THE EFFECT OF SUMMER RAINFALL ON JAPANESE BEETLE POPULATIONS

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The amount of rainfall during the summer is an important cause of year-to-year fluctuations in the abundance of the Japanese beetle (*Popillia japonica* Newm.). Such fluctuations are often independent of long-time trends, which may be brought about, in part at least, by the action of biotic factors, such as pathogenic microorganisms (9)*, insect parasites and predators, and nematodes. Hawley and Dobbins (7) have given a comprehensive account of changes in beetle abundance from 1935 through 1943; the reducing effect of summer droughts on beetle populations and the increase in numbers resulting from unsually favorable rainfall conditions are also discussed.

In the large eastern section of the country now infested by the Japanese beetle, summer rainfall is sufficient in average years to ensure survival and, in most places, to permit an increase in the number of beetles. When precipitation is deficient, however, the soil may become so dry that certain of the soil-inhabiting stages are killed. As pointed out by Fox (1), summer rainfall has such an important effect on Japanese beetle populations that this insect would not be expected to survive in certain parts of the western United States if accidentally carried there.

STAGES OF THE JAPANESE BEETLE SUSCEPTIBLE TO DESICCATION

According to Ludwig (2), Japanese beetle eggs increase in weight during the incubation period from about 0.86 to 2.4 milligrams, chiefly by the absorption of moisture through the egg shell from the surrounding soil. If there is not sufficient moisture, the eggs will not complete their embryological development, but will perish. A dry soil condition is also unfavorable to the newly hatched larvæ. According to Fox (1), the body wall of the newly hatched larva is only lightly chitinized and not

* Numbers in parentheses refer to Literature Cited.

adapted to conserve moisture. Furthermore, the soft-bodied small grub is unable to dig long distances through the soil to find food to replenish its body moisture.

Older larvæ of the Japanese beetle are resistant to desiccation under conditions of low soil moisture. As Ludwig (3) has shown, larvæ in all three instars may be reduced to about 50 per cent of their initial weight and still survive if returned to a favorable soil moisture condition. The prepupæ and pupæ are also able to stand considerable desiccation.

SEASONAL OCCURRENCE OF STAGES AFFECTED BY LOW SOIL MOISTURE CONDITIONS

In an average year in the Philadelphia area, soil surveys have indicated that eggs and first instars of the Japanese beetle occur in the soil from July 1 through September 30. Data on these surveys, which consisted of 13,413 square-foot diggings made in turf between June 21 and September 30 during an 11-year period, are given in table 1.

TABLE 1

FREQUENCY DISTRIBUTION OF ALL EGGS AND FIRST INSTARS OF JAPANESE BEETLES FOUND IN SOIL SURVEYS IN THE PHILADELPHIA AREA, 1926 TO 1936, INCLUSIVE

Period	Eggs (per cent)	First instars (per cent)
June 21–30	1.2	0.0
July 1–10	14.1	0.5
11–20	38.0	3.4
21–31	30.2	19.7
Aug. 1–10	11.8	30.9
11–20	3.1	24.3
21–31	1.2	13.6
Sept. 1–10	0.4	5.2
11–20	0.1–	1.7
21–30	0.0	0.5

All the viable eggs were found in the period shown in the table. First instars were found throughout the year, but 99.7 per cent of them occurred between July 1 and September 30.

The data in table 1 apply only to conditions in the Philadelphia area. South of this point, events in the seasonal cycle occur earlier, and at points further north, later. At Richmond, Va., the beetle season normally begins about 10 days earlier than at Philadelphia; at Washington, D. C., 3 days earlier; at New York City, 5 days later; and at New Haven, Conn., Boston, Mass., and Cleveland, Ohio, 10 to 12 days later than at Philadelphia. At the extreme northern range of the insect in New Hampshire, beetles and eggs often continue to be found late in the fall (5). For this reason, a severe drought in late summer or fall would have more of an adverse effect on beetle populations in New Hampshire than it would further south.

RAINFALL DEFICIENCIES AND THEIR EFFECT ON JAPANESE BEETLE POPULATIONS

The Japanese beetle was first found near Philadelphia in 1916 (4), and for 15 years or more the general infestation was restricted to a comparatively small area having much the same climatic conditions. In determining the effect of rainfall deficiencies on the beetle in this area, the records of the Philadelphia office of the United States Weather Bureau have been used. During a 75-year period, rainfall has averaged 12.01 inches at this station for the three summer months of June, July, and August. In 11 of the 30 years since 1916, summer rainfall was below 10 inches, as may be seen from table 2. The rainfall for July alone is also given since this is the month when rainfall has the greatest influence on egg survival in that area as is evident from table 1.

Rainfall in the summer of 1916, the year beetles were first found, and 1918 (table 2), was considerably below normal. If these years had been more favorable for the survival of eggs and small larvæ, the Japanese beetle would probably have built up more rapidly at the time that it was becoming established in the United States. The summer of 1929 has been mentioned as one in which rainfall was markedly deficient in the Philadelphia area (1). From July 1 through August 10, the critical period for eggs, the rainfall was only 2.29 inches. Since 94 per cent of all eggs are usually found in this period, the marked reduction in the beetle population in 1930 was not surprising.

Summer rainfall from 1932 through 1937 (table 2), was generally unfavorable for the survival of eggs and small larvæ of the Japanese beetle, since in all but two of these years there had been less than 10 inches of rain. In addition, the winter of 1935–36 was the only one, since the beetle first became established in this country, in which larval mortality is known to

TABLE 2

YEARS WITH LESS THAN 10 INCHES OF SUMMER RAINFALL, 1916–45, PHILADELPHIA, PA.

Year	Rainfall June, July, August (inches)	Rainfall July alone (inches)
1916	7.17	3.40
1918	7.96	2.43
1923	8.42	3.51
1925	8.16	4.99
1929	7.49	1.53
1932	8.71	2.25
1934	9.69	2.18
1936	9.86	2.60
1937	8.77	1.16
1943	8.06	4.26
1944	5.27	0.73

have been high (6). As a result of the action of these unfavorable conditions, the beetle population in the Philadelphia area by 1937 had fallen far below that in the summer of 1932. In soil surveys made near Philadelphia in the spring of 1937, larvæ averaged only 1.7 per square foot as compared with 16.0 per square foot in 1932. The beetles continued to be present in reduced numbers in this area until 1946, but the continued low population was probably due as much to the action of biotic agents as to climatic influences.

The drought of 1944 was general throughout most of the continuously infested area, which by this time extended from Massachusetts to Virginia, but the greatest rainfall deficiency was in the area running from eastern Massachusetts through Rhode Island and southern Connecticut to the New York City area.

In this latter area rainfall was especially deficient on Long Island and in northern New Jersey. Rainfall was also markedly reduced in eastern Pennsylvania, southern New Jersey, northern Delaware and parts of Maryland, and at some points in the Middle West. The severity of the drought is apparent when summer rainfall in 1944 is compared with the normal summer precipitation for various places in the beetle infested area; this comparison for a few selected locations is as follows: Boston, Mass., 47.8 per cent of the normal amount; Providence, R. I., 34.0 per cent; New Haven, Conn., 23.7 per cent; Setauket, N. Y., 48.9 per cent; New Brunswick, N. J., 44.6 per cent; Moorestown, N. J., 52.3 per cent; Cape May, N. J., 44.0 per cent; Coatesville, Pa., 45.0 per cent; Millsboro, Del., 51.0 per cent; Elkton, Md., 58.0 per cent; Frederick, Md., 60.6 per cent; Salisbury, Md., 52.1 per cent; and Indianapolis, Ind., 61.2 per cent. The deficiency was less pronounced in central Delaware and in the adjoining part of Maryland than elsewhere in the southern part of the area of general distribution. Rainfall was normal only at certain inland points in New England, in the upper Hudson River Valley, at some points in Lancaster and York Counties in Pennsylvania, and at isolated colony sites in Virginia and North Carolina.

At most places in the 1944 area of low rainfall fewer beetles were found in 1945. A marked drop in beetle populations occurred in Rhode Island, southern Connecticut, on Long Island, in New Jersey, eastern Pennsylvania, most of Delaware, and in parts of Maryland, all of which are in the zone where rainfall was most deficient in 1944. Less marked reductions were observed at other points. The only parts of the infested area that maintained their previous population densities, or where numbers increased in 1945, were those already mentioned where rainfall was close to the normal or higher. In some places, such as the Berkshire section of Massachusetts, rainfall was far above normal, and the beetles greatly increased in numbers.

THE EFFECT OF RAINFALL DEFICIENCIES ON GRUB POPULATIONS

Variations in the abundance of the Japanese beetle from year to year may be estimated in several ways. The degree of brown-

ing of favored food plants (8) may be used to judge the density of beetle populations, but the most accurate method is to make a series of soil surveys to determine the abundance of the soil-inhabiting stages. If a large number of scattered diggings are made at the same time and place each year, an accurate indication of population trends may be obtained.

In a few specific locations reductions in grub populations could be traced to the deficient rainfall in 1929 and 1932. On a golf course at Merchantville, N. J., soil surveys showed that the larval population per square foot decreased from 17.1 in the spring of 1929 to 2.0 in the spring of 1930 (5), and at Moorestown, N. J., from 9.4 to 1.9 in the same period. On a golf course at Jenkintown, Pa., there was a drop from 24.9 larvæ per square foot in 1932 to 8.9 in 1933. The evidence of reductions elsewhere as determined by soil surveys was not always so clear as in these cases, owing perhaps to local variations in rainfall that did not show up in the records of Weather Bureau stations, or to the action of other influences.

THE EFFECT OF ABUNDANT RAINFALL ON BEETLE POPULATIONS

Just as a deficiency in summer rainfall brings about a reduction in beetle populations so an excess of precipitation usually results in a marked increase in numbers. The importance of summer rainfall is especially apparent when two or more favorable years fall in succession. Beetles apparently reached their peak of abundance in the Philadelphia area about 1929, following three years with summer rainfalls of 15.54, 17.84, and 14.88 inches. This suggests that the normal summer rainfall for Philadelphia, about 12 inches, may be slightly below the optimum for the insect.

Summer rainfall was normal, or above, at most points in the infested area in both 1945 and 1946. The precipitation at nine key stations of the United States Weather Bureau in the heavily infested area averaged 25.5 per cent above normal in 1945, and 14.3 per cent above in 1946. In 1945 the variation was from 1.2 per cent below normal to 54.6 per cent above, and in 1946, from 19.1 per cent below normal to 51.8 per cent above at these

nine stations. The high rainfall in these two years brought about increased beetle populations in 1947 in most parts of the infested area. This was true where the insect was already abundant, as well as where it had become reduced in numbers, as in the long-infested area about Philadelphia. Soil surveys in the Philadelphia area in the fall of 1947 showed from 10 to 20 larvæ per square foot where the count had been 2 or less prior to 1946. The trend was the same in most of the infested area and numerous counts of 30 or more grubs per square foot were found in the fall of 1947. It should be noted that the increasingly high grub populations favor the activity of milky disease organisms and other parasitic forms, and that these factors will, in turn, operate to reduce soil populations before emergence starts in 1948.

DISCUSSION

It has been pointed out that the normal summer rainfall is about 12 inches at Philadelphia. It is also close to this amount in much of the beetle-infested area in southern New England, southeastern New York, the eastern half of Pennsylvania, New Jersey, Delaware, and Maryland. At points in the Central States, such as Saint Louis, Mo., Chicago, Ill., and Indianapolis, Ind., the normal summer rainfall is about 10 inches, and at Cleveland, Ohio, it is only 9.5 inches. An infestation of the Japanese beetle in Cleveland has been under observation by entomologists of the Ohio Agricultural Experiment Station since 1939, and large increases in numbers had occurred there by 1944, following two years in which the summer rainfall was 11.68 and 11.89 inches; in both of these years it was plentiful during the critical month of July. Rainfall in 1944, 1945, and 1946 was below normal, the totals for these three years being 8.01, 9.13 and 8.11 inches. The 1947 beetle populations were greatly reduced.

It has been suggested that, because of the low summer rainfall, the Japanese beetle will never become so serious a pest in the Central States as it has in the Eastern States (1). It is obvious that years with less than 10 inches of summer rainfall occur more frequently in the Central States. The beetle infestations in this area are still relatively new and small, but popula-

tion trends at Cleveland in recent years indicate that summer rainfall may have a most important influence on population trends in that area.

In July 1943 rainfall at Philadelphia totaled 4.26 inches, but only 0.62 of an inch in August and 1.18 inches in September. The soil became so dry that the grass turned brown and some plants wilted. At the time of the drought most of the larvæ had developed to a point where they were resistant to desiccation (3) and probably few were killed, though many appeared shrunken and stunted. Except in certain northern areas, where beetles and eggs are commonly found in the fall months, droughts of this type are less critical to the Japanese beetle than those in mid-summer.

At some nearby points in eastern Pennsylvania, there was less rainfall in 1932 than at Philadelphia. The records of eighteen United States Weather Bureau Stations show that at six of these points the summer rainfall was lower than at the Philadelphia city office, and at eleven locations it was higher. At twelve stations the summer rainfall was below 10 inches. There was a variation of from 5.56 inches at Marcus Hook southwest of the city to 14.02 inches at Neshaminy Falls north of Philadelphia. In July 1932 alone, the rainfall ranged from 1.25 inches at Marcus Hook to 4.04 inches at Conshohocken northwest of the city. These variations in rainfall are often due to local thunderstorms, but differences as large as those experienced at Philadelphia in 1932 are unusual. Such variations result in wide differences in beetle populations in relatively small sections of the infested area, with increases in numbers at some points and reductions at others. It is evident that to correctly interpret the action of rainfall deficiencies on beetle populations, it is necessary to have an exact knowledge of the precipitation at numerous points throughout an area.

CONCLUSIONS

Soil surveys carried out over a period of years have shown that in dry summers the beetles tend to congregate their egg laying in low places with favorable soil moisture where entrance into the soil is comparatively easy. A concentration of larvæ

in these moist areas and low populations in the drier places is the result. In years with abundant evenly-spaced precipitation, the eggs are more generally distributed and the larval populations are more uniform. When this condition prevails, the number of larvæ per square foot will be lower in the locations favored in dry years, even though there may be more larvæ in the area as a whole.

The distribution of summer rainfall is important. Moderate amounts of rain evenly distributed are more favorable for the survival of the Japanese beetle than several heavy showers close together. In the latter case, much of the water runs off and, beyond certain limits, contributes little to wetting the soil where the immature stages occur.

Although summer rainfall is important, several other factors are now acting to bring about changes in beetle abundance and these must be considered in evaluating changes in numbers. The effectiveness of the milky disease organisms in destroying larvæ is generally recognized and other biotic factors are known to operate in restricted areas. The high grub populations of 1947 will aid in the distribution and build up of the milky diseases, so that a favorable rainfall condition has a bearing on the action of this and other biotic control factors.

The area infested by the Japanese beetle is now so large that the amounts of summer rainfall will vary widely and populations will differ accordingly. As the beetle spreads into new areas, it will encounter new rainfall conditions and differences in ecological influences, such as soil type, food plants and the nature of breeding areas, as well as new combinations of biotic factors. All of these factors working together will determine whether the insect will build up and become a serious pest, or whether it will only persist in small numbers and cause little damage.

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