratory experiments and field tests indicates that there is a specific relation between relative humidities and temperatures in the survival of the Mexican bean beetle (*Epilachna corrupta*) at high summer temperatures.

Experimental studies like those of Shelford (*9*)[2] and Headlee (*4*), and some more recent work like that of Chapman (*2*), Beattie (*1*), and Hefley (*5*) have indicated that atmospheric humidity and evaporation rate are very important factors in the life histories and ecology of insects. To some extent this also seemed to be true for the Mexican bean beetle, according to field data collected by Howard[3] and Douglass (*3*). It

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[2]References made by number in italics refer to literature cited at end of paper.

[3]Howard, Neale F. Studies on the atmospheric evaporation in relation to bean beetle abundance. Unpublished notes.

seemed advisable, therefore, to make a rather careful study of this problem under completely controlled conditions in order to determine with some exactness how important were the effects of these factors upon the bean beetle.

APPARATUS. A single unit of the apparatus that was constructed to control and measure the humidity and evaporation rates is shown in Figure 79. Six units were used in order to make possible the running of a variety of humidities simultaneously. The materials used were sulphuric acid, saturated solutions of sodium hydroxide, sodium bromide, sodium chloride, sodium nitrate, and distilled water; and the percentages of relative humidity obtained by their use were approximately 0, 30, 56, 73, 80, and 100.

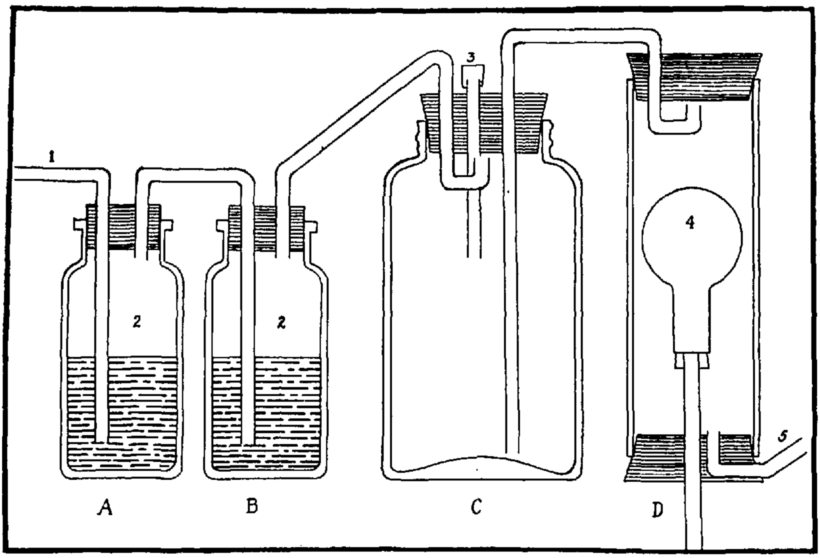

Fig. 79.—A and B, Bottles containing solutions to produce known relative humidities. C, Experimental chamber where beetles were placed during the experiment. D, Glass cylinder containing atmometer over which air was drawn in order to get the relative rates of evaporation. 1, Glass tube furnishing the inlet for the air current. 2, Salt solution or acid through which air was drawn to give it a known relative humidity. 3, Tube through which a thermometer was thrust to obtain the temperature of the inside of the experimental chamber. 4, Atmometer for recording the rate of evaporation. 5, Outlet tube connected with the pump on the water tap.

Parts A and B, bottles containing solutions producing known vapor tensions, and part C, a honey jar used as an experimental chamber, are similar in principle to apparatus used previously by Headlee and by

Hefley. Part D is a glass cylinder closed at both ends by rubber stoppers. The standard porous cup atmometer was placed inside the cylinder and the air from the experimental chamber C entered the upper end of the tube and passed down around the atmometer cup and out through the outlet, 5, to a suction pump attached to a water tap. Separation of the atmometer from the experimental chamber insured the correct percentage of humidity in the chamber.

Relative Evaporation Rates at Normal Temperatures. Of all the parts of the life history it was decided that those most susceptible to the effects of evaporation and humidity would be: (1) incubation, (2) larval period, (3) ecdysis, (4) pupation period, and (5) emergence. The first of these was postponed because of certain difficulties involved, but the others were tried, since mature larvae could be started, ecdysis would occur at time of pupation, the pupae would remain quiescent during the pupal period, and emerge as adults, all without feeding.

Mature larvae which had stopped feeding and most of which had already attached themselves preparatory to pupation were put into small screen-wire cages and placed in the experimental chambers (Figure 79, C). They were left here until they had passed through the pupal period and emerged as adults. They were examined daily during this period and records made of their condition.

Temperatures in the experimental chambers were checked three times per day and averaged. The greatest variation in temperature for any one day was from 25.8° to 31.1° C.; and for the entire period, from 22.1° to 31.1° C. The results of running the experiment for thirteen days are summarized in Table 1.

Table 1. Summary of the Effects of Relative Humidity and Rate of Evaporation on the Later Stages of the Mexican Bean Beetle

Per cent of relative humidity	Evaporation (cc.) Daily	Evaporation (cc.) Total	Number of larvae started	Number of larvae pupating	Number of adults emerging	Per cent of survival
0	25.14	264.0	31	31	31	100
30.7	17.83	187.2	31	31	30	96.6
56.18	8.2	94.3	31	30	29	93.3
73.4	6.60	69.7	31	30	30*	100
80.03	5.70	65.6	31	30*	30	100
100.0	1.06	12.3	31	30	30	96.6

*One individual killed in handling.

These figures show that for the extremes of dry and saturated air the percentages of pupation and emergence were very high and at no degree of relative humidity did the survival fall below 93 per cent, a figure well above normal for field conditions.

TABLE 2. SURVIVAL OF ADULTS OF THE MEXICAN BEAN BEETLE EXPOSED FOR THREE HOURS TO HIGH TEMPERATURES AND DIFFERENT RELATIVE HUMIDITIES

Per cent of relative humidity	Temperature °C.	Number of beetles used	Number of beetles killed	Number of survivals	Per cent of survivals
0.0	37.5	100	3	97	97.0
30.72	37.5	100	1	99	99.0
56.18	37.5	100	2	98	98.0
73.414	37.5	100	3	97	97.0
80.035	37.5	100	7	93	93.0
100.0	37.5	100	2	98	98.0
Check	26.0	100	2	98	98.0
0.0	38.5	260	128	132	50.8
30.72	38.5	260	105	155	59.6
56.18	38.5	260	97	163	62.7
73.414	38.5	260	51	209	80.4
80.035	38.55	260	118	142	54.6
100.0	38.5	260	180	80	30.8
Check	26.6	260	17	243	93.5
0.0	39.5	260	166	94	36.2
30.72	39.5	260	166	94	36.2
56.18	39.5	260	158	102	39.2
73.414	39.5	260	87	173	66.5
80.035	39.5	260	163	97	37.3
100.0	39.5	360	235	25	9.6
Check	27.3	260	1	259	99.6
0.0	40.5	100	92	8	8.0
30.72	40.5	100	92	8	8.0
56.18	40.5	100	84	16	16.0
73.414	40.5	100	66	34	34.0
80.035	40.5	100	99	1	1.0
100.0	40.5	100	100	0	0.0
Check	25.0	100	0	100	100.0
0.0	41.5	100	98	2	2.0
30.72	41.5	100	97	3	3.0
56.18	41.5	100	91	9	9.0
73.414	41.5	100	81	19	19.0
80.035	41.5	100	99	1	1.0
100.0	41.5	100	100	0	0.0
Check	25.5	100	2	98	98.0
At all humidities	42.5	100	100	0	0.0
Check	26.0	100	5	95	95.0

Table 1 shows clearly that for normal summer temperatures with no sudden or great variations, for relative atmospheric humidities varying from approximately 0 per cent to approximately 100 per cent, and for relative evaporation rates varying from 1.06 cc. to 25.14 cc. per day the Mexican bean beetle is sufficiently resistant to pass through its final ecdysis, pupation, and emergence with no apparent effect from the abnormal conditions.

RELATION OF RELATIVE HUMIDITY TO TEMPERATURE. The failure of the experiment of relative humidity and evaporation rate at ordinary summer temperatures to disclose any effect upon the beetles from the late larval stage to adult, led to the idea of testing relative humidity with higher temperatures. Some previous work with temperature by Kramer (*6*), Miller and Gans (*7*), Miller (*8*), and especially Beattie (*1*) and Hefley (*5*) showed that temperature is a vital and perhaps the most important single factor in insect life and activity.

Apparatus: Parts of the apparatus used in the preceding experiment (Figure 79, A, B, C,) were installed in a large electrical oven for the regulation of temperatures.

TABLE 3. SURVIVAL OF LARVAE AND PUPAE OF THE MEXICAN BEAN BEETLE EXPOSED FOR THREE HOURS TO HIGH TEMPERATURES AND DIFFERENT RELATIVE HUMIDITIES

Per cent of relative humidity	Temperature °C.	Number of larvae used	Per cent of survival	Number of pupae used	Per cent of survivals
0.0	37.5	100	96	100	99
30.72	37.5	100	100	100	97
56.18	37.5	100	99	100	100
73.414	37.5	100	100	100	99
100.0	37.5	100	97	100	98
Check	—	100	94	100	97
0.0	38.5	100	88	100	83
30.72	38.5	100	91	100	94
56.18	38.5	100	93	100	93
73.414	38.5	100	96	100	95
100.0	38.5	100	94	100	79
Check	—	100	97	100	95
0.0	39.5	200	88	100	86
30.72	39.5	200	88	100	89
56.18	39.5	200	82.5	100	85
73.414	39.5	200	89	100	94
100.0	39.5	200	88	100	90
Check	—	200	98	100	92
0.0	40.5	110	60	120	30
30.72	40.5	110	68.1	120	39.2
56.18	40.5	110	77.2	120	35
73.414	40.5	110	91	120	46.6
100.0	40.5	110	82.7	120	40
Check	—	110	97.2	120	92.5
0.0	41.5	130	2.3	100	6
30.72	41.5	130	10.7	100	0
56.18	41.5	130	0.0	100	1
73.414	41.5	130	10.7	100	3
100.0	41.5	130	3.1	100	4
Check	—	167	86.8	100	89
0.0	42.5	100	3	100	0
30.72	42.5	100	4	100	0
56.18	42.5	100	3	100	0
73.414	42.5	100	1	100	0
100.0	42.5	100	0	100	0
Check	—	100	98	100	93

Methods and results: When the oven had reached a given constant emperature the beetles were counted out and placed in the experimental

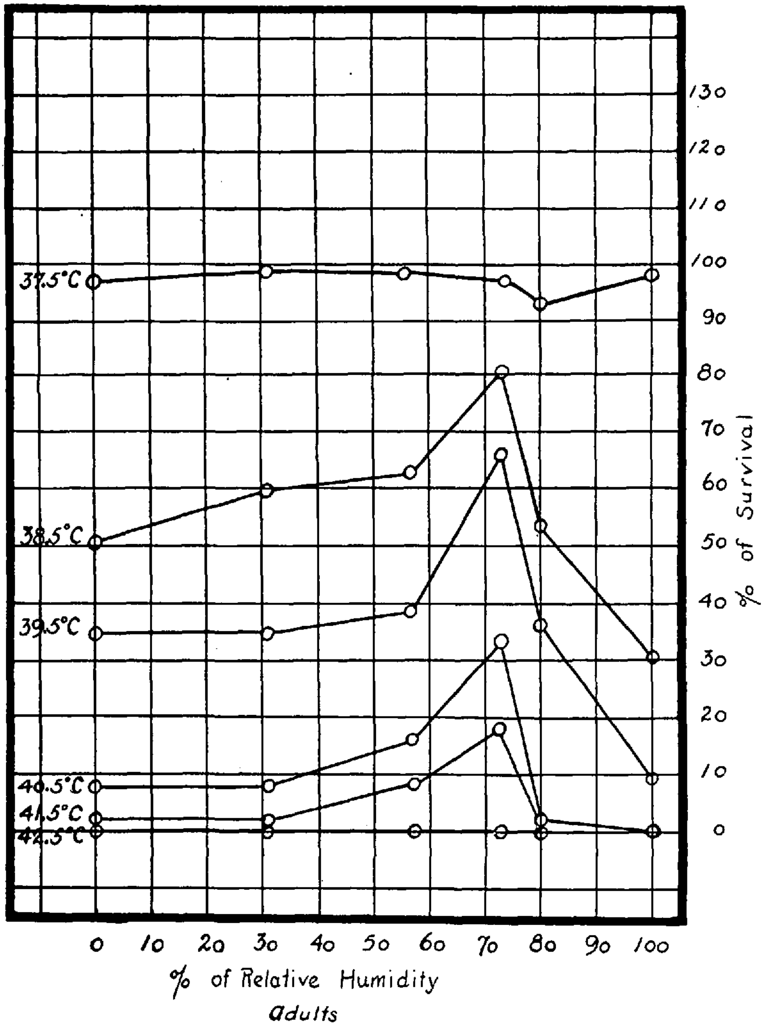

Fig. 80.—Chart showing the effects of exposure to various temperatures at different relative humidities upon the survival of adults of the Mexican bean beetle. (The percentages of survival in the checks were 98, 93.5, 99.6, 100, 98, and 95; see Table 2.)

chambers of the apparatus (Figure 79, C), an equal number in each chamber, and exposed to the temperature for three hours. After the exposure they were removed and allowed to stand from fourteen to sixteen hours, and then the beetles were removed and carefully examined to determine the percentage which had survived. For comparison, in each

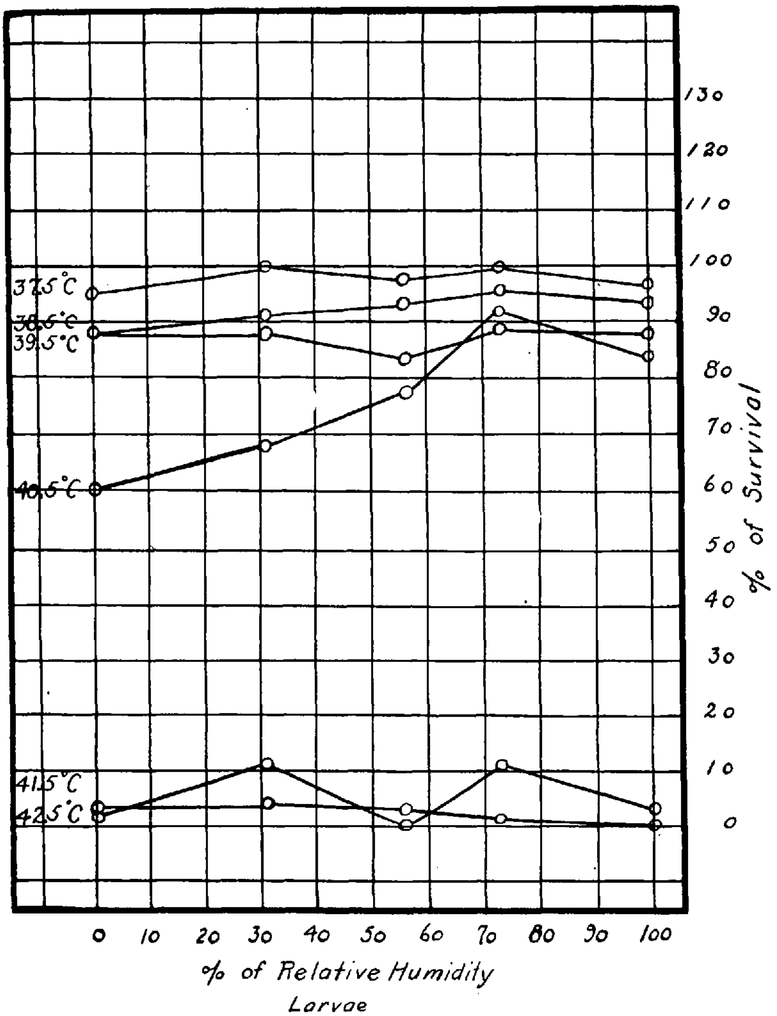

Fig. 81.—Chart showing the effects of exposure to various temperatures at different relative humidities upon the survival of larvae of the Mexican bean beetle (The percentages of survival in the checkswere 94, 97, 98, 97.2, 86.8, and 98; see Table 3.)

experiment, a check chamber was run outside the oven at room temperature. The very definite results obtained are summarized in Tables 2 and 3.

On the graphs of Figures 80, 81, and 82 the temperatures used (37.5,° 38.5,° 39.5,° 40.5,° 41.5,° 42.5° C.) are shown along the left margin; each per cent of relative humidity (given in Tables 2 and 3) and each per cent of survival of the larvae, pupae, and adults is indicated by the position of a circle with reference to the scale at the bottom and at the right, respectively. These should be compared with the results of the checks (as given in the legends of the figures) to obtain the true kill. It will be noticed here that at 37.5° C. there was normal survival at all humidities giving nearly a straight line. For a 1° rise in temperature, however, there was a marked kill below 60 per cent and above 80 per cent relative humidity, with a very decided optimum at about 73 per cent. For temperatures of 39.5° C., 40.5° C., and 41.5° C., the results are very similar, with a decidedly lower per cent of survival for each increase of one degree of temperature. For a temperature of 42.5° C., one degree higher, there was an almost complete kill at all humidities and the curve becomes essentially a straight line. Regardless of the temperature, the optimum humidity is near 73 per cent. These results are somewhat similar to those obtained by Hefley (5).

From the graphs it is apparent that there is a critical thermal increment at about 40.5° C. Below this temperature there is no great gap in the percentages of survival for each rise of 1° C., and above it the same holds true, but from 39.5° C. to 41.5° C. there is a wide break.

Egg hatch: All attempts to determine the effects upon per cent of hatch in eggs showed tendencies toward results similar to that for other stages, but the mortality was so high even in checks that the results were not considered valid and hence are not presented.

The results of this series of experiments show very clearly the definite relationship between temperature and humidity. While the temperatures used were all high they are within the range of an occasional hot spell for climate such as may be found in the United States from Ohio south. They are well below the temperature frequently reached at the surface of the ground where exposed to the summer sun. The three-hour exposure was chosen as representing the probable duration of high temperature for any one day.

The fact that from 37.5° C. down there was no effect of either temperature or humidity explains why the first experiment on relative humidity and rate of evaporation gave completely negative results.

FIELD TESTS. Exposure to sunlight: In order to check in the field some of the results obtained by the preceding laboratory tests, pupae were exposed to bright direct sunlight. The leaves containing pupae were turned over and tied to stakes so as to expose the pupae to the direct rays of the sun. Different lengths of time were taken for the exposure and days were chosen when comparative temperatures varied consider-

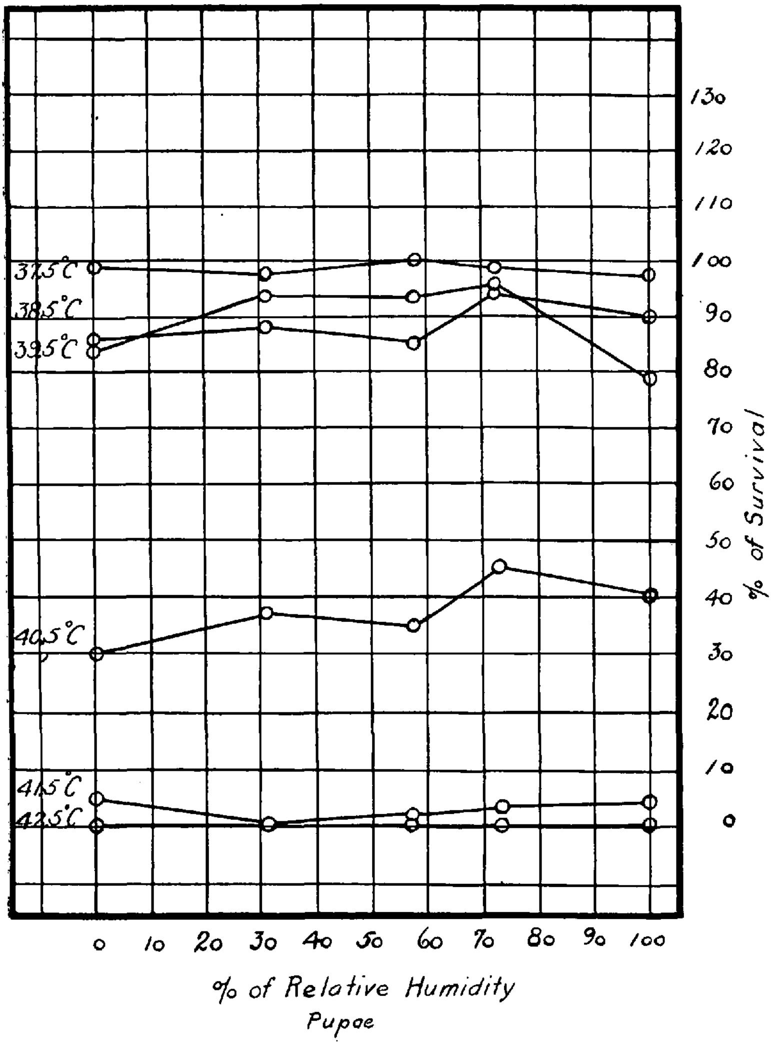

Fig. 82.—Chart showing the effects of exposure to various temperatures at different degrees of humidity upon the survival of pupae of the Mexican bean beetle. (The percentages of survival in the checks were 97, 95, 92, 92.5, 89, and 93; see Table 3.)

ably so as to make it possible to test for the effects of temperature and light rays separately. The results, which are summarized in Table 4, show:

a. That exposure for short periods (3 hours), when the temperature is high, kills pupae, since only 32 per cent of the exposed pupae emerged while 91 per cent of a check emerged.

b. That exposure for longer periods (15–18 hours) has practically no effect if the temperature is not high.

c. That it seems probable that temperature is more important than light rays in killing when exposure occurs in the field.

TABLE 4. EFFECTS OF EXPOSURE OF PUPAE TO MID-DAY SUN

Number of pupae	Length of exposure Hours	Hours of day	Mean temperature °C.	Number alive	Number died	Percentage of survival Experiment	Check
64	3	12.00–3.00	35	20	44	32	91
64	15	9.00–12.00	26.5	56	8	88	98
106	18	11.30–7.30	24.5	102	4	96.2	88

Position of beetles on the leaf: The question of the orientation of insects upon their host plants is a matter of both biological and economic importance. This is especially true in artificial control. The Mexican bean beetle, like many other insects, is usually found upon the under surface of the leaf where it feeds, ordinarily not breaking through the upper surface. Various explanations for this limitation of its activities have been suggested, usually with very little supporting evidence.

a. Response to gravity. Since the question is one of position, geotropism naturally suggests itself as an explanation.

b. Differences in leaf surface. This involves a number of things, such as the different nature of the surfaces themselves, the clinging ability of the beetle, the difference in humidity, the ability of the beetle to feed on one surface rather than the other, etc.

c. Response to light or heat of the sun. It has been observed that many more beetles are found on the upper surface of leaves just after daybreak than during later hours of the day.

A few specific tests were made which gave considerable definite information upon these points. A potted bean plant was suspended in an inverted position in bright sunlight. A number of beetles were placed upon the leaves in a place exposed to the direct sunlight. In most cases this was the under surface of the leaf which was now turned uppermost. The beetles immediately showed signs of restlessness and moved about until they came to the shaded side of a leaf. This was usually the upper surface which, being inverted, was not now exposed to direct light. If the leaf was turned edgewise with neither surface above or below, the beetle "chose" the shaded side regardless of which one it was. The response was negative to either the light or temperature which was about 34° C. in the sun on this day. The beetles had been taken from cages where food was not plentiful. Feeding commenced almost at once and those beetles which came to rest upon the upper leaf surface began feeding upon it as readily as those on the lower surface.

To check these rather obvious results, a screen was placed in such a position as to shade the plant from direct sunlight. Then a mirror was set beneath the plant and the light of the sun reflected up against the leaves. This placed most of the beetles in the bright light again, whereupon they showed signs of restlessness and moved to less lighted areas as before.

This experiment was repeated later at a time when the temperature was not above 28° C. and the same results were apparent.

It would seem from the above that the distribution of the Mexican bean beetle upon the plant was primarily influenced by the intensity of the light rather than by gravity, leaf surface, ability to feed, or temperature, although they may respond to these influences when light does not enter in.

To test this, larvae were placed on plants which were then kept in a dark room. Counts made over a period of several days gave a total of 125 larvae on the under surface of leaves as compared with 84 on upper surfaces, stems, and cage walls. Other experiments carried on at the same time in a dark room by Howard and Mason in connection with a different project showed very similar distribution in the dark. Feeding had taken place on all parts of the plants, which seems to indicate that the only factor of much importance is light.

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