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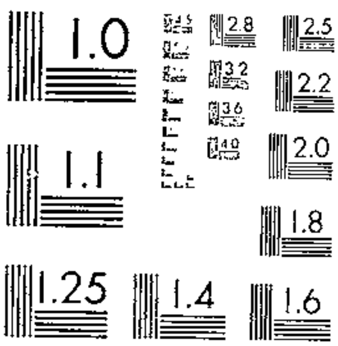

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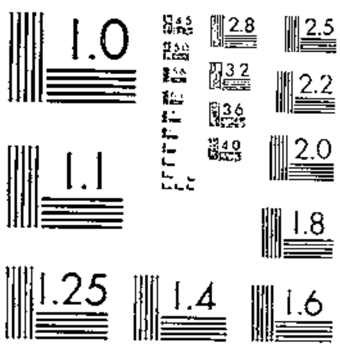

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UNITED STATES DEPARTMENT OF AGRICULTURE

WASHINGTON, D. C.

BIOLOGY OF THE PEA WEEVIL IN THE PACIFIC NORTHWEST WITH SUGGESTIONS FOR ITS CONTROL ON SEED PEAS[1]

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United States Department of Agriculture, Bureau of Entomology and Plant Quarantine, in cooperation with the Agricultural Experiment Stations of Idaho, Oregon, and Washington

CONTENTS

INTRODUCTION

The growing of seed peas has become a very profitable source of agricultural income, at the present time ranking as the most important horticultural seed-growing industry in this country (*15*)[3]. This industry is centered in the Pacific Northwest, where the production of a profitable crop has at times been seriously threatened by infestations of the pea weevil (*Bruchus pisorum* L.; order Coleoptera, family Bruchidae). The percentage of germination and the value of mature peas as food for livestock are lowered by the presence of this insect. Green

[1] Received for publication June 22, 1937.

[2] Credit is due to H. J. Shipman, assistant field aide, for the performance of many arduous tasks in connection with this study. The investigations upon which this bulletin are based, with the exception of those for the year 1934, were made under the direction of E. A. Back, in the former Division of Household and Stored Product Insect Investigations.

[3] Italic numbers in parentheses refer to Literature Cited, p. 47.

14587°—38——1

peas intended for market or for canning and mature peas prepared for human consumption are rendered liable to legal seizure under the provisions of the Federal Food and Drug Act, if they are infested.

Although the insect has been reported as damaging peas in many districts where this crop is grown, there is a dearth of complete information regarding pertinent features of its biology. Many and varied are the methods that have been suggested for the control of the pea weevil in the field and in storage, but the frequent reports of damage caused by this pest indicate either the inadequacy of such methods or failure to apply them in a proper manner. Whitehead (*20*), in 1930, expressed the opinion that the control measures thus far recommended must be fundamentally incorrect, because the damage caused by this insect had not been appreciably lessened in any district where environmental conditions were suitable for its development in sufficient abundance to make it a pest. Recent research on this destructive insect has brought out many new facts that may aid in explaining the inadequacy of currently recommended control measures, and that indicate the possibility of more effective control through the development of new methods and the improvement of old ones.

HISTORY

The pea weevil was first mentioned in the literature as a pest of peas as early as 1756 by Kalm (*7, v. 1, pp. 173–175*), a Swedish traveler, who observed it damaging the crop in New York, Pennsylvania, and New Jersey, during the decade following 1740. Harris (*6*) states that the pea weevil was first noticed in Philadelphia, whence it spread to New Jersey, New York, and Massachusetts. This author also stated that the insect probably spread from the United States to England and southern Europe. Wakeland (*18*) mentioned climate as the principal limiting factor in the survival of the weevil and that, if environmental conditions are favorable for its survival, it is now known as a pest in all localities in which peas are grown.

According to all information thus far recorded, it is probable that the United States was not the original habitat of the pea weevil. Even though it is reported to have been introduced from this into other countries, the insect has no known host plants other than the garden and field peas belonging to the genus *Pisum*, and these were not known to exist in this country before their introduction. It seems possible that the original source of the pest may have been one of the two primary points of distribution of the field pea, Ethiopia or the Iranian-Afghanistan mountain region (*15*).

DISTRIBUTION IN THE UNITED STATES

The insect is very widely distributed in the United States. Records compiled by the Insect Pest Survey of the United States Department of Agriculture indicate that the pea weevil has been reported from 33 States, ranging from Vermont to California and from Florida to Washington. A detailed survey would no doubt reveal the presence of the insect in every State in the Union.

A few districts devoted to the production of seed peas are reported to be free from weevil infestation because of the severity of the climate. It has been reported that because of the normally low temperature the pea weevil rarely hibernates successfully in the upper Snake River Valley in eastern Idaho. This has also been reported as true of the Gallatin and Flathead Valleys in Montana.

Recently the production of weevil-free peas during the winter months has been reported from the Rio Grande Valley in Texas. The industry is only a recent development in Texas and it is still too early to determine whether the weevil will be able to adapt itself to conditions there.

DESCRIPTION OF THE STAGES

THE ADULT

The adult pea weevil is of a general brownish color, flecked with white, black, and gray patches (fig. 1). It is approximately one-fifth

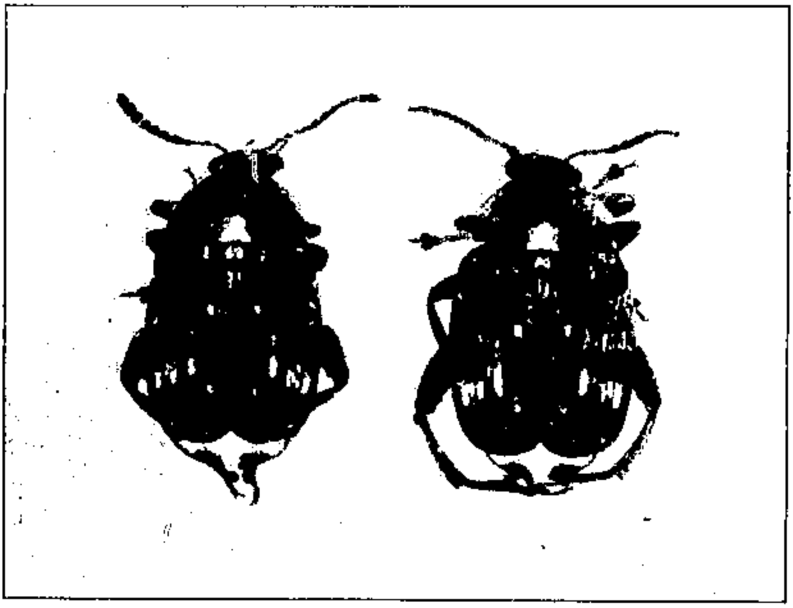

FIGURE 1.—Adult pea weevil; × 8. (Photograph by K. W. Gray.)

of an inch long, but there is much variation in the size. Adults reared or collected in the Pacific Northwest had an average length of 5.5 mm and an average width at the thorax of 2.0 mm. The width of the thorax in the smallest individuals was only 1.09 mm, whereas the largest measured 2.27 mm. Females were found to be slightly larger than the males. The size of the weevil appears to be affected by the available food supply, since small, completely formed individuals emerged from small peas. Figure 2 illustrates the variation in the size of the adults.

J. C. Bridwell states that the sexes can be distinguished by the presence or absence of a small, acute spine on the distal end of the tibia of the middle leg. This spine is present in the male and absent in the female.

FIGURE 2.—Variation in the size of adult pea weevils that developed in large and small seeds; approximately × 3. (Photograph by N. F. Howard.)

Blatchley (*3, p. 1236*) has given the technical description of the adult of the pea weevil as follows:

> Oblong-oval, subdepressed. Black, feebly shining; above, densely clothed with reddish-brown and whitish hairs; thorax with a triangular whitish space in front of scutellum; elytra with yellowish, grayish and whitish hairs, the latter forming an oblique band behind the middle; pygidium covered with gray hairs except two oval black spots near apex; antennæ black, the three basal joints rufous; legs black, front tibiæ and tarsi rufous; under surface black, shining, densely punctate, sparsely clothed with fine grayish hairs. Thorax broader than long, coarsely and densely punctate. Elytra slightly longer than broad, striate, the striæ finely punctate. Length, 4.5–5 mm.

THE EGG

The egg has been described by Skaife (*16*), who states that it is "of a rich, amber-yellow colour, oval in shape, and measures about 1.5 mm. by 0.6 mm." It is attached to the pod by a transparent gluelike substance that soon hardens on exposure to the air. Frequently two eggs are laid at a time, one on top of the other, in which case the lower egg almost invariably develops the faster of the two. The head of the larva can be seen as a black spot in the egg about 2 days before it hatches.

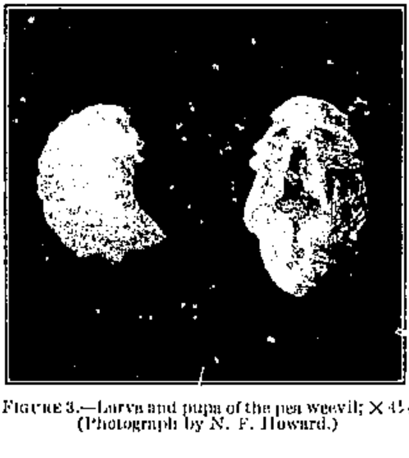

FIGURE 3.—Larva and pupa of the pea weevil; × 4½. (Photograph by N. F. Howard.)

THE LARVA

The first-stage larva, described by Riley (*14*), has six short temporary legs and can move freely. It is also provided with a spiny prothoracic plate that enables it to support itself while entering the pea. Within the pea the larva molts, loses its temporary legs, and becomes a helpless grub.

THE PUPA

Just before pupating the larva forms a circular exit, closed only by the outer skin of the pea, which is also partially cut by the larva before the prepupal stage. The adult has only to push against this cap to effect its escape from the pea. Figure 3 shows a fully grown larva and pupa of the pea weevil. Figure 4 shows the adult weevil emerging from the pea.

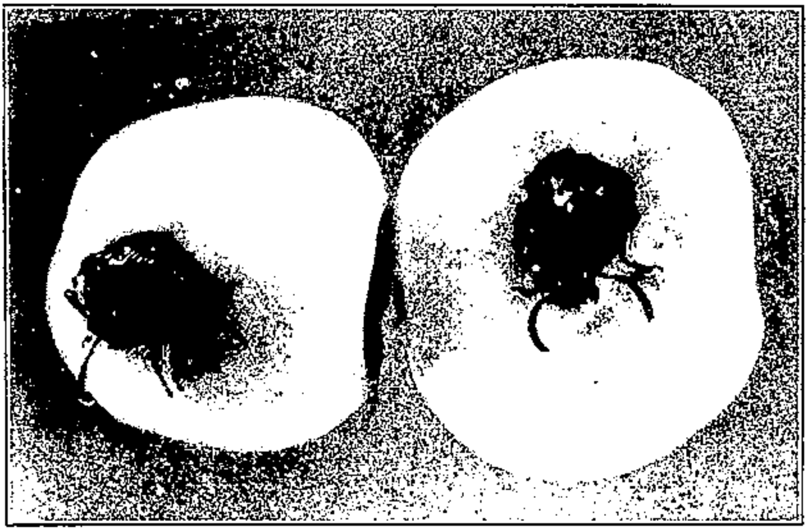

FIGURE 4.—Adult weevils emerging from peas; × 5½. (Photograph by K. W. Gray.)

LIFE HISTORY AND HABITS

HIBERNATION OF THE ADULTS

The pea weevil emerges from infested seeds in the fall and spring. Those that emerge in the fall pass the winter in storage places, in cracks and crevices out of doors, and in rubbish about the fields (*12, 19, 21*). It has been reported that in certain localities in the Union of Soviet Socialist Republics the weevil is unable to hibernate successfully out of doors (*9*).

Table 1 shows the results obtained in the examination of debris around the border of a badly infested field near Moscow, Idaho, in April 1932. The examination was made after winter mortality had occurred and before the spring flight had started.

TABLE 1.—*Typical localities in which pea weevils were found overwintering at Moscow, Idaho, April 1932, and record of survival*

Locality	Weevils found	Weevils dead	Weevils alive
	Number	*Number*	*Percent*
2 square feet of pine duff beneath a group of small pines	23	8	65.2
1 square foot of pine duff beneath a lone tree	19	5	73.7
Do	26	12	53.8
1 square foot of surface beneath a large rose bush near the same field	14	1	92.8
Beneath a 2 by 4, 3 feet long, lying in debris at the base of brush	14	6	57.1
Beneath bark of an old rotten stump.	24	16	33.3

An examination of the cracks and crevices of 175 posts in the fence bordering this field revealed an average of 39 hibernating weevils per post, while a large crack in one post served as a shelter for 502 weevils. It took only 15 minutes to find 100 hibernating weevils beneath the bark of a ponderosa pine (*Pinus ponderosa* Lawson) growing near this field.

Not far distant from this field, in a large grove of ponderosa pines, 181 weevils were collected from a cage covering 4 square feet of bark on a large tree. These pines seem to furnish an ideal hibernating place for the weevil, as very little mortality occurs among the insects hibernating in the shelter of its loose bark.

Brindley (*4*) has reported the collection of eight weevils in a cage covering 12 square feet of the surface of a pea field in the locality of Moscow, Idaho. These data are interesting because the weevils were collected in the spring after they had been exposed to all the rigors of winter. As the cage was set at random, a like number probably overwintered in the trash and debris covering many other similar areas on the field. Winter survival on the surface of harvested uncultivated fields may account for the large weevil populations that appear each year in some of the localities of this territory.

No evidence is available, however, of hibernation on the pea fields of western Oregon. If the temperatures are high enough for the weevil to become active it leaves excessively moist situations, and in this region it is forced by the early fall rains to seek better protection in the shelter of the loose bark of numerous species of trees growing near the majority of the pea fields, in the lichens on the oak trees, in the cracks of fence posts, and in other situations above the level of the field surface (*12*). Collections made in 1932, 1933, and 1934 in the Willamette Valley indicated that, for each of these years, approximately one-third of the weevils that had sought hibernation quarters in the cracks of fence posts were dead in the spring. This mortality was due in part to the attack of the fungus *Botrytis bassiana* (Bals.) Vuill.

Weevil-infested peas stored in poorly made or damaged sacks, waste peas in stored pea hay, and pea screenings destined to be fed to livestock also serve as important hibernating media unless such peas are utilized, destroyed or fumigated before the weevils emerge in the spring.

Low temperatures have been shown to be one of the most important factors affecting the survival of weevils in hibernation. In small hibernation cages distributed throughout Oregon and Idaho and placed in situations where they were protected from rain and snow, but otherwise exposed to outside temperatures and humidities, all the weevils were killed where exposed to temperatures of −19° F., but where the lowest temperature recorded was −16° a small percentage of the weevils remained alive in the spring. Weevils in cages that were protected by snow or grass survived in localities where air temperatures as low as −23° were recorded.

SURVIVAL OF ADULTS THROUGH TWO WINTERS IN STORED PEAS

Zavitz and Lochhead (*21*) relate that a few live weevils were found in peas that had been fumigated in Ontario and shipped to England, after they had been left undisturbed for almost 2 years. Skaife (*16*) indicated that the adult weevils may live into the second winter.

This has been found to be true during the course of the present investigations, for not only were living weevils found in peas stored in a warehouse during the winters of 1931–32 and 1932–33, but some were found alive during the following spring and summer. At Moscow, 16 percent of the weevils were alive in samples of threshed peas examined on March 25 of the second winter. On April 28 the percentage of survival was unchanged; on May 27 the survival was 11; on June 10, 6; on July 7, 2 percent; and late in July of the second summer all were dead. One of the weevils, after surviving two winters in the storehouse, lived all summer and laid 467 eggs. At Corvallis, Oreg., 4 living adults and 400 dead adults were found in examining weevily peas on May 23, 1933, after they had passed the two previous winters in a warehouse. A pair of these 2-year-old weevils taken from the peas on April 30 mated in the laboratory, and the female laid 28 viable eggs. Living weevils that apparently had never left their hibernating places under the loose bark of pine trees (*19*) have also been found throughout the summer. It seems possible that some of the weevils hibernating out of doors may be able to survive until the next crop season.

FIGURE 5.—A pea weevil in a typical position on a pea blossom.

EMERGENCE FROM HIBERNATION

The weevils emerge from hibernation in large numbers during the first warm days of spring when the air temperatures exceed approximately 70° F. The emergence usually coincides with the blooming of volunteer peas in Idaho and the blossoming of the earliest varieties of garden peas in western Oregon. Seven weevils, in one case, were collected on June 5, 1932, in 100 sweeps of a 15-inch collecting net on volunteer peas which were in bloom. Five days later, 1,015 weevils were collected in a like number of sweeps from the same patch. Weather conditions were quite similar on both days. Some weevils locate the crop before blooming starts, but when blossoming begins large numbers of weevils soon find the peas, almost completely ignoring peas which are not in bloom for those which are. In one case 1,415 weevils were collected in 100 sweeps of a collecting net on flowering peas, while only 8 individuals were collected in a like number of sweeps on less mature vines immediately adjoining. The weevils are apparently attracted to the peas by some odor from the blooms rather than by the color, for white blossoms attract them in as large numbers as the colored blossoms. Figure 5 shows a pea weevil in a typical position on a pea blossom.

FLIGHT

Judging from available evidence it is apparent that weevils may fly several miles to and from hibernation. Korab (*9*) liberated marked pea weevils in the spring and later found them on peas more than 2 miles away. Wakeland (*18*) reports finding living weevils under the bark of trees as far as 3 miles from pea fields. The adults are very active and alert. The slightest disturbance will cause them to feign death or to take flight; consequently, the casual observer seldom sees the pea weevil adult in the field. When warm weather induces it to emerge in large numbers from stored, infested peas, however, or when heavily infested peas are harvested late in the season, the insect may become a source of annoyance to those in the vicinity of the infested material (*1*).

DISPERSAL IN THE FIELD

The dispersal of the weevil within the field has been discussed in an earlier paper (*11*). The number of pea weevils may vary considerably in the different parts of the field. The border, as a general rule, is always more heavily infested than the interior of the field; as many as 28 times as many weevils have been collected with an insect net at the the edge of a field as were collected near the center in the same number of sweeps. The edge nearest the principal hibernating quarters usually has the greatest infestation, more than 10 times as many weevils having been collected along the side of a field adjoining a forested area as were collected along the opposite side. Weevils prefer the low places to the high places in the field. In one instance twice as many weevils were found on the peas in the valleys as were found on the ridges of a large field.

FEEDING HABITS OF ADULTS

The adults feed on the pollen of blossoming peas. If the infestation is severe they may feed on the calyxes, make holes near the base of

FIGURE 6.—Pods injured by the feeding of adult pea weevils.

the receptacles to obtain nectar, or injure the developing pod by eating small holes in its surface. Figure 6 shows a view of the injury that results when adult weevils feed on the pods. In the majority of cases, however, they merely make their way into the interior of the flower to feed on the pollen. Frequently two or more weevils may enter the same blossom. Adults that cannot find pea pollen will feed on that of other available plants. They have been observed to feed on the pollen of yarrow, dogfennel, wild rose, many other flowers, and several undetermined species of grasses. Pollen seems necessary for the development of the eggs.

OVIPOSITION

After feeding on the pollen of the pea blossoms for several days the weevils mate and soon begin to lay eggs. Mating continues throughout the period of oviposition. Pairs in cages have been observed to mate several times. The eggs are laid on pods of all sizes from those just beginning to form to those just beginning to ripen. Occasionally they are laid on the petals, stamens, calyx, receptacle of the blossom, or other parts of the pea plant.

Experiments were conducted at intervals during the summer of 1933 to determine the length of the preoviposition period. It was necessary for the insects to feed on pea blossoms before they would mate and lay eggs. In each of the experiments a total of 25 to 50 pea weevils, taken directly from the pea seeds to insure that previous feeding had not occurred, were placed on a bouquet of blooms in a quart fruit jar. Pods were placed in the jars and examined daily to determine when the first eggs were laid. The maximum duration of time after the weevils start to feed until the first eggs are laid, as shown by a series of 16 tests conducted at intervals from June 6 to August 11, 1933, was 14 days early in June, and the minimum was 4 days in the case of two groups of weevils placed on blooms in July.

Much variation exists in the published literature concerning the number of eggs laid by each pea weevil. Skaife (*17*) reported an average of 24 eggs, but commented on the fact that this figure seemed very low. Korab (*9*) found them to lay as many as 222 eggs with an average of 126 and stated that the egg-laying period was not long and could be wholly included in a period of 15 days. The data obtained by the authors are in direct contrast to these figures.

In a study conducted at Moscow during 1932 on 12 caged females, a maximum of 735 eggs, a minimum of 92 eggs, and an average of 432 eggs were recorded. The maximum oviposition period was 83 days, the minimum was 17, and the average was 47. This study was terminated at the end of 84 days because cold weather had ended the activity of the weevils. A summary of the results obtained at Moscow during 1933 with 40 pairs of weevils showed a maximum of 467 eggs, deposited over a period of 41 days. The minimum recorded in 1933 was 38 eggs, laid over a period of 24 days. One female of the 1933 series laid 235 eggs in 90 days, while another laid 300 eggs in 25 days, or an average of 12 eggs per day.

A summary of the data obtained in a study of the oviposition of 41 caged pairs of weevils at Corvallis in 1933 showed that a maximum of

14587°—38——2

749 eggs was recorded from one female during a period of 113 days. In these cage experiments 43 percent of the eggs laid were sterile. The largest number of fertile eggs laid by one female was 325.

The weevils used in the oviposition studies at Moscow were taken directly from pea seeds and placed in jars on pea blossoms. Here they were allowed to feed and mate until the first eggs were laid on pea pods placed in the jars. Female weevils were then segregated in individual test tubes previously provided with a pea blossom and a pea pod. At Corvallis the weevils were taken from seeds, and a male and female were placed in each test tube without previous feeding. The results at both stations were obtained by daily observations. Each day the eggs were counted and a fresh pod and a fresh bloom were added. The cages were kept at room temperature in a field insectary. Owing to the presence of the pod and blossom, the relative humidity was very high, as evidenced by condensation of water on the inner surface of the tubes.

FIELD STUDY OF OVIPOSITION

The seasonal occurrence and duration of the egg-laying period are of importance in the application of control measures for the pea weevil, because it is during this period that the actual damage to the pea crop begins. A study was therefore carried on at Moscow during 1933 and 1934 which was designed to determine (1) the duration of the period the weevils would continue to lay eggs under field conditions if a continuous supply of vines were available, (2) the duration of the period an individual planting of peas would be susceptible to weevil damage, and (3) the duration of the period an individual pod would be acceptable to the weevils for egg laying. The major part of this information was obtained by planting peas at intervals throughout the spring and early summer and then each day recording all the eggs laid on 25 vines from each planting. The counts were made daily from the same vines, which had been selected at random before oviposition started.

In 1933 plantings were started on April 6 and repeated at weekly intervals for 11 consecutive weeks until hot weather halted the growth of peas. The plantings during 1934 were started on February 19 and repeated at irregular intervals until May 29. The results for 1934 are shown graphically in figure 7.

The results of these experiments reveal many interesting facts regarding the oviposition habits of the insect. Weevils capable of laying fertile eggs were present in the field each year, from the time the earliest seedings started to produce pods until hot weather prevented further pod development. The peak of egg deposition in 1933 occurred on the sixth planting, seeded on May 11, and in 1934 on the second planting, seeded on March 14. The development of a very early spring during the latter year probably accounted for this difference. In 1934, at Moscow, the earliest planted peas were acceptable for the deposition of eggs during a total period of 32 days, while the last planting, seeded on May 29, was acceptable for oviposition for only 12 days. Practically the same results had been obtained during 1933, since the maximum time during which eggs were laid on any one planting was 30 days and the minimum was 8 days. A similar study during 1932 on the pods of Early Washington peas had demonstrated that they were acceptable for egg laying during a period ranging from 6 to 16 days.

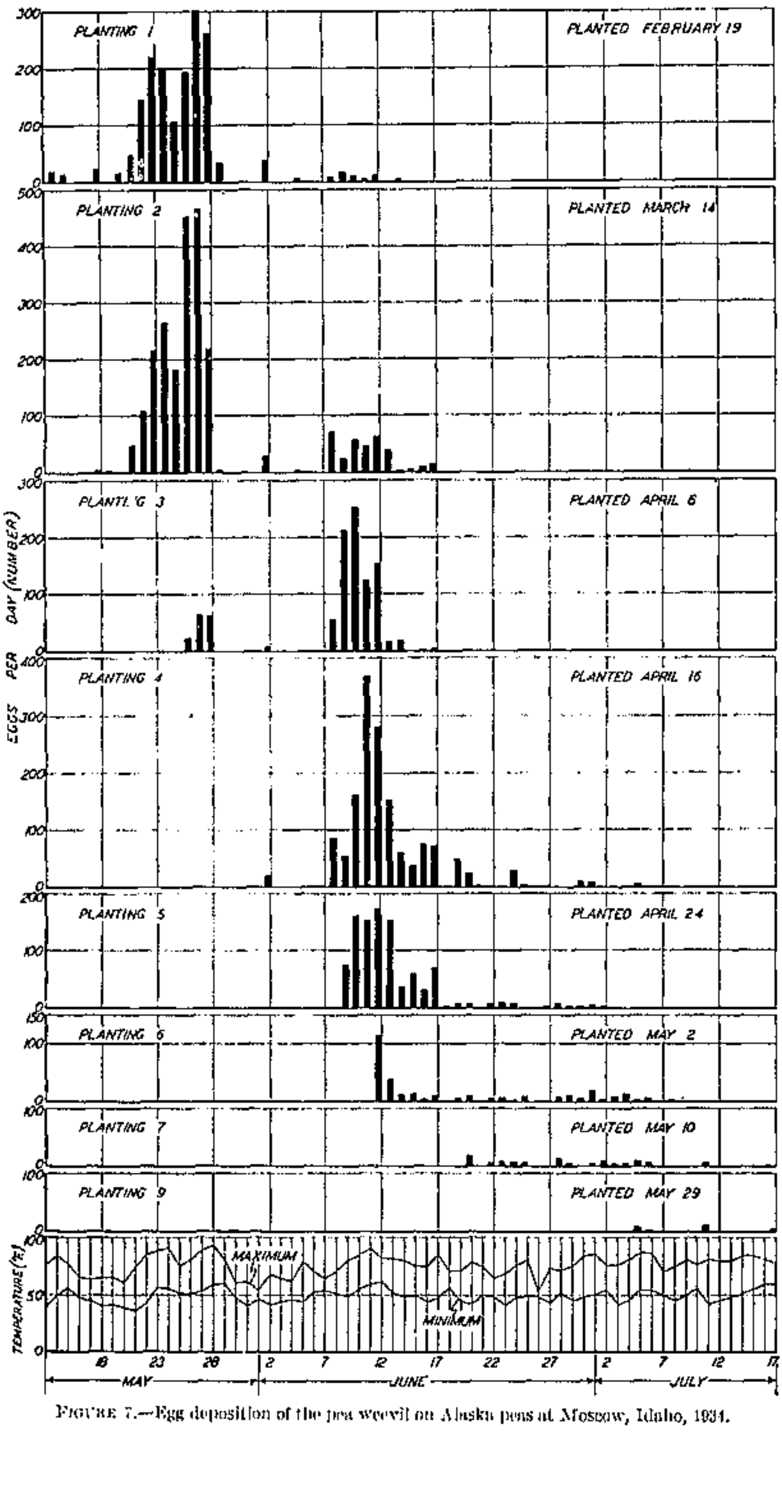

FIGURE 7.—Egg deposition of the pea weevil on Alaska peas at Moscow, Idaho, 1934.

Figure 7 shows graphically the influence of air temperatures on egg deposition. Eggs were laid in greatest number when the maximum temperature exceeded 80° F., very few eggs were laid when the maximum fell below 70°, and no eggs were laid at temperatures below 65°. This is in agreement with field observations made at Corvallis. Considerable time was spent in observing the oviposition of the females in the field. By suspending a thermometer in such a manner that the bulb was situated only a short distance from the ovipositing female and at the same height from the ground, it was determined that, under field conditions, oviposition was greatly accelerated at temperatures above 70° and ceased at temperatures below 66°. Oviposition may occur at any time during the daylight hours when the temperature exceeds this limit. At Corvallis this is generally from about 9 a. m. until 5 p. m.

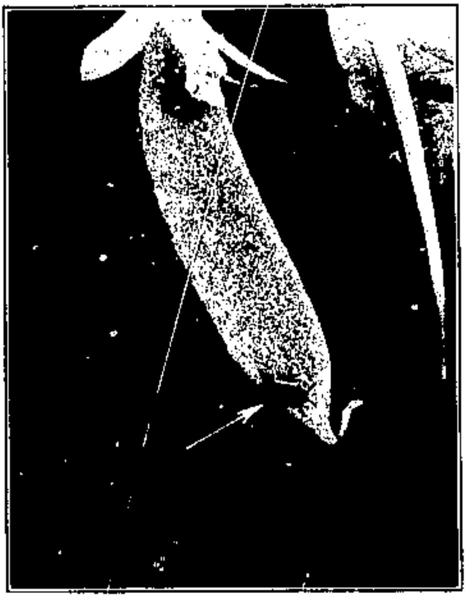

FIGURE 8.—Pea weevil ovipositing.

Observations and measurements revealed that the pods most favored for egg deposition are those that have nearly reached their maximum size, but which are still in the process of growth. The number of eggs laid on each pod depends principally upon the number of pods available to each weevil for oviposition. One pod about 2 inches in length, picked from a very badly infested field near Moscow, Idaho, bore 116 eggs on its surface. The duration of the period the individual pods under observation were acceptable for oviposition ranged from 6 to 18 days.

No particular part of the pod seems to be preferred for egg laying. Figure 8 illustrates the appearance of an ovipositing weevil, and figure 9 the typical appearance of eggs laid on the pods and calyxes of Austrian Winter field peas.

Observations in western Oregon have demonstrated that the weevils may oviposit on the earliest garden peas and on the late fall peas if the temperatures are high enough. Eggs were found in that section as late as August 28 in 1933 and as early as April 10 in 1934. Eggs that were found on peas at Coquille, Oreg., on August 21, 1932, did not hatch until 5 days later when kept at room temperature. On September 19, 1933, weevil eggs were found on late peas grown at Cannon Beach Junction, Oreg.

At Corvallis, the number of eggs per pod laid on the field peas increased until the peak of the blossoming period was reached and then decreased rapidly in direct proportion to the availability of blossoms and suitable pods for egg deposition.

FIGURE 9.— Eggs of the pea weevil laid on pods and calyxes.

INCUBATION PERIOD

The incubation period of the eggs of the pea weevil depends greatly on the temperature. Skaife (*17*), in South Africa, reports a range of from 16 to 18 days in summer and from 21 to 40 days in winter, and Korab (*9*), in the Union of Soviet Socialist Republics, found the period of incubation to range from 6 to 10 days. Wakeland (*18*) stated that the maximum duration of the incubation period of the eggs at Moscow, Idaho, was 17 days in 1930 and 14 days in 1931, with a minimum incubation period of 4 and 7 days, respectively.

In the specimens under observation at Moscow in 1932 and 1933 this stage ranged from 5 to 14 days, with an average of approximately 9 days. These studies were made under field conditions during June and July. The temperature, as recorded by the United States Weather Bureau, for June averaged 62.6° F. in 1932 and 60.6° in 1933, and for July averaged 64.8° in 1932 and 67.9° in 1933. The results of this study are incorporated in tables 2 and 3. The range in duration of the incubation period at Corvallis, however, was much greater than at Moscow. At Corvallis the time required for the eggs to hatch ranged from a maximum of 23 days in May to a minimum of 6 days in June. The temperature during the incubation period averaged 56° in the first instance, and from 61.5° to 68° in the case of those hatching in 6 days. The average incubation period for 2,451 eggs on Austrian Winter field peas in 1932 was 10.4 days, and for 659 eggs on early garden peas in 1933 was 10.3 days.

TABLE 2.—*Summary of life-history data on the pea weevil, Moscow, Idaho, 1932*

Stage	Length of the stage					First and last observation	
	Maximum	Minimum	Average	Standard deviation	Mode	First	Last
ON ALASKA PEAS, 76 INDIVIDUALS REARED							
	Days	*Days*	*Days*	*Days*	*Days*		
Egg	14	7	10.3	1.62	10	June 7	June 21
Larva	60	38	42.7	3.18	43	June 20	June 29
Pupa	18	8	13.5	1.59	14	July 31	Aug. 13
Developmental period	75	60	66.3	3.76	67	June 7	Do.
ON EARLY WASHINGTON PEAS, 72 INDIVIDUALS REARED							
Egg	13	6	8.5	1.53	8	July 7	July 24
Larva	45	33	38.3	2.84	37	July 16	July 31
Pupa	27	16	22.6	2.85	25	Aug. 24	Sept. 10
Developmental period	81	61	69.4	4.81	70	July 7	Do.
ON FIRST AND BEST PEAS, 400 INDIVIDUALS REARED							
Egg	13	6	8.7	1.46	9	June 9	June 25
Larva	56	28	41.7	3.48	41	June 21	July 2
Pupa	18	10	13.7	1.07	14	July 27	Aug. 17
Developmental period	82	50	64.1	4.01	65	June 9	Do.

To obtain the duration of the egg stage, a series of recently laid eggs were marked by making a circle about them on the surface of the pod with india ink, and examining them at intervals until they hatched. The ink remained visible throughout the season and caused no appreciable injury to the pod if care was taken in its application.

LARVAL STAGE

The newly hatched larva ordinarily enters the interior of the pod by boring through the chorion of the egg and into the pod through the under side of the egg. The small, round entrance hole can easily be seen when the eggshell has been scraped away. A few of the larvae, however, instead of boring directly into the interior of the pod, construct mines in the outer shell of the pod before entering.

TABLE 3.—*Summary of life-history data on the pea weevil reared in Alaska peas at Moscow, Idaho, 1933*

SERIES 1, 19 INDIVIDUALS

Stage	Length of the stage					First and last observation	
	Maximum	Minimum	Average	Standard deviation	Mode	First	Last
	Days	*Days*	*Days*	*Days*	*Days*		
Egg	14	5	9.6	2.16	(1)	June 16	July 6
Larva	51	31	37.3	5.98		June 26	July 14
Pupa	16	8	10.7	2.00		Aug. 4	Aug. 31
Developmental period	72	48	57.5	6.06		June 16	Do.
SERIES 2, 101 INDIVIDUALS							
Egg	11	6	8.5	1.03	9	June 27	July 16
Larva	41	25	34.8	2.83	33	July 5	July 22
Pupa	17	9	12.2	1.79	12	Aug. 11	Aug. 28
Developmental period	65	45	54.9	3.72	53	Jun* 27	Do.
SERIES 3, 111 INDIVIDUALS							
Egg	11	5	9.1	1.22	9	July 1	July 12
Larva	40	29	32.1	1.69	31	July 6	Aug. 20
Pupa	16	8	11.1	1.42	11	Aug. 7	Sept. 3
Developmental period	65	47	52.3	2.05	52	July 1	Do.

[1] The number of observations in this series was insufficient to establish a modal class.

Once inside the pod, the tiny larva soon penetrates the seed. A small, dark spot forms on the seed coat over the point where it enters the pea. Many larvae may enter the same pea, since as many as 17 "stings", as the small black scars are termed, have been counted on a single pea. Figure 10 shows a typical illustration of these scars on green peas of market size and figure 11 shows the stings on an enlarged scale. The relation of the incubation period to the development of the seed is interesting, for even though the egg is laid when the pod is very small, by the time the egg hatches the pea has attained a size sufficient to provide suitable nutrients for the weevil larva. After gaining entrance to the pea the larva usually feeds near the seed coat for a short time and then works its way toward the center of the pea as shown in figure 12. A large portion of the contents of the pea is consumed by the larva during its period of growth. Figure 13 shows, at approximately weekly intervals, the injury resulting from the feeding of the larva. The mature larva usually cuts a small, round hole leading to the exterior of the pea approximately 2 days before it pupates, in order to facilitate the emergence of the adult.

When two weevil larvae enter the same pea they frequently develop until they become so large that their feeding tunnels meet. The details of the reactions of these companion larvae are not known definitely, but it is probable that one eats into the other and kills it. Sometimes both of the larvae die. This probably occurs when a larva eats into the tunnel of a larger one or one of the same size and, after killing it in an attempt to feed, starves because it is unable to reach the side of the tunnel with its jaws. In other instances two larvae complete their development within the same pea, but only one living adult emerges. Repeated observations in such instances have revealed that one larva develops faster than the other, pupates, and transforms to the adult stage, but becomes the victim of its more slowly developing rival, which then develops to maturity. In one instance two living adult weevils were found by the authors within the same pea, a unique occurrence which has not been reported in the literature previously.

The durations of the larval and pupal stages were determined by continuing the observations on the newly hatched larvae that developed in the incubation experiments on the eggs and entered the pods at that time. The pods containing these weevil-infested seeds were left on the vine until they had ripened. Then each marked pod was removed and shelled into a compartment of a development tray. They were kept in a field insectary building and examined daily until the adult emergence aperature, or "emergence window", became visible. When this appeared, the end of the larval stage was known to be near, so the thin membrane of the seed coat was opened to determine the exact day of pupation. The larva was usually in the prepupal stage when the pea was opened and seemed to be unaffected by the abnormal situation.

FIGURE 10.—Green peas showing entrance stings of pea weevil larvae.

As shown in tables 2 and 3, the average duration of the larval stage in the different series at Moscow ranged from 32.1 to 42.7 days, the maximum period of the larval stage in any series being 56 days and the minimum 25 days. At Corvallis, from 94 records of the larval development in Blue Bantam garden peas during June and July 1933, the time from hatching to the pupal stage averaged between 37 and 38 days, while the maximum period of the larval stage was 48 days and the minimum was 27 days.

At times, however, the larval stage may be greatly prolonged. Seven small living larvae were found in peas that had been shelled for periods ranging from at least 116 days to at least 131 days. During this time the peas in which they were found had remained in the field exposed to the warm sun for periods ranging from 1 to 4 days and had later been kept in a heated building. Two live larvae were found in fumigated peas which had been taken from the warehouse

84 and 91 days previous to being opened. It is extremely doubtful whether any of these long-lived larvae would have developed to adults.

The study of this insect, developing as it does within the pea,

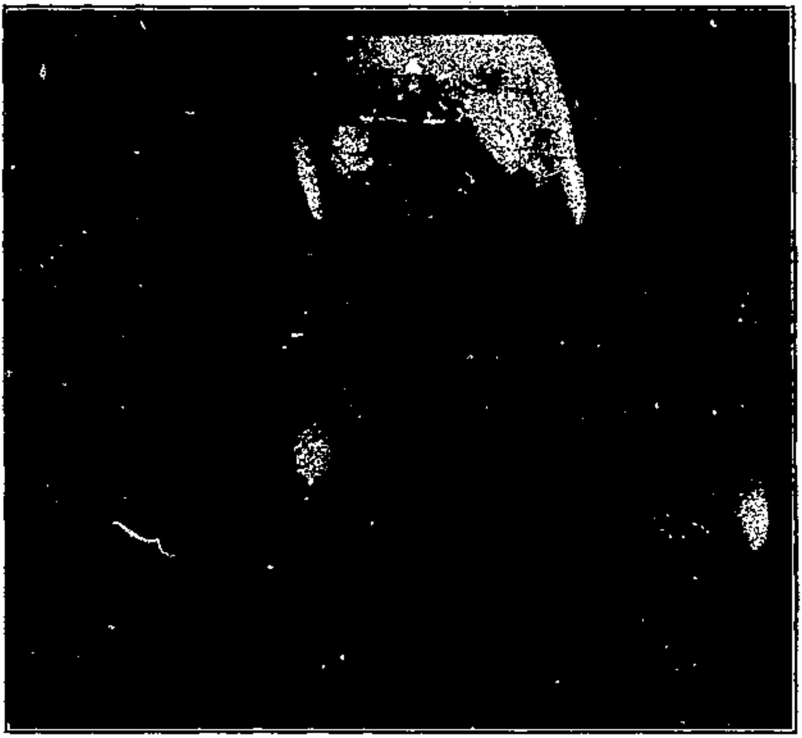

FIGURE 11.—Scars over larval entrance holes; × 4½. (Photograph by N. F. Howard.)

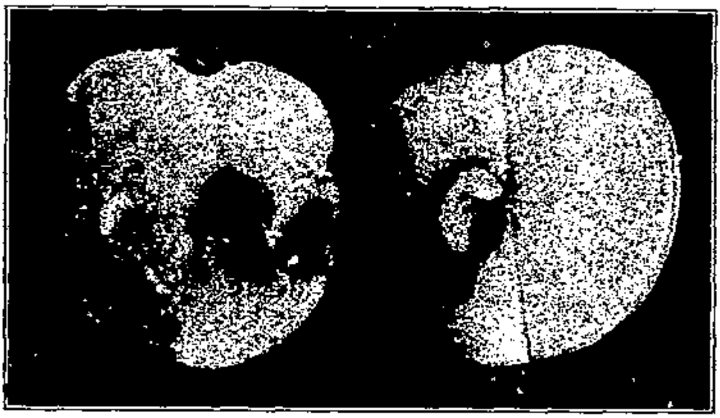

FIGURE 12.—Larva feeding in green pea; × 4½. (Photograph by N. F. Howard.)

presents difficulties that make it impossible to conduct a series of measurements on an individual larva during its period of growth to determine the number of molts. Brindley (*4*) has obtained this

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information, however, by splitting peas at 2-day intervals and measuring the head capsules of the larvae collected from the split peas. He found that the measurements grouped themselves logically into

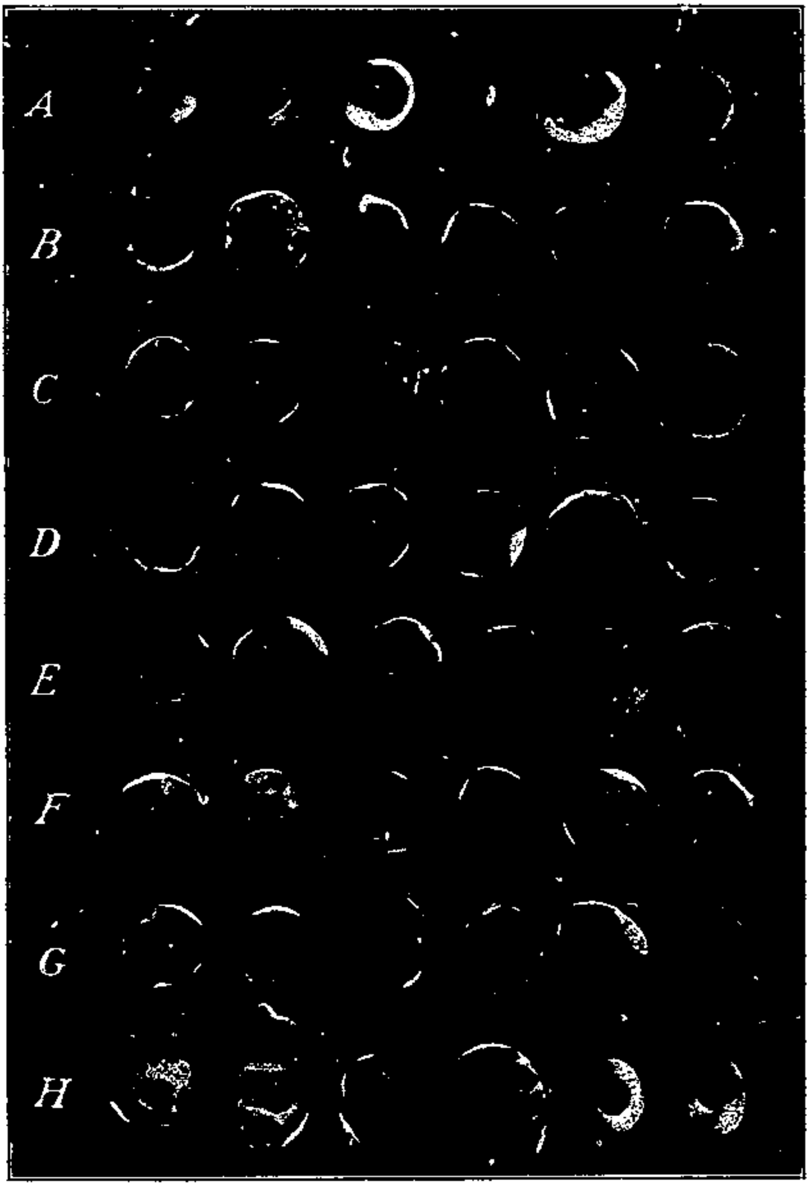

FIGURE 13.—Peas split open to illustrate the progressive injury by the pea weevil. Condition on: *A*, July 22; *B*, July 28; *C*, August 3; *D*, August 11; *E*, August 17; *F*, August 26; *G*, August 31; *H*, September 8, 1933.

four classes, denoting three molts and four instars in the larval development. The average widths of the head capsules for the instars as obtained by this method were: First instar, 0.14 mm; second instar, 0.35 mm; third instar, 0.64 mm; and fourth instar, 0.91 mm. A study of these data showed that during the crop season of 1932 at Moscow the insect spent approximately 12 days in the first instar, 6 to 8 in the second, 12 to 14 in the third, and 10 to 12 days in the fourth instar.

Korab (*9*) lists five larval stages of the pea weevil, the fifth evidently constituting the prepupal stage. He apparently determined the number of stages by measuring the length and width of the insect at short intervals. He found that the entire larval stage lasted approximately 40 days. Skaife (*17*) reported the duration of the larval stage in South Africa to be from 70 to 90 days.

PUPAL STAGE

The larva pupates within the pea with its head toward the emergence hole. At Moscow the average duration of the pupal stage in 1932 was 15 days, the maximum 27, and the minimum 8 (table 2); in 1933 the average duration of the pupal stage was 11.5 days, the maximum 17, and the minimum 8 (table 3) in observations made throughout the crop season. At Corvallis in 1933, out of 88 larvae reared in early garden peas the average duration of this stage was 10 days, the maximum 12, and the minimum 8.

Korab (*9*) found that in the Union of Soviet Socialist Republics the weevil spent about 26 days in the pupal stage. Skaife (*17*) found the pupal period to range between 18 and 24 days.

THE DEVELOPMENTAL PERIOD

One hundred and forty-nine records of the development of the weevil from eggs laid from May 28 to June 15, 1933, on early garden peas (Blue Bantam) at Corvallis, show an average time of development from egg to adult of 57 days, a minimum of 46, and a maximum of 71.

Table 2 presents a summary of the length of the immature stages of 548 individuals reared at Moscow, during the crop season of 1932, and table 3 presents a summary of these data from 231 complete records obtained during the summer of 1933. A study of table 2 shows that the development from egg to adult was completed in an average of about 66 days. The individual developing most slowly required 82 days, and the individual representing the most rapid development became an adult 50 days after the egg was laid. These data differ considerably from the records obtained by the same technique in 1933. During this season the average length of this developmental period for the 231 individuals reared was 55 days, 11 days less than in the previous year. The maximum developmental time was [redacted] 72 days and the minimum was 45. The difference was undoubtedly due to the weather conditions of 1933, which favored the development of both the pea plant and the pea weevil.

These detailed studies were paralleled by field examinations. Every 2 days throughout the development of the weevil in 1932, 1933, and 1934, a total of 250 weevily peas from two different plantings of peas were split open. Figures 14, 15, and 16, presenting a summary of the results of these observations, illustrate the influence of temperature and rainfall on the development of the pea weevil. It will be noted that the weevils start emerging from the peas shortly after the adult stage is reached, but that emergence is stimulated greatly by rainfall, probably owing to the fact that the rain supplies moisture to facilitate the escape of the weevils from the tightly closed pods and peas. Records obtained by splitting peas were discontinued when cold weather

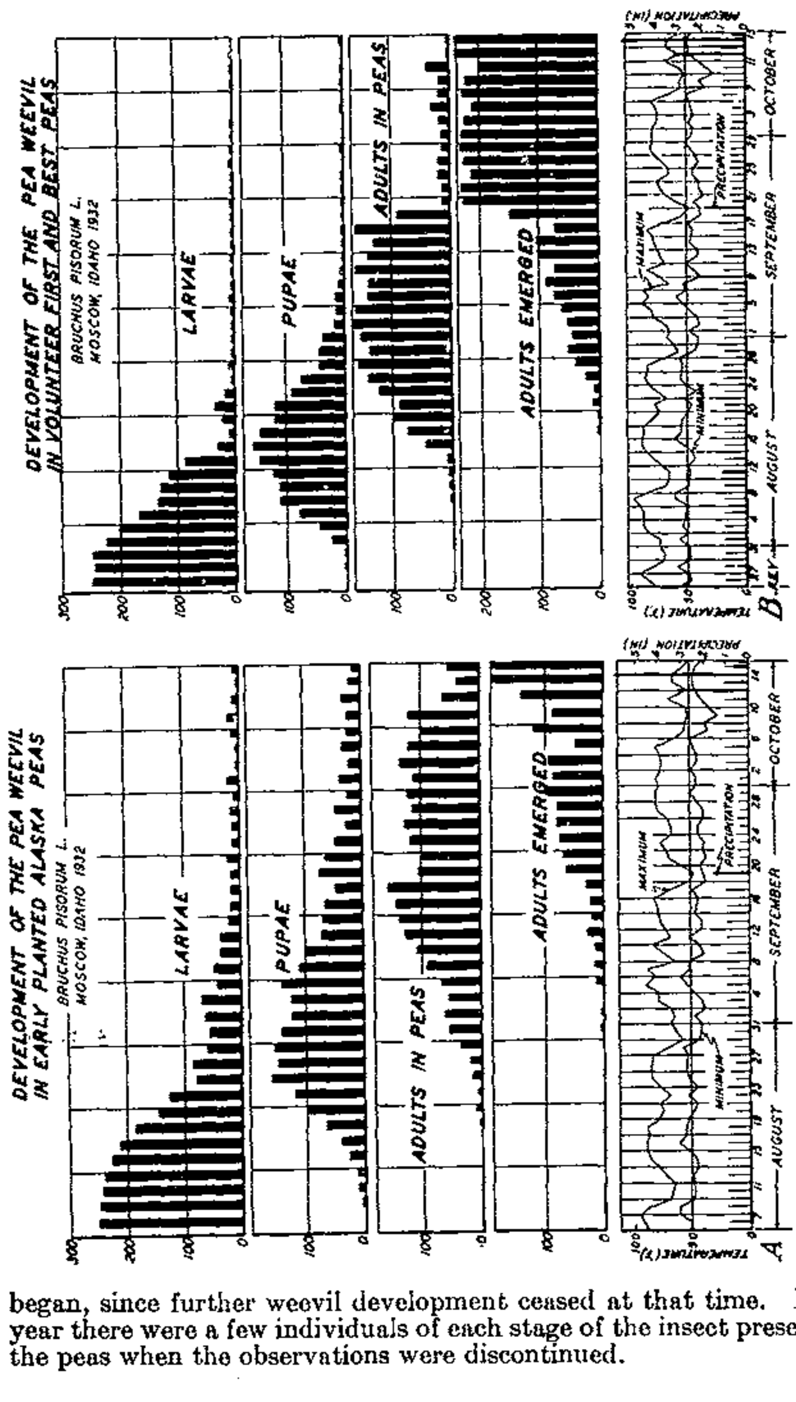

FIGURE 14.—Seasonal development of the pea weevil at Moscow, Idaho, in 1932 in relation to temperature and precipitation: *A*, In early-planted Alaska peas; *B*, in volunteer First and Best peas.

began, since further weevil development ceased at that time. Each year there were a few individuals of each stage of the insect present in the peas when the observations were discontinued.

Korab (*9*) found that the pea weevil developed from egg to adult in a period ranging from 67 to 68 days. According to Skaife's data (*17*) this period would range from 104 to 154 days in South Africa.

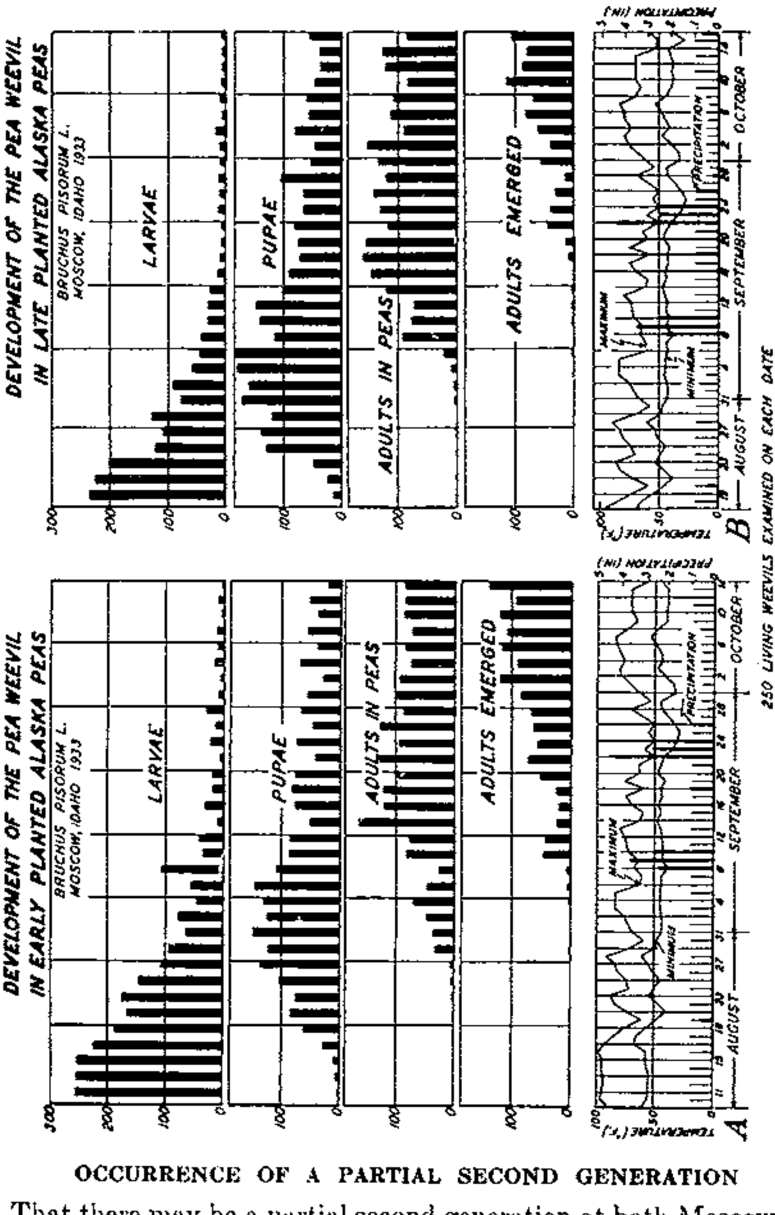

FIGURE 15.—Seasonal development of the pea weevil at Moscow, Idaho, in 1933 in relation to temperature and precipitation: *A*, In early-planted Alaska peas; *B*, in late-planted Alaska peas.

OCCURRENCE OF A PARTIAL SECOND GENERATION

That there may be a partial second generation at both Moscow and Corvallis, in some seasons at least, has been indicated by several observations. Newly deposited weevil eggs have been found on peas as late as September—long after the earlier peas had been harvested. In 1933 the pods that were gathered daily from late-planted peas did not reveal the presence of eggs during a period of several weeks in August, but late in that month eggs were found on the pods. During the same year three pairs of weevils that had developed during the summer were placed in breeding cages. The females of two pairs

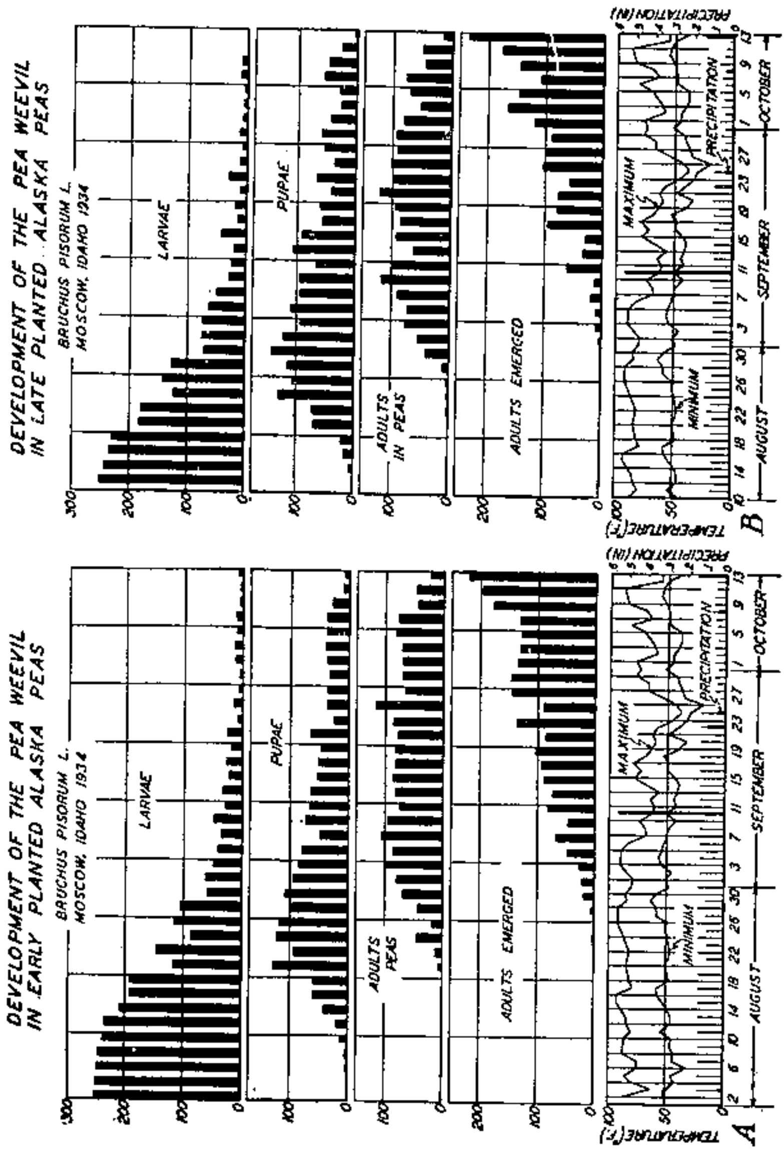

FIGURE 16.—Seasonal development of the pea weevil at Moscow, Idaho, in 1934 in relation to temperature and precipitation: *A*, In early planted Alaska peas; *B*, in late-planted Alaska peas.

each laid more than 100 eggs, but none was fertile. The female of the third pair laid 76 eggs, of which 7 were fertile.

These results are in agreement with those of Skaife (*16*), who found that in South Africa a few eggs were laid late in the summer and that most of them were infertile, but he reared adults from some of them.

He states: "It seems as though the habit of hibernating, inherited from their northern progenitors, is growing weaker in this country, with the result that there is a partial second generation."

EFFECT OF THE PEA WEAVEL ON THE PEA SEED

EFFECT ON GERMINATION

Weevil-infested peas, in addition to being undesirable for human food, are also unfit for agricultural purposes. Some controversy exists in the literature and among pea growers with reference to the influence of pea weevils on the germination of seed peas.

Coincident with the obtaining of records upon the duration of the larval and pupal stages of the pea weevil, in 1933 and 1934, samples of

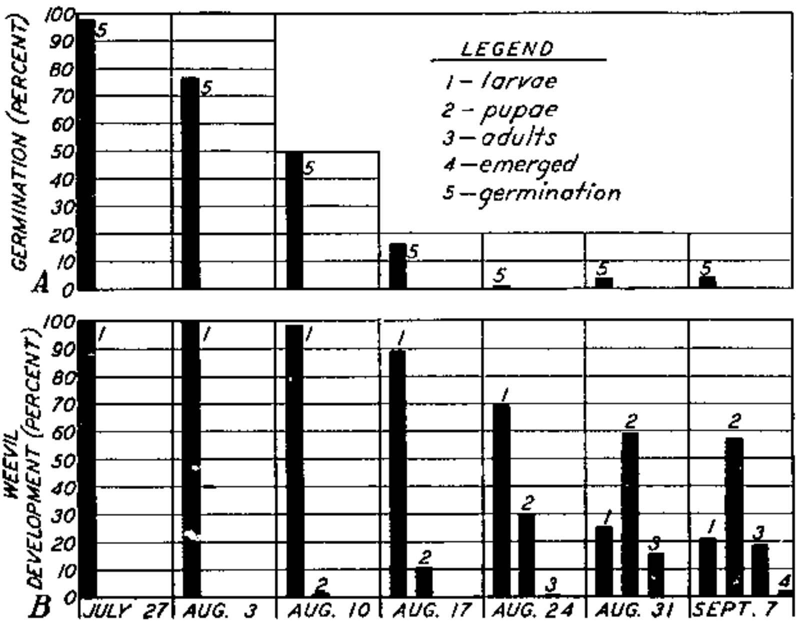

FIGURE 17.—Influence of the development of the pea weevil (*B*) on the germination of weevil-infested peas (*A*) during 1933 at Moscow, Idaho.

peas containing larvae and pupae in all stages of development were fumigated at weekly intervals from the time the peas began to ripen until the adult weevils had begun to emerge. The germination tests of these samples revealed, as illustrated in figures 17 and 18, that the percentage of germination of weevil-infested seed peas depends upon the extent to which the pea weevil has developed when the peas are fumigated. It will be noted that 98 percent of the weevily peas picked on July 27, 1933, germinated, whereas the percentage of germination of later pickings decreased rapidly. The germination of Alaska peas was not greatly affected until after the weevil had completed the third instar.

A comparison of figures 17 and 18 shows that the percentage of infested peas germinating varies from year to year. This is due to the fact that during some years the developing larvae attain a greater

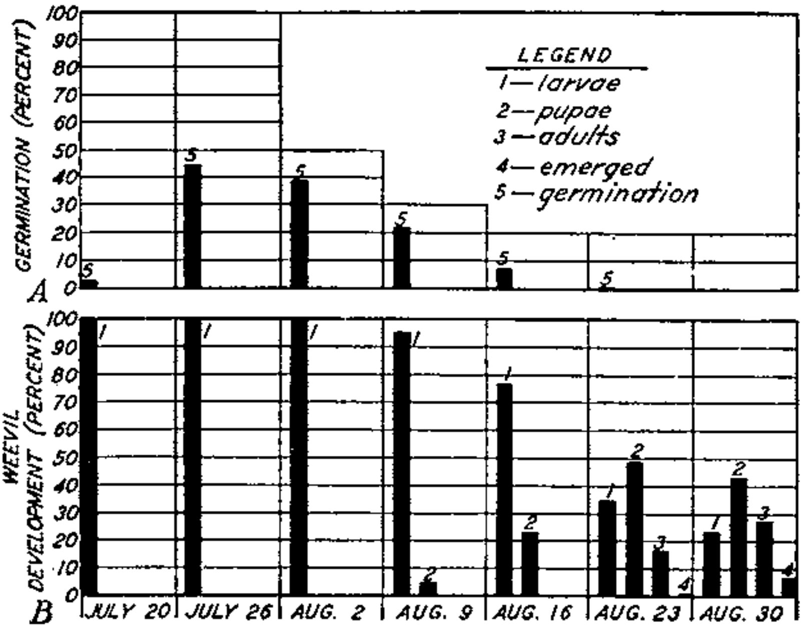

FIGURE 18.—Influence of the development of the pea weevil (*B*) on the germination of weevil-infested peas (*A*) during 1934 at Moscow, Idaho.

size in the peas before they are ripe enough to harvest. Also, it is shown in the first column of figure 18 that the viability of the seed is lowered greatly when peas are picked and fumigated with carbon disulphide before they have completely ripened.

EFFECT ON WEIGHT

Pea growers are well aware of the fact that peas containing weevils weigh less than sound peas. Korab (*9*) found that the loss in weight of eight different varieties of weevil-infested peas ranged from 9.6 to 30.3 percent.

During the summer of 1933, as soon as the pods on the vines had ripened sufficiently to permit threshing, weighings were made, at 2-day intervals, of a sample of weevilly peas and a sample of sound peas picked from the same field. It was found, as shown in figure 19, that the original weight of the infested peas decreased 22.2 percent as compared to a decrease of 1.1 percent in the sound peas.

FACTORS AFFECTING THE ABUNDANCE OF THE WEEVIL

Several sources of pea weevil infestation which operate to maintain very high populations of adult weevils have been observed during the course of this study. The elimination of these sources presents many serious difficulties, but their solution would aid greatly in the control of the pea weevil. The principal sources of infestation are (1) the peas shattered in the field during or prior to harvest, (2) volunteer peas, (3) pea hay containing weevil-infested peas, and (4) the planting of weevil-infested seed.

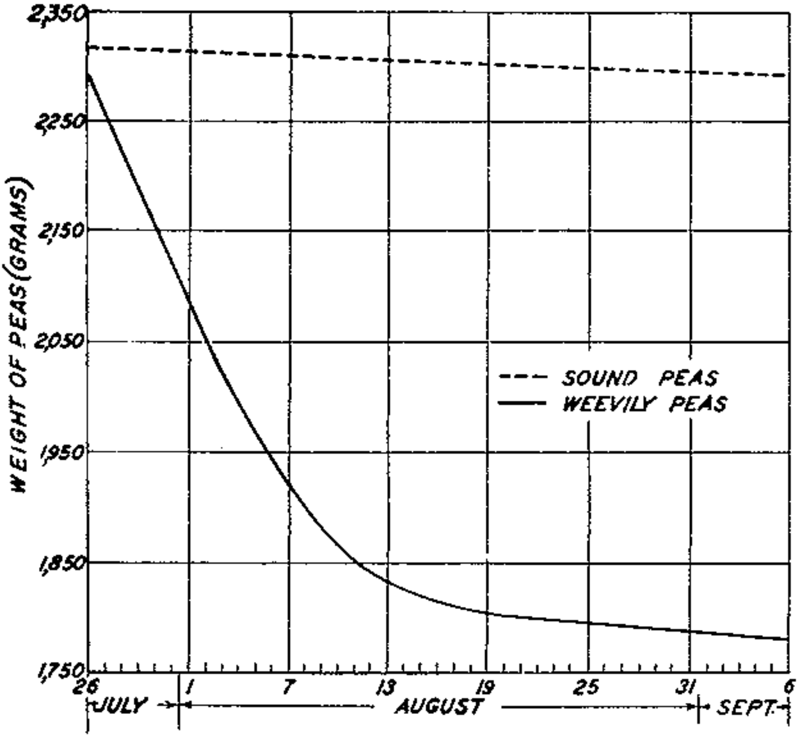

FIGURE 19.—Loss in weight of Alaska peas due to infestation by the pea weevil.

FIELD SHATTER

Field shatter, or the shelling out of ripe peas on the ground, is due primarily to faulty harvesting methods and to climatic factors. It constitutes an important source of pea weevil infestation in all pea-growing sections of the Pacific Northwest. Larson *(10)* has reported the serious results of careless harvesting of peas in the Willamette Valley of Oregon, and states that the burning of the debris on the field, when performed properly, will kill nearly 100 percent of the weevils in the shattered peas. Korab *(9)* found that weevil emergence from field-shattered peas in the Union of Soviet Socialist Republics was of little import, since the weevils were unable to survive the winters out of doors in the pea-growing sections of that country.

At Corvallis, Oreg. *(10)*, the estimated number of Austrian winter peas left on the field after harvest, as determined by collecting all of the seeds shattered on areas covering 100 square feet of field surface, ranged from 500,000 to more than 3,000,000 per acre, and the number of pea weevils ranged from 1,500 to more than 1,000,000 per acre. It was estimated that approximately 47,000,000 weevils emerged from peas shattered on one 40-acre field.

At Moscow, Idaho, the percentage of loss in yield from field shatter was studied by picking up all of the peas found on a total of six 10-foot-square plots in each field under observation. All the peas gathered from each plot were weighed, counted, and examined to determine the percentage of weevil infestation. In these fields the maximum loss per acre was found to be 50 percent of the total number of peas that the vines had produced on a field harvested with a combine machine, in which the peas actually harvested averaged 690 pounds per acre. The minimum loss per acre, which also occurred on a combine-harvested field, was 7 percent on a field from which 1,428 pounds of peas were harvested per acre.

Several different methods of harvesting peas are in general use in Idaho and Washington and several fields harvested by each method were sampled to determine whether any one of the harvesting methods was superior. A summary of this study carried on during the falls of 1931 and 1932 is presented in table 4. These data show that the combine method of harvesting field peas is superior to the other methods used. A portion of the heavy field shatter is due to wind, hail, and rain. Much of it is due, however, to careless harvesting methods, as revealed by a comparison of the harvest loss suffered by the same group of farmers during the 2-year period represented in table 5.

TABLE 4.—*Summary of loss of peas by different harvesting methods, Moscow, Idaho, 1931–32*

Harvesting method	1931			1932		
	Fields examined	Plots examined	Loss	Fields examined	Plots examined	Loss
	Number	*Number*	*Percent*	*Number*	*Number*	*Percent*
Combine-harvested	11	82	29	12	72	12
Mowed and threshed	6	32	31	5	30	17
Mowed, raked into windrows, and combine-harvested	2	10	34	2	12	15

TABLE 5.—*Comparison of harvest loss and weevil infestation in individual fields, Moscow, Idaho, 1931–32*

Ranch no.	Harvesting method	1931				1932			
		Infestation	Yield per acre	Loss per acre	Loss	Infestation	Yield per acre	Loss per acre	Loss
		Percent	*Pounds*	*Pounds*	*Percent*	*Percent*	*Pounds*	*Pounds*	*Percent*
1	By combine	5.2	966	667	41	6.8	980	252.6	20.5
2	do	14.0	1,037	457	31	4.4	1,400	152.5	9.8
3	do	.6	1,395	388	22	9.0	1,680	121.9	6.8
4	do	50.0	1,056	404	20	6.7	2,100	90.2	4.1
5	do	5.7	1,482	116	7	7.1	1,680	82.8	4.7
Average					24.20				9.18
6	By mow and thresh	58.8	1,375	442	24	20.5	1,080	278.8	14.2
7	do	7.4	1,573	510	24	8.2	1,750	252.0	12.6
Average					24				13.40
8	By combine in 1931 and by mow and thresh in 1932.	18.5	690	693	50	3.3	1,260	230.9	15.5
9	do	2.2	1,518	492	24	5.6	1,400	187.3	11.8
Average					37				13.65

With but one trifling exception, the growers who had the lightest harvest loss in 1931 also had the lightest loss in 1932 and, conversely, the two that suffered heavy losses in 1931 also had the heaviest losses in 1932. The total loss from field shatter in 1931 was approximately twice as great as the loss in 1932. This was due, at least in part, to the shorter length of the vines in 1931.

The significance of the potential infestation from field shatter during harvest is shown by the fact that 1,480,178 weevil-infested peas per acre, judging from the samples examined, were left on the ground in one badly infested field on which the loss was extremely heavy. Figure 20 shows a typical bit of harvest loss from field shatter.

Weevils in shattered peas suffer a high degree of mortality when these are exposed to the heat of the sun. In order to obtain data upon this point, three samples of infested peas, one shelled, one shelled and

FIGURE 20.—A typical bit of harvest loss in a field of Alaska peas, illustrating the peas lost by shattering prior to or during harvest.

covered by a thin layer of pea straw, and the other in pods, were spread out on the soil surface at weekly intervals, beginning when the pods first ripened and ended on September 8. A sample of peas from each lot was split to determine the stage of the weevils at the time they were exposed. The maximum mortality occurred among those weevils in shelled peas that were exposed early in the season.

The peas were picked up on October 3, 1934, and were stored in the field insectary until they were examined from March 17 to April 17, 1935. In this test weevils that had emerged were considered as living weevils.

A study of figure 21 shows a survival of only 9.2 percent among the unprotected shelled peas spread out on the ground on July 28, while 79.2 percent survived in peas protected by a thin covering of pea straw. Of those that were alive at the time the samples were examined only 1.2 percent had emerged from unprotected shelled peas whereas 69.6 percent had emerged from those that were protected. Weevils in peas protected by pods spread on this date showed a survival of 43.6

percent and an emergence of 13.3 percent. The survival and emergence gradually increased in the peas spread until of those put out on September 8, 61.2 percent of the weevils in the unprotected shelled

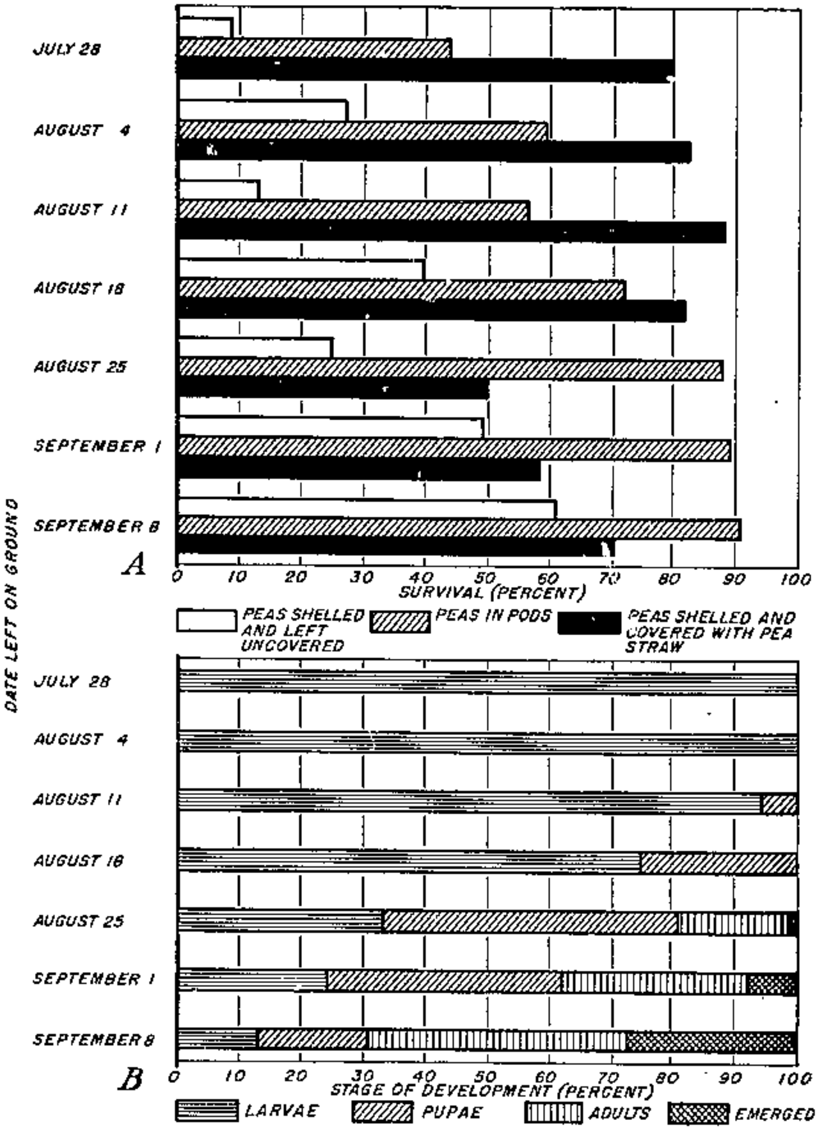

FIGURE 21.—Influence of length of exposure and stage of weevil development on the survival of pea weevils in peas left on the ground in the field, Moscow, Idaho, 1934: *A*, Survival in peas placed on the ground on the dates shown; *B*, stage of development of the pea weevil in similar samples on the dates shown. The experiment was terminated on October 3.

peas were still alive and 56.0 percent had emerged; 70.7 percent of those in peas covered by a light covering of pea straw were still alive and 61.3 percent had emerged; and those in peas still in pods showed a survival of 91.2 percent and an emergence of 66.8 perce

Peas were picked up at irregular intervals on a field of Austrian Winter peas near Corvallis, Oreg., that had been cut early in the season with a mower, raked into windrows, and then threshed with a stationary thresher. These peas were collected under three different conditions: (1) From peas found on the ground; (2) from pods found on the ground; and (3) from pods suspended normally on vines above the soil surface which had escaped the mowing operation. The results are summarized in table 6. In this series of samples a progressive increase in mortality occurred until the last collection on September 27, when 91.7 percent of the weevils in shattered peas were dead and 73.4 percent of those in pods lying on the soil surface had suffered a similar fate. During the same period a mortality of only 10.2 percent occurred in the weevils contained in pods on the vines suspended normally above the soil surface.

TABLE 6.—*Mortality of the pea weevil in Austrian Winter peas on a field near Corvallis, Oreg., 1933*

[The peas averaged 89 percent weevily]

Date of collection	Mortality in peas—			Date of collection	Mortality in peas—		
	Shattered on the ground	In pods on the ground	In pods on vines above the ground		Shattered on the ground	In pods on the ground	In pods on vines above the ground
	Percent [1]	*Percent* [1]	*Percent* [2]		*Percent* [1]	*Percent* [1]	*Percent* [2]
July 27	34.7	19.9		Aug. 28	88.3	53.6	5.0
Aug. 1	47.3	24.0		Sept. 8	90.8	53.8	29.0
Aug. 15	75.7	54.7		Sept. 27	91.7	73.4	10.2

[1] Each figure determined by the examination of 600 peas.
[2] Each figure determined by the examination of 200 peas.

In another instance a series of samples of peas were collected late in the summer from a field that had been threshed with a stationary thresher. The pea straw had been hauled back and scattered over a part of the field. Seventy-three percent of the weevils were dead in the peas collected from the part of the ground where the layer of straw had not been added. On the other hand, the weevils in peas under the added straw and the weevils in pods on vines in the field which had been missed by the mower suffered a mortality of 29 and 30 percent, respectively.

In view of the foregoing information it will be appreciated that the shattering of peas in the field constitutes an important source of pea weevil infestation, the degree of importance depending principally upon the time of harvest, the methods used in harvesting, the condition of the field after harvest, and the methods adopted to destroy these shattered peas.

VOLUNTEER PEAS

In the vicinity of Moscow the shattered peas often pass the winter without sprouting and grow as volunteer peas in the winter wheat during the following spring. Under favorable conditions these volunteer peas develop into producing vines and make a partial crop. Large numbers of weevils complete their development in these volunteer peas and escape to infest the next year's crop. Examination of samples from 12 patches of volunteer peas during 1932 revealed that an average of 71 percent of the peas contained weevils.

In western Oregon most of the shattered peas decay; therefore the problem of volunteer peas is much less important than in Idaho.

WEEVILS IN PEA HAY

Peas that are grown for forage sometimes serve as a source of weevil infestation, unless the hay is used or destroyed before the weevils in the infested peas complete their development and escape. Even

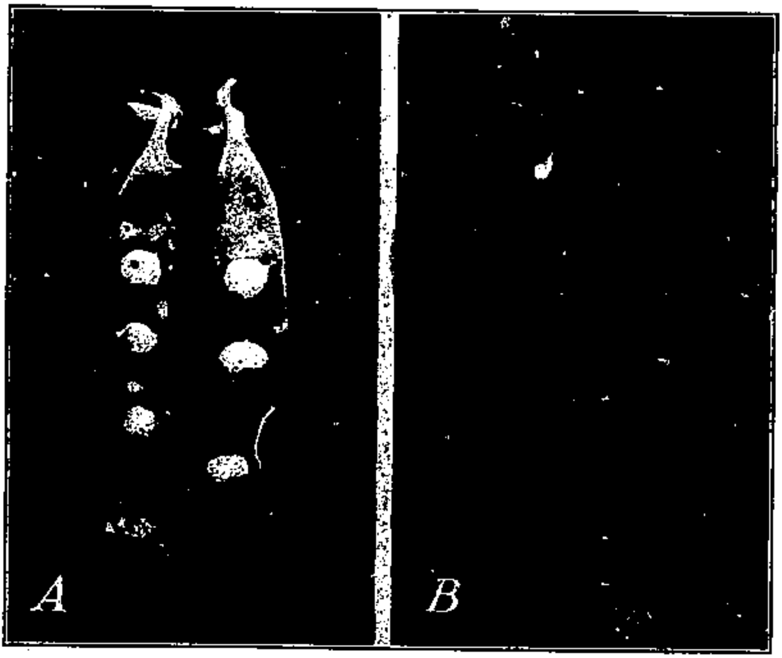

FIGURE 22.—A comparison between pods picked ripe, *A*, and pods picked green, *B*. Weevils developed and emerged from both.

though the peas are cut for hay while they are immature, many of the pods contain seeds large enough to permit the development of weevils. Figure 22 shows an immature pod in which a pea weevil developed. Pea hay also furnishes a favorable place for hibernation, and many weevils remain in the hay until spring, when they emerge to infest the new crop of peas.

PLANTING WEEVIL-INFESTED PEAS

In order to reduce the cost of production many farmers sow weevil-infested peas for seed, on the assumption that the adult weevils contained therein will be killed by burying, but experiments have demonstrated that large numbers of weevils emerge from peas planted at the normal depth of 3.5 inches.

The percentage of weevils that emerge seems to depend principally upon the temperature of the soil when the peas are planted. In a series of experiments at Moscow during 1932, 1,000 peas were planted on April 18, which was the earliest possible planting date in that year; another 1,500 peas were planted on April 26 when field planting was starting; and a final series of 1,500 peas was seeded on May 9. These peas were planted at a depth of 3.5 inches, and a screen cage was placed over them to intercept the weevils that emerged. Collections were made from these cages at 4 p. m. each day and the soil temperature was recorded at that hour. From the first planting 10.7 percent, from the second 34.7 percent, and from the last planting 62.7 percent of the weevils emerged. The average soil temperature at a depth of 3.5 inches during the period of emergence of the weevils was 59.9°, 63.3°, and 64.7° F. for the respective plantings.

Korab (*9*) planted weevily seed in the spring at depths ranging from 1 to 15 cm and reported that some of the adults found their way to the soil surface from a depth of 15 cm.

NATURAL ENEMIES

Several insects are recorded in the literature as parasites of the pea weevil. Skaife (*17*) reared *Bruchocida orientalis* Cwfd. from the pea weevil and reports that he reared a small green pteromalid and *Aplastomorpha* sp. from weevil-infested peas. *Bruchobius lacticollis* Ashm. was listed by Pierce (*13*) and by Cushman (*5*) as a parasite of the pea weevil. Korab (*8*) found the egg parasite *Bruchoctonus sènex* Grese destroying as high as 60 percent of the weevil eggs. None of these species has been found in the Pacific Northwest. Two species, however, *Microdontomerus anthonomi* Cwfd. and *Eupteromalus leguminis* Gahan (determined by C. F. W. Muesebeck) were reared at Moscow, Idaho, and *E. leguminis* (determined by A. B. Gahan) was reared at Corvallis, Oreg. These parasites were found as larvae or pupae within the pea seeds, and in every case outside of a dead weevil larva or pupa. They have been obtained only occasionally from field collections. It is interesting to note that this same species of *Eupteromalus* has been reared in Utah, Wyoming, and Nevada from *Bathyplectes* parasitizing the alfalfa weevil (*Hypera postica* Gyll.)[4] In September 1935 shipments of *Triaspis thoracicus* Curtis were received from Angern, Austria, and were liberated at Moscow, Idaho. As yet it is not known whether this parasite has become established. A small red mite belonging to the family Erythraeidae and the genus *Atomus* (determined by H. E. Ewing) fed extensively on the eggs of the weevil during 1932 at Moscow. A staphylinid, *Staphylinus nigrellus* Horn, was found among the remains of a number of pea weevils near Corvallis. In the laboratory this specimen devoured an additional 29 individuals of the pea weevil before it died.

The English sparrow was observed to feed freely on the weevils on an experimental plot and where they were escaping from a concentration cage. The violet-green swallow fed on weevils emerging from shattered peas. Woodpeckers and flickers completely stripped the loose outer bark from a grove of ponderosa pine that was known to shelter an abundance of pea weevils.

[4] These data were taken from correspondence between W. H. White and A. B. Gahan.

CONTROL EXPERIMENTS

Many aspects of the problem of pea weevil control remain to be solved before complete recommendations for combating this pest can be formulated. The results of the control experiments presented herein are only preliminary, but as soon as experimental results warrant the procedure, a publication dealing primarily with control phases will be prepared.

The experimental program on pea-weevil control has followed three main lines of endeavor: (1) Experiments directed toward eliminating the principal sources of infestation, (2) experiments with insecticides, and (3) experiments with methods of cultural control.

FUMIGATION OF HARVESTED PEAS

Fumigation is the most satisfactory and successful method of killing the weevils in the newly harvested crop. It is inexpensive, and if performed properly it kills all stages of the weevils in or among the peas without injuring the peas either for seed or for food. Fumigation should not be attempted, however, unless the seed peas are thoroughly dry. They should not contain more than approximately 12 percent of moisture by weight.

It is important that the peas should be kept in closely woven sacks or in some tight container to prevent the escape of weevils from the stored seeds prior to fumigation (*1*).

The fumigant to be used depends to a great extent upon the quantity of peas to be fumigated and the facilities available for fumigation. The materials most commonly used for the fumigation of weevil-infested peas are carbon disulphide, hydrocyanic acid gas, chloropicrin and an ethylene oxide-carbon dioxide mixture (*2*). In Oregon, where the peas are fumigated during warm summer weather, either carbon disulphide or chloropicrin has given satisfactory results. Irrespective of the fumigant to be used, the entire crop should be fumigated immediately after harvest and before it is cleaned. This procedure reduces greatly the weevil infestation in the screenings, which contain the majority of the infested peas present in the crop.

The seeds to be fumigated should be placed in a comparatively air-tight container, such as a tin pail, wash boiler, watertight barrel, garbage can, barrel lined with heavy paper, refrigerator car, freight car, or a specially constructed fumigation chamber or room, depending upon the quantity of seed to be fumigated. Large quantities of seed peas are now being fumigated in refrigerator cars or freight cars, at a dosage, when the car is of average airtightness, of 15 pounds of carbon disulphide to each 1,000 cubic feet of space. When the car is in poor condition a 20-pound dosage should be used, and if in good condition so that it can be made nearly airtight, 10 pounds is a sufficient dosage. The tighter the receptacle, the better the results. The fumigated seeds should be aerated immediately after the close of the fumigation period.

CARBON DISULPHIDE

Carbon disulphide is one of the most effective, cheapest, and simplest fumigants used to kill pea weevils wherever insurance companies or regulatory considerations permit its use. The dosage (at atmospheric pressures) should be from 4 to 20 pounds to each 1,000 cubic feet of space to be fumigated, depending upon the airtightness of the container. Under average conditions of fumigation, 10 pounds of the material should be used per 1,000 cubic feet. (1 gallon of carbon disulphide weighs approximately 10½ pounds at ordinary temperatures.) In estimating the quantity of carbon disulphide needed, the number of cubic feet in the container should always be measured and not solely the space occupied by the seeds. It is better to use too much rather than too little of the carbon disulphide.

In the process of fumigation, the liquid carbon disulphide should be poured into shallow pie tins or similar shallow dishes and placed *on top* of the seeds to be fumigated. The gas from this fumigant is heavier than air and the liquid evaporates more quickly if a large surface is exposed to the air.

Fumigation with carbon disulphide should be conducted at or above a temperature of 75° F. It is not effective at temperatures below 60°. Fumigation should continue from 24 to 48 hours, depending upon the tightness of the receptacle and the dosage, although most of the actual killing takes place during the first 6 or 8 hours of exposure. The germ in thoroughly dry seeds (not more than 12-percent moisture content) is not injured by this treatment and the food value of the seeds is not affected.

Caution.—While carbon disulphide is a standard fumigant and has been used safely for many years by observing proper safeguards, it must be remembered that the gas is explosive and inflammable if exposed to fire, such as a lighted match, cigarette, cigar, or lantern, or the spark from an electric fixture.

HYDROCYANIC ACID GAS

Fumigation with hydrocyanic acid gas is recommended when large quantities of peas are infested by weevils in warehouses, seed houses, freight cars, and similar situations. For best results the seeds should be in sacks and so stacked that the gas can reach a large portion of the outside of each sack. Under these circumstances, fumigation with this gas has been found very effective in killing pea weevils.

Hydrocyanic acid gas is extremely poisonous, in fact, fatal to human beings if breathed in concentrated form. Consequently, it should be used as a fumigant only by skilled, responsible persons who are thoroughly informed upon the subject of fumigation. The advantages of this fumigant are that it is noninflammable and nonexplosive when mixed with air in the proportions used in fumigation, it does not injure the germination or food value of the seeds, and it does not injure warehouse equipment. Also, hydrocyanic acid gas acts more quickly than any other known fumigant, and for this reason it often proves effective in warehouses, freight cars, and similar structures that are not entirely airtight, because the gas performs its killing action before escaping through cracks or other openings. Under these or similar circumstances, particular precautions should be observed against any persons coming into contact with the escaping gas.

For general fumigation work, one-half pound of liquid hydrocyanic acid or 1 pound of granular sodium cyanide should be used for each 1,000 cubic feet of space. For large warehouses or similar buildings well filled with peas the dosage should be increased to 20 ounces of liquid hydrocyanic acid or 2½ pounds of crystalline sodium cyanide (96 to 98 percent, containing 54 percent hydrogen cyanide) per 1,000 cubic feet.

CHLOROPICRIN

Chloropicrin has been utilized to some extent in the fumigation of peas infested by the pea weevil. It possesses the advantage of being noninflammable and of costing less than some of the other fumigants, but the fumigated seed must be thoroughly ventilated or air washed before they can be handled, because traces of chloropicrin gas may be retained in the fumigated product for several days. When fumigating with this gas 1 pint (1.7 pounds) of liquid chloropicrin should be used for each 1,000 cubic feet of space. The treatment should continue for at least 36 hours, and it is most effective at or above a temperature of 75° F. It is not effective at temperatures below 60°.

This fumigant should be applied by sprinkling it upon pieces of burlap sacking, or by pouring it into shallow evaporating pans. A gas mask is essential if large quantities of chloropicrin are to be used.

Although this gas is a deadly poison, it has a disagreeable and irritating effect upon the eyes and the respiratory passages, preventing people from entering buildings or other structures where there are dangerous concentrations of chloropicrin.

ETHYLENE OXIDE-CARBON DIOXIDE MIXTURE

The ethylene oxide-carbon dioxide mixture, a gas composed of 1 part of ethylene dioxide and 9 parts of carbon dioxide, by weight, is a noninflammable and nonexplosive gas not highly toxic to humans. For these reasons it is often used for the fumigation of peas intended for food purposes, but it should not be used for peas intended for planting, since this gas ordinarily injures the seed for germination.

EFFECTIVENESS OF FUMIGATION

In order to investigate the effectiveness of widely practiced fumigating methods, a total of 88 samples of fumigated peas was obtained during 1934 from six different large-scale fumigators in the Willamette Valley. Two of these fumigators had used carbon disulphide at the rate of 25 pounds (approximately 2½ gallons) to each 1,000 cubic feet of space, and the other four had used chloropicrin at the rate of approximately 1½ pounds per 1,000 cubic feet of space. The duration of exposure had ranged from 24 hours to several days. Records maintained at one warehouse indicated that the temperature during the period of fumigation had ranged from 73° to 85° F. Only one living specimen of the weevil was found in the samples examined.

CONTROL OF THE WEEVIL IN SHATTERED PEAS

Although the shattering of weevil-infested peas from the vines in the field constitutes one of the important sources of weevil infestation for the next year's crop, no method of preventing this common occurrence has been devised. This problem is complicated by the fact that the equipment and methods used in large-scale harvesting operations add to the apparently inescapable shattering of the peas caused by weather conditions, particularly by wind, hail, and rain. Under these circumstances it appears that the destruction of the shattered peas by field methods, immediately after harvest and before weevil emergence begins, affords the only practicable solution of the problem.

BURNING HARVEST DEBRIS

Under the conditions existing in the pea-growing districts of western Oregon, according to Larson (*10*), the burning of the plant debris and chaff on the field immediately after harvest, when conducted properly, kills nearly 100 percent of the weevils in the shattered peas.

The burning can be performed most efficiently where the pea straw left on the field is heavy enough to maintain a running fire. In such fields the burning of the pea straw on the ground will scorch the peas sufficiently to kill practically all of the weevils contained in those peas that the fire actually passes over. Before burning is attempted, at least two plow furrows should be made around the outer edge of the field to prevent the fire from spreading to other fields. A fire permit should be obtained, and then, on a hot afternoon as soon after harvest as possible, the field should be burned, due care being taken to conduct a backfire near other crops and buildings.

An effective application of the method of burning is illustrated by the following procedure adopted by the farmers in the Barlow, Oreg., district: Each grower obtains a fire permit and plows a few furrows around his field. Then the growers of the neighborhood cooperate in burning the fields. A truck is loaded with barrels of water, buckets, and burlap sacks and is driven to the edge of one of the fields to be burned. Torches are made of tightly rolled burlap sacks soaked in oil or gasoline. After taking the precaution to start a backfire these torches are lighted and dragged at the end of a wire around the edges of the field. Usually two men drag the torches, and the other men in the group, each supplied with a wet burlap sack and a bucket of water, patrol the field borders and extinguish any incipient fires outside the barrier.

During the 5-year period 1930–34, approximately 60,000 Austrian Winter field peas containing 12,201 weevils were collected from 65 burned fields in Oregon. Only 129 of the weevils contained in these peas, slightly more than 1 percent of the total weevils present, survived. Some weevils survive in portions of burned fields where the covering of straw is too thin to maintain the fire and also in the field borders which are plowed to prevent the spread of the flames. If weather conditions are favorable, however, and the field is covered with straw, the weevil survival is negligible.

Pea-weevil infestations in Oregon have been found to be consistently lower in localities where the fields have been burned than in localities where burning has not been practiced. Further proof of the efficiency of burning is shown by the examination of the hibernating places, adjacent to the burned fields, that are usually frequented by the weevils. Very few weevils can be found in the vicinity of fields that have been burned, whereas examinations along the borders of fields that have not been burned often reveal many hibernating adults.

Since pea vines in the extensive pea-growing areas of the Palouse section of Idaho and Washington do not produce sufficient straw to maintain a continuous fire across the harvested fields, the burning method is of little value in that section. Since burning destroys almost all of the plant material on the surface of the soil, it has been justly condemned as incompatible with soil conservation practices and is not recommended if other control measures can be employed.

BURYING WEEVIL-INFESTED PEAS BY PLOWING AND DISKING

Korab (*9, p. 33*) suggested field cultivation immediately after harvest as a method of killing the weevils in shelled peas. He found that the immature stages of the weevil are killed when buried at a depth of 8 cm, but that many of the adults are able to escape.

In order to determine more definitely the percentage of weevils escaping from buried peas, 14 ounces of weevil-infested peas were buried in wire-screen cages at depths of 2, 4, 6, and 8 inches, respectively, at Moscow, Idaho, late in the summer of 1931. These cages were cylindrical in shape, 8 inches in diameter, 15 inches long, and constructed of wire screen having 16 meshes to the linear inch. They were set upright in the soil with their lower ends 10 inches below the ground level and then filled with the soil containing the peas at a designated level. The percentages of weevils emerging from the peas and escaping to the soil surface, as compiled from daily records, are summarized in table 7. It will be noted that from a depth of 8 inches 0.9, 1.2, and 3.6 percent, respectively, of the weevils escaped in the three series. From a depth of 4 inches as many as 13.2 percent of the weevils escaped in one series and as few as 2.8 percent in another.

TABLE 7.—*Emergence of weevils from buried peas,*[1] *Moscow, Idaho, 1931*

Depth buried (inches)	Series 1, started Aug. 19		Series 2, started Sept. 3		Series 3, started Sept. 8	
	Number	*Percent*	*Number*	*Percent*	*Number*	*Percent*
Surface	311	[2] 100.0	250	100.0	1,178	100.0
2	50	16.0	42	16.8	599	50.3
4	10	3.2	33	13.2	33	2.8
6	3	.9	21	8.0	32	2.7
8	3	.9	3	1.2	42	3.6

[1] 14 ounces of weevily peas were buried at each depth in each series, but they were not from the same sample.

[2] The number of weevils that emerged from the 14 ounces of peas was assumed to be the total emergence that would occur from the buried peas provided the treatment was ineffective; thus the 100-percent emergence in these check lots.

A similar test was conducted in 1932 to determine the influence of the stage of the development of the weevil at the time of burial on its ability to emerge and escape from shattered peas. Lots of 500 mature infested peas were buried to a depth of 3.5 inches at intervals from the time the peas were ripe until emergence of the weevils was in progress. Fifty pods were also buried at the same depth. A similar number of shelled peas and pods were placed on top of the ground as a check. Very few of the weevils in the buried peas reached the soil surface, and, as shown in table 8, there was practically no difference in the number of weevils that escaped on the different dates.

Table 8.—*Emergence of pea weevils from peas buried 3½ inches deep at weekly intervals, Moscow, Idaho, 1932*

Date buried	Weevils escaped				Date buried	Weevils escaped			
	From loose peas [1]		From pods [2]			From loose peas [1]		From pods [2]	
	Buried	Check	Buried	Check		Buried	Check	Buried	Check
	Number	*Number*	*Number*	*Number*		*Number*	*Number*	*Number*	*Number*
Aug. 6	2	351	0	201	Aug. 27	2	216	0	98
Aug. 13	1	234	1	178	Sept. 3	1	230	0	108
Aug. 20	0	224	1	140	Sept. 10	1	213	0	122

[1] 500 shelled peas were buried and 500 additional peas were placed on top of the ground as a check on each date.
[2] 50 pods were buried and 50 additional pods were placed on top of the ground as a check on each date.

FIELD EXPERIMENTS IN BURYING WEEVIL-INFESTED PEAS

Since cage experiments showed such favorable results, an experiment was planned to test the effect of burying weevil-infested peas on a larger scale by the use of farm machinery. In the small experiments it was apparent that the weevils were covered with a more finely pulverized soil than they would be if buried by a plow or disk. Three plots of ground 6 feet square were staked out on a pea field from which the peas had been harvested recently. A total of 15,000 weevil-infested peas was then spread out on the soil surface of each of the plots. One of these plots was plowed to a depth of about 8 inches—this is approximately the average plowing depth—with a caterpillar tractor and a four-gang plow, the second was disked under, and the third was left as a check. In addition, pea vines bearing infested peas were plowed under on a plot containing 6 square feet, and an adjacent similar plot left as a check. A large cage covered with wire screen having 16 meshes to the linear inch was placed over each of the plots to retain the weevils as they emerged. The results of this field experiment, as shown in table 9, agreed very well with the small cage experiments.

Table 9.—*The influence of plowing under and disking on the number of weevils emerging from unharvested infested peas, Moscow, Idaho, 1932*

Treatment	Infested peas	Weevils emerged	
	Number	*Number*	*Percent*
Placed on the soil surface as a check	15,000	9,140	60.97
Disked under with a two-way disk	15,000	2,073	13.82
Plowed under with a four-gang plow	15,000	395	2.63
Do	(1)	127	[2] 11.02
No treatment	(3)	1,152	100.00

[1] A plot containing 6 square feet was covered with pea vines which were plowed under.
[2] Derived from the supposition that the vines contained the same number of weevil-infested peas as those in the check shown below.
[3] A plot containing 6 square feet was covered with pea vines which were left on the surface.

PASTURING WITH LIVESTOCK

In the Willamette Valley the harvested pea fields are often pastured with cattle, hogs, or sheep, but detailed field examinations demonstrated that the livestock consumed only a small percentage of the infested peas. In the Palouse section of Idaho and Washington large flocks of sheep are sometimes turned into the fields. This has some value there as a pea-weevil control measure, as is illustrated by the fact that field examinations made before and after pasturing 1,500 sheep on a 25-acre field of Alaska peas near Moscow, indicated that the sheep consumed 54 percent of the peas in 1 day. In both areas, however, it is the common practice to pasture the fields late in the fall after the majority of the weevils have escaped from the peas.

DESTROYING SHATTERED PEAS AND VINES

At the viners there occurs a loss of peas in which weevils may develop. Consequently, all vines and peas left in the vicinity of the viners should be utilized by being fed to livestock or otherwise disposed of so that the weevils will not be allowed to develop. They may be used for silage, or plowed under cleanly and deeply, or placed in a pile and kept so moist that they will soon decompose.

If the crop is grown for the green-pea market or for home consumption, the vines should be destroyed as soon as possible after the last picking of the pods. Frequently the vines are left standing in the field, after the close of the harvest period, with sufficient peas on them to harbor large numbers of weevils. The method of disposing of such peas depends upon local conditions, but they should not be permitted to stand long enough to allow the emergence of a crop of weevils. In general, such peas should be utilized or destroyed by the methods indicated in the preceding paragraph.

PREVENTIVE PRACTICES

TREATMENT OF IMPORTED DRIED PEAS

All dried peas shipped into a canning area should be fumigated or processed at the point of origin to kill or remove any contained weevils. If this has not been done, and living weevils are found in dry peas imported into a canning area, such peas should be fumigated before being distributed or planted.

EFFECT OF GROWING CANNERY PEAS AND SEED IN THE SAME DISTRICT

Cannery peas are more likely to be infested if they are grown in a seed-producing district where the weevil is destructive. Similarly, the growing of peas for seed in a pea-canning district may increase infestations in the cannery stock. To avoid heavy losses only one branch of the pea industry should be carried on in any one district.

INSECTICIDES

LABORATORY AND PLOT TESTS

Four series of tests to determine the effectiveness of stomach poisons in controlling the pea weevil were carried out at Moscow during the summer of 1934; the first, to compare the effectiveness of calcium arsenate, barium fluosilicate, zinc arsenite, sodium fluoaluminate, lead arsenate, and lime; the second, to test the effectiveness of several applications of calcium arsenate; the third, to determine the influence of various dosages of calcium arsenate; and the fourth, to test the effectiveness of two different brands of calcium arsenate, one of which contained an adhesive agent.

The plots in this experiment were replicated four times (four plots per treatment) and distributed by chance according to the random block method. Each of the plots was one-fortieth of an acre in extent and measured 66 feet in length and 16½ feet in width. All the plots were planted along the edge of the field in such a manner as to expose each of them to the heavy weevil infestation that occurs usually in this part of a pea field. Regular field practices were followed in seeding the plots except that the peas were planted earlier than the normal date for commercial plantings, in order to attract large numbers of weevils to these peas for oviposition before any other peas in the same locality started to blossom. A 22-foot border of peas was planted between the plots and a late main-crop planting of peas in order to prevent heavy infestation of this crop through the migration of the weevils attracted to the early planted insecticide plots.

The plots were dusted with hand dusters. Five trips, traversing the length of the plots, usually sufficed to cover the plants with the desired quantity of the insecticide. The dust guns were weighed before and after each application. If more than the desired quantity of insecticide had been applied, it was recorded but if less than that quantity had been applied, an additional trip was made through the plot. Continued use of the dusters enabled the operators to become proficient in applying approximately the correct quantity of dust.

The insecticides used in these tests, the rates of application, and the results are shown in table 10. The commercial brand of calcium arsenate designated as "brand A" contained 70 percent of active ingredients and 30 percent of inert matter. This material was applied at the rates of 40, 20, 15, and 5 pounds per acre. In order to obtain an even distribution at rates of less than 20 pounds per acre, it was necessary to dilute the material with hydrated lime. Calcium arsenate, brand B, contained 50 percent active ingredients, with dehydrated, powdered molasses as an adhesive. The barium fluosilicate contained 80 percent active ingredients.

TABLE 10.—*Results of insecticide tests, arranged according to their effectiveness*

Insecticide	Applications	Rate of applications per acre	Peas harvested	
			Sound	Weevily [1]
	Number	*Pounds*	*Percent*	*Percent*
Sodium fluoaluminate	6	20	93.9	6.1
Zinc arsenite	6	20	93.2	6.8
Calcium arsenate, brand A	6	20	92.7	7.3
Do	4	20	91.9	8.1
Do	2	20	91.6	8.4
Barium fluosilicate	6	20	90.3	9.7
Calcium arsenate, brand A	7	40	90.3	9.7
Do	7	20	89.7	10.3
Calcium arsenate, brand B	7	20	89.4	10.6
Calcium arsenate	6	40	87.9	12.1
Lead arsenate	6	20	86.1	13.9
Calcium arsenate, brand A	6	15	84.4	15.6
Do	6	5	83.6	16.4
Calcium arsenate, brand B	4	20	78.9	21.1
Lime	6	20	77.6	22.4
Check			67.1	32.9

[1] Average of the results from four 1/40 acre plots. 1,000 peas were examined from each plot.

The method used in determining the effectiveness of the insecticides applied to the plots consisted of harvesting all the peas on a strip 3 feet wide and 12 feet long from the center of each plot. One thousand peas were taken at random from the quantity thus obtained and examined by the salt flotation method to determine the percentage of the peas containing weevils.

Sodium fluoaluminate, which gave the best control of all of the insecticides tested, reduced the infestation for the four plots treated with this material to 6.1 percent, on an average, as compared to an average infestation of 32.9 percent for the undusted check plots. None of the insecticides included in these tests, however, gave results that justified the cost of application.

AIRPLANE DUSTING EXPERIMENTS

In the spring of 1934 several fields of Austrian Winter field peas in Oregon were dusted by airplane with undiluted calcium arsenate in an effort to control the pea weevil. The dust was applied early in the morning at a dosage ranging from 15 to 22½ pounds per acre. The results, as measured by the collection of adults with an insect net before and after dusting, indicated that the dusting caused a marked reduction in the population of adult weevils, amounting to as much as 80 percent in certain of the fields. Directly significant comparisons, however, could not be made later in the season between the percentage of the seeds infested in the dusted and undusted fields, since a normal variation existed in the time of planting, seasonal development of the crop, density of stand, and other important influences which also affected the abundance of the weevil in each of the fields under observation.

That the airplane dusting with calcium arsenate had a slightly beneficial effect was indicated from the records of the warehouse where practically all peas grown near Barlow, Canby, and Aurora, Oreg., were cleaned and fumigated. Of the first 36 lots handled by this warehouse 27 lots were from fields that had been dusted. The peas from only 1 of these 27 fields failed to pass the required germination of 90 percent. Of the nine lots from fields which had not been dusted, six failed to pass the 90-percent germination test.

The difference in germination and weight of peas from dusted and undusted fields, handled at this warehouse, is shown in the following summary:

	Percent
Average germination of peas from 33 fields dusted	91.64
Average germination of peas from 22 fields not dusted	87.89
Difference	3.75
	Pounds
Average weight per bushel of peas from 28 fields dusted	65.82
Average weight per bushel of peas from 20 fields not dusted	64.99
Difference	.83

All germination tests were made by the United States Department of Agriculture seed testing laboratory at Corvallis, Oreg.

CULTURAL CONTROL

TIME OF PLANTING

Extensive field observations in Idaho have indicated that the time of planting has an important effect upon the degree of weevil damage suffered by peas. Usually the percentage of peas infested by the weevil has been greater in early-planted peas than in the later plantings. In order to determine more definitely the influence of the time of planting upon subsequent pea weevil infestation, under directly comparable conditions, a series of plantings were made at Moscow in 1933 and 1934 on progressive dates from early to late in the season.

In 1933 these plantings were made at weekly intervals for 11 consecutive weeks, extending from April 6 to June 15. Each planting consisted of a single plot of five rows 60 feet long and 3 feet apart. The highest infestation, 59.6 percent, occurred on the eighth planting, which was seeded on May 25. The first planting had an infestation of 14.4 percent and ranked next to the lowest in the percentage of weevil-infested peas. The first planting also produced the maximum number of peas on 25 vines. The weevil-infestation data were computed from a sample picked at random through the plantings. The yield data were obtained from 25 vines picked at random. In order to eliminate the error caused by the difference in weight between weevil-infested and sound peas, the yield was based upon the total number of peas produced on 25 vines taken at random from each plot.

In 1934, 13 plantings of peas were made at intervals during the period extending from February 19 to July 2. Each planting was replicated four times (four plots per treatment), and the plots were distributed by chance according to the random-block method. The individual plots consisted of five rows of peas 58 feet long, planted 2 feet apart. Each planting was made on the date when the preceding planting started to come up, or as soon after that date as possible.

As shown in table 11, there was a generally progressive decrease, from the early to the later plantings, in the percentage of peas infested by the pea weevil. The decrease in infestation was accompanied by a corresponding decrease in the yield and quality of the seed produced, indicating that the intensity of weevil infestation in peas grown under comparable conditions, except time of planting, is intimately associated with the vigor of the plants as reflected by yields. The data regarding infestation and yield, in this series of experiments, are based upon an examination of the total peas produced on 100 vines taken at random from each plot.

TABLE 11.—*Relation of the time of planting peas to the degree of pea weevil damage, Moscow, Idaho, 1934*

Date planted	Infestation					Date planted	Infestation				
	Series A	Series B	Series C	Series D	Average		Series A	Series B	Series C	Series D	Average
	Percent	*Percent*	*Percent*	*Percent*	*Percent*		*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Feb. 19	52.2	(1)	(1)	(1)	52.2	May 17	(1)	(1)	7.6	3.6	5.6
Mar. 14	59.0	51.4	42.2	66.2	54.7	May 29	6.8	16.2	14.2	4.8	10.5
Apr. 6	61.4	44.4	38.8	72.0	54.1	June 5	22.0	5.2	15.0	3.0	11.4
Apr. 16	42.8	53.4	40.2	46.9	45.8	June 12	17.4	4.8	1.2	(2)	7.8
Apr. 24	44.2	31.2	31.2	34.1	35.2	June 19	5.1	(2)	(2)	(1)	5.1
May 2	35.4	30.6	24.0	5.6	25.4	July 2	(2)	(2)	(2)	(1)	------
May 10	21.0	17.4	14.6	7.5	15.1						

[1] Not planted.
[2] Failed to produce peas.

TIME OF HARVESTING

Early harvesting is an important factor in the control of the pea weevil. This practice allows the early fumigation of the peas, and an early fumigation not only prevents the escape of any weevils from the harvested crop but destroys many small weevil larvae before they are able to affect adversely the germination and weight of the peas. Moreover, many of the weevils are killed during the process of harvesting. In 1934 an examination of 61 different samples of Austrian Winter field peas prior to fumigation revealed that approximately 48 percent of the weevil larvae therein had been killed in passing through the harvesting machinery. Early harvesting usually results in less loss of peas on the field from shattering than does later harvesting. It also allows time to burn or plow the field before the weevils begin to emerge from the shattered peas. As discussed in preceding paragraphs, the weevils contained in peas left on the field from early harvesting are more likely to be killed by the heat of the sun than peas shattered from the vines during later harvesting, because they will be exposed over a longer period of time.

BORDER TRAP CROPS

As has been stated, the edges of a field are usually more heavily infested by the pea weevil than the remainder of the field, and the infestation usually decreases from the edge to the center. This fact suggested the desirability of a border trap crop to aid in the control of the weevil.

To determine more definitely the possible effectiveness of this method, a series of field borders 10 feet in width were planted early in the spring of 1932 along the edges of several fields in a district badly infested by the pea weevil. They were seeded nearly 3 weeks before the main crop was planted and began blossoming from 10 to 14 days earlier than the main crop. As soon as the peas in the borders blossomed they attracted large numbers of the weevils.

To illustrate the high concentration of weevils that sometimes occurred on the field borders it may be stated that in one instance 1,415 weevils were collected in 100 sweeps of a collecting net in the field border before the main field blossomed, whereas only 8 weevils were collected in the same number of sweeps in the main field immediately adjacent.

The weevils remained in the borders, feeding on the blooms and depositing eggs on the newly formed pods, until the peas in the main field began to bloom. Then they moved into the main field. At this time the peas in the borders had passed the full blossoming stage. The movement of adult weevils in relation to border trap crops in two of the fields under observation is shown graphically in figure 23.

It was hoped that the weevils would exhaust their egg-laying capacities on the border plantings, but later examination of the mature peas revealed that the main fields were heavily infested.

In general, these preliminary observations demonstrated that the early planted field borders would concentrate and retain the weevils until the main fields began to blossom, but that such borders are a serious menace to the main crop of peas unless methods are devised for destroying the weevils before they move into the main field.

These tests were repeated in 1933 with the same general results as in 1932, except that fewer weevils were present.

BURNING BORDER TRAP CROPS

Since it seemed possible that the border trap plantings, together with the weevils concentrated thereon, could be quickly and effectively destroyed by burning, the cooperation of the agricultural engineers was obtained in 1934 in the construction of a burner designed to accomplish this purpose. O. K. Hedden of the Bureau of Agricultural Engineering of the United States Department of Agriculture, cooperating with the Department of Agricultural Engineering of the University of Idaho, designed and constructed the burner and the burner mounting. The burner was suspended by spring tension from the motor supports and pushed ahead of a crawler-type tractor. The fuel was passed through generating tubes under pressure and issued from burner jets as a flaming gas.

The field borders were planted in the same manner as in preceding years except that they were 22 feet wide. Favorable weather conditions allowed the planting of these borders on March 20, 1934, more than a month earlier than it had been possible to sow them in 1932 and

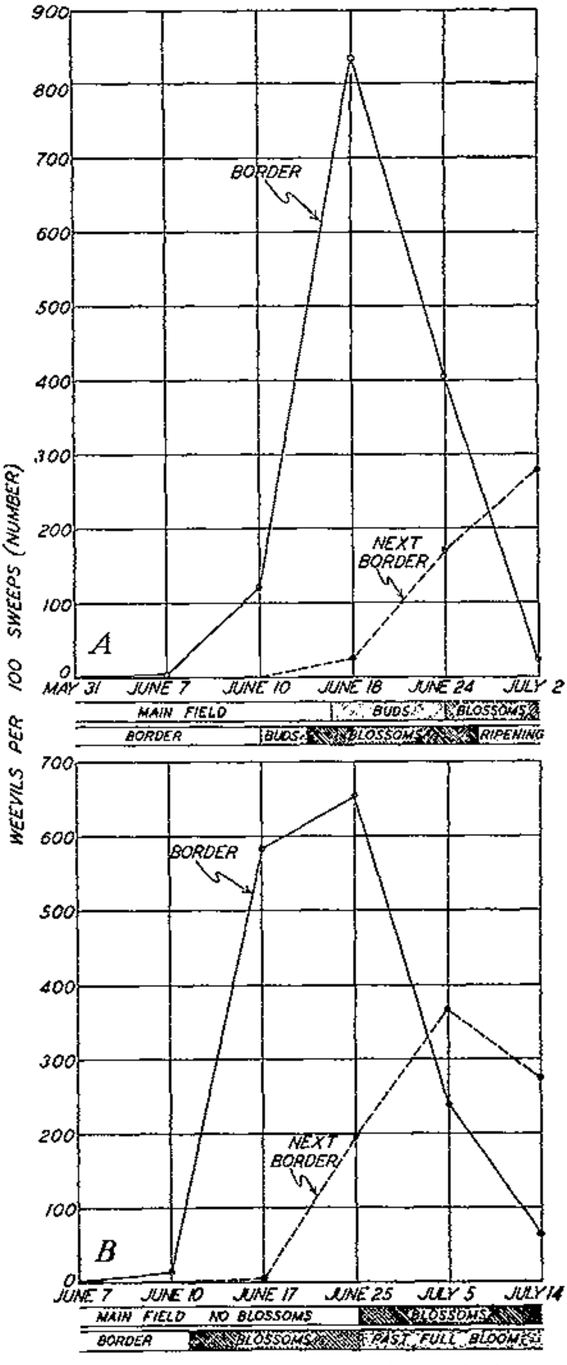

FIGURE 23.—Movement of adult weevils in relation to border trap-crop plantings, Moscow, Idaho, 1932: *A*, Field no. 1; *B*, field no. 4.

1933. The main portion of the experimental field was sown on two different dates so that there were, in reality, two experimental fields within the border. The border planting bloomed 18 days before the first planting on the main field and 33 days before the second planting.

Immediately prior to burning, 46.8 weevils, on an average, were collected in 100 sweeps of a net in the part of the main field first planted, while in the adjacent border an average of 737 weevils was collected in the same number of sweeps, and in one place a maximum of 1,365 were taken in 100 sweeps. The weevil population in the main field prior to burning was rather large because the sparse stand of peas in the border did not produce a sufficient number of blooms to harbor

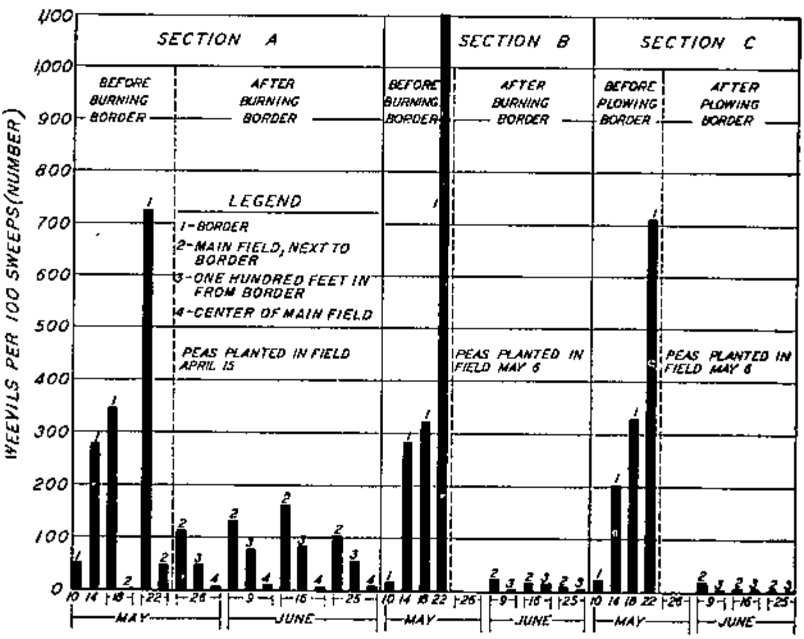

FIGURE 24.—Effect of border trap crops upon pea-weevil infestation in the main crop, and relative effectiveness of the burning and plowing methods of destroying the trap crops, Moscow, Idaho, 1934.

all of the weevils present. Also, a few volunteer or aberrant types of peas were blooming in the main field and probably attracted some of the weevils to them.

In general, the burning operation was not effective in killing the weevils. The borders were burned at night, since the weevils were inactive and hidden in the blossoms of the pea plants at that time. Many living weevils were caught in cages placed over the pea vines immediately after the burner had passed and living weevils were caught by the operators of the tractor. On the night of the burning 16 living weevils were also collected from the blooms over which the flames had passed. One hundred weevils found on the soil surface were examined with the aid of a flashlight to determine the mortality resulting from the burning operation. Thirty-four of these flew away unharmed. A total of 562 weevils were then collected from the soil surface to determine the number that would recover. Of this number 115 weevils, or 20.5 percent, recovered sufficiently to fly away. These figures, in conjunction with the information obtained in sweeping the different sections of the field before and after burning (shown in fig. 24, secs. *A* and *B*, and in table 12), indicate that many of the weevils survived the burning.

The average number of weevils collected per 100 sweeps in the inside of the field, adjacent to the border of the part of the field first planted, increased from 46.8 before burning to 113.3 after burning. This increase can be attributed to the migration of the weevils that escaped the burning process. However, there is also the possibility that some of the weevils which were not attracted to the border might have moved into the field from outside sources. The first planted field was heavily infested. In the second planting the weevil infestation was less, as shown in table 12, even though the number of weevils in the border of this section had been much greater than in the border of the section planted first.

TABLE 12.—*Weevil infestation in the ripe peas after the burning or plowing of the border trap crop, Moscow, Idaho, 1934*

Item	Sample no.	Adjoining border	100 feet in	Center
		Percent	*Percent*	*Percent*
Section A; planted, Apr. 15, border burned	6	96.6	78.6	4.4
	7	93.8	91.0	16.2
	8	76.4	87.6	22.4
	9	67.0	84.6	9.6
	10	83.4	86.0	9.0
	11	72.6	62.4	17.4
	12	55.0	37.0	25.0
	13	38.2	93.4	15.6
	14	47.8	34.4	19.6
	15	56.8	42.4	21.4
	16	36.6	27.8	
	17	65.4	31.0	
	18	78.8	56.0	
	19	76.4	40.2	
	20	74.2	61.8	
Average		68.0	61.9	16.1
Section B; planted May 6, border burned	1	1.0	2.6	0.0
	2	29.4	10.0	.4
	3	35.6	14.8	.2
	4	25.6	14.4	.0
	5	8.2	14.4	1.2
	21	6.0	1.0	
Average		17.6	9.6	.5
Section C; planted May 6, border plowed	22	4.0	3.2	1.6
	23	4.0	3.2	1.0
	24	.4	3.0	
Average		2.8	3.1	1.3

Although the burner equipment used during 1934 failed to give the desired control, certain minor changes in the burner construction and in the experimental procedure may render this method of destroying the border trap crop much more efficient.

PLOWING UNDER BORDER TRAP CROPS

The results obtained in destroying the weevils in the border by plowing were more favorable than those obtained by burning, as shown in section *C* of figure 24, and table 12. Approximately 1,800 feet of the border of a small, isolated section adjacent to the field on which the burner was tested was plowed under during the early morning before the weevils became active. An ordinary five-gang plow set to plow at a depth of from 8 to 9 inches was used. After the plowing operation the ground was rolled three times with a cultipacker. Cage collections made in three cages covering 36 square feet of surface, erected on the soil surface of the border, resulted in the capture of 439 adults in the border before plowing and only 8 afterwards, an apparent reduction of approximately 98 percent. The sweeping records shown in section C of figure 24 and the infestation records in table 12 indicate favorable results with plowing.

SUMMARY

The pea weevil (*Bruchus pisorum* L.) is a serious pest in most of the pea-growing territory of the Pacific Northwest.

This insect hibernates successfully in practically every situation affording some degree of protection from the elements. At Moscow, Idaho, it is able to survive under the trash remaining on the surface of pea fields.

The weevils emerge from hibernation when the air temperatures in the spring exceed approximately 70° F. They are attracted to the pea fields when the peas begin to bloom.

The ingestion of pollen is necessary for the production of the eggs by the female weevil. Egg laying begins in from 4 to 14 days after feeding. A maximum of 749 eggs was recorded from a single female, deposited during a period of 113 days.

A study of pea weevil oviposition in the field revealed that this insect is able to lay eggs throughout the entire period in which peas can be grown, although the rate of egg deposition decreases late in the summer. No eggs were laid when the air temperature was below 65° F. Individual plantings of peas were suitable for egg laying during a period ranging from 8 to 30 days, depending on the time the peas were planted.

At Moscow, Idaho, the time required for the eggs to hatch ranged from 5 to 14 days, averaging 9 days. At Corvallis, Oreg., this period ranged from 6 to 23 days, averaging 10 days.

The average duration of the larval stage at Moscow ranged from 32 to 43 days in the different series of peas examined, with a maximum of 56 days in any series and a minimum of 25. At Corvallis, in 1933, the duration of the larval stage ranged from 27 to 48 days, averaging between 37 and 38.

The pupal stage ranged from 8 to 27 days at Moscow, averaging 15 days in 1932 and 11.5 days in 1933. At Corvallis, in 1933, the pupal stage ranged from 8 to 12 days, averaging 10 days.

A summary of the data on 548 individuals revealed that at Moscow the insect developed from egg to adult in an average of 66 days in 1932. In 1933 the average length of this developmental period for 231 individuals was 55 days. The maximum period required for total development was 82 days and the minimum period 45. Records for 149 individuals at Corvallis in 1933 showed the average time required for development from egg to adult to be 57 days, while the maximum was 71 days and the minimum was 46.

The development of a partial second generation was indicated by a sudden increase in the abundance of eggs laid late in the summer and by the fact that weevils that developed during the summer laid fertile eggs in the laboratory the same season.

Infested peas that are shattered in the field prior to or during harvest, volunteer peas, stored pea hay containing peas, and seed peas constitute the principal sources from which the weevils that infest the next season's crop are recruited. Of these sources, the shattered peas in the field is the most important. As much as half of the potential yield of peas may be lost on the field from shattering, principally

as the result of careless harvesting methods. Weevils emerge readily from weevil-infested peas planted by customary methods.

Two chalcid parasites, *Microdontomerus anthonomi* and *Eupteromalus leguminis*, were found attacking the pea weevil. Parasites and predators appear to be of little importance in the natural control of this pest.

Fumigation with carbon disulphide, hydrocyanic acid gas, or chloropicrin is used to kill the weevils in harvested peas.

Burning harvest debris on the surface of the field has proved to be an effective method of killing the weevils in shattered peas where there is sufficient straw and other plant material remaining on the field to maintain a fire. However, since burning is contrary to good soil conservation practices, it is not recommended except as a last resort.

Cage experiments and field tests showed that from 0.9 to 3.6 percent of the weevils in infested peas were able to reach the soil surface when buried to a depth of 8 inches, in a manner simulating the methods ordinarily employed in plowing.

Pasturing harvested pea fields with livestock proved to be an unsatisfactory method of controlling the weevil in shattered peas. Usually the animals consumed only a small percentage of the peas.

Laboratory and field tests with insecticides applied as dusts have given little promise thus far of their use as a control measure, although research on this phase is being continued. Airplane dusting with calcium arsenate gave incomplete control.

Early and clean harvesting and early and complete fumigation of the entire crop harvested are important measures in reducing the degree of weevil damage.

A study of plantings made at different times at Moscow in 1933 showed that all plantings were heavily infested, with the greatest damage recorded on the eighth planting. Results in 1934 showed a decline in the degree of damage after the second or third planting. The decrease in weevil damage was accompanied by a corresponding decrease in yield.

The planting of trap crops of early peas around the field borders seems to offer possibilities for weevil control. The weevils concentrate in large numbers on these peas when they blossom and remain until the flowers develop on the main crop of peas in the remainder of the field. For this method to be effective, the weevils in the border planting must be killed before the peas in the main field bloom. Attempts have been made to destroy such weevils by burning and by plowing. Thus far, clean plowing, followed immediately by the packing of the plowed soil surface, has proved to be the most effective method for destroying the weevils in the field-border trap crop.

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