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The Potato Scab-gnat, *Pnyxia scabiei* (Hopkins)

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THE POTATO SCAB-GNAT, *Pnyxia scabiei* (Hopkins)

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INTRODUCTION

The potato scab-gnat, *Pnyxia scabiei* (Hopkins), is a member of that family of two-winged flies (Diptera) known as Mycetophilidae or fungus gnats.

Both the common and scientific names of this family were assigned because the larvae feed upon fungi, but the potato scab-gnat, while possessing this characteristic, also feeds upon a variety of other materials including the potato to which it often inflicts serious damage. This damage frequently resembles in a superficial way the lesions of common potato scab; hence, the common name assigned to this insect is the potato scab-gnat, and the scientific, *Pnyxia scabiei* (Hopkins). Although the relationship of the potato scab-gnat to potato damage has been known for many years, it was not until about 1926, when a critical study of the insect pests of this crop was launched in Ohio, that the economic status of this insect was fully established. It is entirely possible that previous to that time the scab-gnat had been somewhat prevalent and that injury caused by it may have been mistaken for common scab.

The fact that the insect for the most part lives below the surface of the soil or under cover and is of very small size has rendered its study exceedingly difficult; therefore, statements made relative to its activities in nature are based upon general observations or upon damage studies. The detailed life history herein reported is based upon laboratory studies and may or may not represent truly the normal behavior of the insect in nature. It is believed, however, inasmuch as the laboratory data seem to correlate with the necessarily fragmentary field data, that the life history notes recorded in this bulletin are substantially correct.

HISTORICAL CONSIDERATIONS

The first record of potato tuber injury by fungus-gnat larvae was made in 1867 by Walsh (15). Similar observations were reported by Hopkins (9, 10, 11) in 1895, who described the insect which caused the damage and assigned to it the scientific name, *Epidapus scabiei,* and the common name, potato scab-gnat. Howard (12) reported the insect from Missouri in the same year. In 1911, Gossard (5) reported serious scab-gnat damage to potato seed pieces as having occurred in Cuyahoga County, Ohio, in 1910.

Johannsen (13), in 1912, determined that the species did not belong to the genus *Epidapus* and erected the genus *Pnyxia,* of which *scabiei* is the sole representative. Speyer (14), in 1923, reported that serious injury had occurred on cucumbers in greenhouses in England and that a control was effected by submerging the beds under water for 12 hours. The author (6, 7),

[1]The subject matter of this bulletin was presented in slightly different form in partial fulfillment of the requirements for the degree of Doctor of Philosophy in the Graduate School of the Ohio State University (8). The author acknowledges the helpful suggestions and criticisms of J. S. Houser, Chief of the Department of Entomology of the Ohio Agricultural Experiment Station, both in the collection of the data herein presented and in the preparation of the manuscript. The photographs were prepared by H. M. Prager, Experiment Station Photographer.

in 1928, reported seed-piece and tuber injury to potatoes as having occurred in several localities in Ohio during the years 1926 and 1927. It may be noted further that some injury has been recorded each year since 1927 (8, 16).

DISTRIBUTION

The distribution of *P. scabiei* is undoubtedly quite general. According to the literature, the insect occurs in North America in the states of West Virginia (9), Missouri (12), New York (13), and probably in Delaware (15) and has been reported from England (14). The writer has observed specimens from Michigan, Illinois, and New York. In Ohio it has been collected in the following counties: Allen, Auglaize, Erie, Franklin, Geauga, Hamilton, Hancock, Holmes, Huron, Logan, Morrow, Portage, Sandusky, Stark, Summit, and Wayne.

DESCRIPTION

The genus and species have been well described by earlier writers (11, 13). The primary purpose of the descriptive material in the following paragraphs is to set forth certain characters not discussed in earlier papers, although a sufficient amount of previously published material is herewith included to render identification possible.

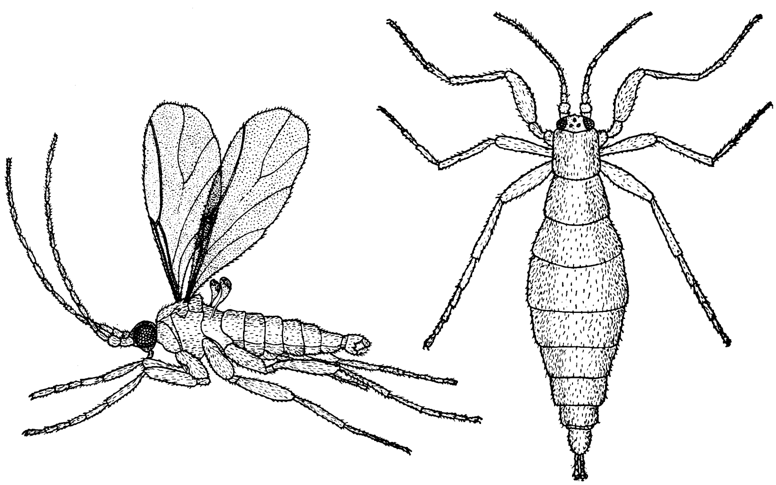

Fig. 1.—Adult stages of the potato scab-gnat. Male on left; female on right. Magnified 30 times

Adult.—Both sexes (Figure 1) are dusky brown in color; male quite dark; female lighter when newly emerged but darkening with age. Entire insect sparsely covered with short hairs. Body length of male, 1 to 1½ mm.; of female, 1 to 2 mm. Antennae of male slightly shorter than, and those of female one-third as long as, the combined length of head, thorax, and abdomen. Females without wings or halteres. Males winged; halteres prominent with light-colored pedicels. Extreme wing lengths vary from 0.53 to 1.16 mm. with a gradation between. Figure 2 illustrates the various wing lengths observed. Earlier writers designated long- and short-winged forms and presumed that this condition was brought about by nutritional factors. However, the writer found the entire range of wing lengths represented in a single lot of males reared concurrently in the same cage with a common food supply, thus disproving the theory of long- and short-winged forms and further that wing-length variation is not the result of differences in nutrition.

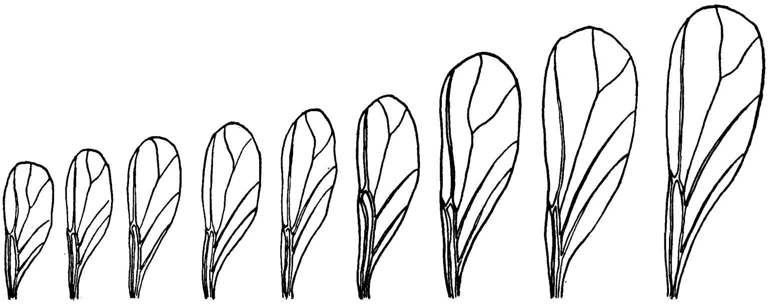

Fig. 2.—Wings of potato scab-gnat males, showing variation in lengths and venation. Magnified 35 times

Egg.—The egg is oblong in outline and, when newly deposited, is pearly white in color, later becoming dark as the embryo within develops. This dark color is due to the dark brown to black head of the embryo which is easily observed through the thin, almost transparent shell. The eggs vary in length from 0.207 mm. to 0.315 mm. and in width from 0.126 mm. to 0.180 mm., with an average length and width of 0.255 mm. and 0.141 mm., respectively.

Larva.—The newly hatched larva is transparent, with the exception of its head, which is heavily chitinized and dark brown to black in color. As growth progresses the body of the larva gradually becomes less transparent until, at maturity, it is almost white in color and nearly opaque. In all instars the internal organs are visible through the body wall. At maturity the body cavity is well filled with adipose tissue. Measurements indicate that a newly hatched larva is about 1 mm. and the mature larva 4 to 5 mm. in length.

Pupa.—When pupation takes place, the larval skin is cast, leaving the pupa bare with its antennal cases distinct but closely applied to the ventral surface. The male pupa has an average length of 1.12 mm. and an average width of 0.45 mm. The wing cases, which are closely applied to the ventor, are easily observed. The female pupa averages 1.78 mm. in length by 0.73 mm. in width.

The newly formed pupa is white in color but soon becomes dark brown. The cephalic end is always darker than the caudal end.

LIFE HISTORY

Egg stage.—The hatchability and the incubation period have been determined for 205 eggs. These eggs were kept at room temperatures in petri dishes about half filled with a mixture of plaster of Paris and finely ground muck soil which had been wetted and allowed to harden. The surface was dusted with pulverized muck soil which rendered the eggs easily visible. Water was added when necessary to keep the muck plate moist. One hundred and ninety-two, or 93.2 per cent, of the eggs hatched. The incubation period varied from 3 to 8 days, with 62 per cent hatching on the fourth day and 29 per cent on the fifth. The average length of time was 4.4 days.

Larval stage.—The larvae which later transform to adult females pass through four instars and those to become males pass through three. Moreover, the females require a longer time to reach adulthood; an average of 14.1 days was required for the development of the female larvae and 11.4 days for the male. Table 1 indicates the length of the instars of each sex. The width of the head capsule was used as the criterion for determining the number of larval instars. The larvae upon which these determinations were made were reared at room temperature upon a medium of starch agar in which soluble starch was substituted for potato starch in Formula 54 of Fred (3).

TABLE 1.—The Larval Instars of *Pnyxia scabiei* (Hop.) Reared on Starch Agar

	Number of observations	Head width, in mm.	Duration, in days	
			Range	Average
Female				
1st instar	17	.088–.090	4– 7	5.6
2nd instar	17	.106–.142	2– 6	2.7
3rd instar	17	.176–.189	1– 6	2.9
4th instar	4	.222–.285	1– 5	2.9
Total period			10–16	14.1
Male				
1st instar	10	.088–.090	4– 6	4.5
2nd instar	9	.132–.142	1– 7	3.1
3rd instar	10	.176–.189	2– 5	3.8
Total period			10–14	11.4

Pupal stage.—The duration of the pupal period varies from 2 to 7 days. There is no apparent difference between the sexes in the duration of this period.

Adult stage.—Under laboratory conditions females have been kept alive for as long as 3 days. It is believed that this is a shorter period than occurs in nature, since most of the females died in captivity before they had deposited all their eggs. Males have lived 7 days in captivity.

Duration of life cycle.—The life cycle, according to laboratory rearings, may be completed in as few as 15 days, although the average length of time is 22.6 days. Since reproduction is continuous throughout the growing season and may extend into the storage season, it is apparent that several complete generations may develop during the course of a single year. Table 2 summarizes the data obtained by rearing the insect on starch agar at room temperature.

TABLE 2.—The Life Cycle of *Pnyxia scabiei* (Hop.)

Sex	Egg stage		Larval stage		Pupal stage		Total	
	Range	Av.	Range	Av.	Range	Av.	Minimum	Av.
	Days	*Days*	*Days*	*Days*	*Days*	*Days*	*Days*	*Days*
Male	3–8	4.4	10–14	11.4	2–6	4.5	15	20.3
Female	3–8	4.4	10–16	14.1	2–7	4.1	15	22.6

METHODS OF OVERWINTERING

The potato scab-gnat is capable of living through the winter under any condition at which potatoes can be stored, provided ample moisture is present. The insect has never been found upon potatoes stored in dry buildings, although a large number of potatoes from such places has been examined. Outdoor pits provide favorable conditions for overwintering, since they are usually quite moist. The insect has been found to overwinter on potatoes in the basement of a residence.

The insect is also able to pass the winter under field conditions. This has been demonstrated by the fact that tuber injury frequently occurs in fields known to have been planted with insect-free seed. The stage in which the insect overwinters in the field has not been determined.

TABLE 3.—The Relation of Temperature to Activities of *Pnyxia scabiei* (Hop.) in Storage

Box	Date of preparation	Date of examination	Range of temperature	Mean temperature	Condition of potatoes at time of examination*	
No.			*°F.*	*°F.*	*Infested*	*Clean*
1	2-24-27	4-1-27	46-100	66.6†	52	8
2	2-24-27	4-1-27	35- 48	38.8‡	36	24
3	2-24-27	4-1-27	23- 42	35.5†	22	38

*Fifty clean and 10 infested potatoes originally in each box.
†By planimeter method (2).
‡Based on 3-hour readings of thermograph sheet.

Low temperature inhibits the activities of the insect, but temperatures as low as those at which it is possible to store potatoes do not prevent its activities. This has been demonstrated by an experiment in which lots of 60 potatoes each were stored in three galvanized iron boxes at different temperatures. The boxes were 14 inches square and 8 inches deep. A 2-inch layer of lake sand was spread on the bottom of each box. Upon this sand was deposited a layer of insect-free potatoes, and upon these were placed 10 potatoes known to be infested. A sufficient number of potatoes to make a total of 60 was placed over the layer of infested potatoes, and all were covered with sand. The contents of each box were kept moist throughout the experiment. One of these boxes was stored in a greenhouse with a mean temperature of 66.6° Fahrenheit, and two were placed in cold storage—one at a mean temperature of 38.8° and the other at 35.5°. When the potatoes were examined 40 days later, it was found that the insects had spread from one potato to another in all three lots and evidently had increased in numbers, thus indicating that reproduction had occurred. The amount of spread was less at the lowest temperature than at either of the higher ones. The results are shown in Table 3.

HABITS

The potato scab-gnat in its larval stages feeds under cover. This cover may be refuse or decaying parts of the infested tuber, the surrounding soil, or a web which the insect spins. The larvae are most easily found by examining wounded areas of infested potatoes. These wounds normally are more or less filled with refuse beneath which the insects feed on the sound parts of the tuber.

When preparing for pupation, the larva leaves the place of feeding and conceals itself either in debris or under a spun web, where it constructs a delicate cocoon. The pupa may be attached by its caudal end when in contact with a solid surface, or it may remain free when no solid surface is present. In all instances the last larval skin and the head capsule may be observed where they were cast, near the posterior end of the pupa.

In the laboratory, when the time for emergence approaches, the pupa migrates to the surface of the medium or to the exterior of the cocoon when not imbedded in the medium. Emergence takes place through a longitudinal slit in the dorsal surface of the pupal case.

Sex attraction is pronounced, copulation occurring almost immediately upon emergence. In several instances males have been observed hovering about a cocoon containing a female pupa from which an adult was soon to emerge. Males have been observed to mate with several females, and the females may also mate with more than one male; but, in the latter case, this always occurs within a brief period of time after the first mating. It is not essential, however, that mating occur immediately after emergence since, under controlled conditions, 24-hour females have been mated and later have produced eggs normally.

No evidence of parthenogenesis has been found. Females have been isolated during the entire span of their adult lives, but under such conditions no eggs were deposited.

Egg deposition begins within a few hours after copulation. When oviposition is to begin, the female searches for a suitable place. The preferred places are soft spots on tubers, cracks and crevices in the soil, and under loose soil particles. In the absence of a suitable place, eggs will be deposited on firm objects, such as the skin of a potato or the surface of the soil.

When the female has found a suitable place for oviposition, her abdomen is inserted for its entire length if the cavity has sufficient size. The number of eggs laid in a given place depends upon the shape and size of the cavity. In many cases the eggs are deposited singly. They may be laid end to end in narrow slits; in larger cavities, clusters of a variable number of eggs may be deposited without apparent systematic arrangement. Almost invariably the eggs were completely hidden from view. The largest number observed in a single cluster was 20. The oviposition studies were conducted in cages similar to those used in determining the incubation period of the eggs.

It is believed that in the field the eggs are deposited singly rather than in clusters, since the few eggs which have been found in the field were thus deposited, either on the tubers or in the soil nearby.

Laboratory observations indicate that each female may deposit from 45 to 110 eggs during her life. In only a few cases, however, had oviposition been completed before death, since after death the abdomen remained distended and usually upon dissection a number of eggs could be found.

Both males and females are adept at concealing themselves by crawling into crevices or under loose particles of soil. Males with long wings readily take to flight when disturbed; whereas those with shorter wings are incapable of flight. It is difficult to see this insect because of its dusky color and extremely small size.

The life cycle of the potato scab-gnat may be completed without the insect leaving the tuber. This is borne out by the fact that all stages of the insect have been found upon a freshly dug tuber.

NATURAL ENEMIES

The potato scab-gnat in its subterranean habitat appears to be relatively free from natural enemies. One of the common centipedes, *Lithobius forficatus* Linn., has been found frequently on infested potatoes in the field and has been responsible on several occasions for the destruction of all scab-gnats in laboratory cultures.

FOOD MATERIAL

The potato scab-gnat may be considered a general feeder. It has been reared on or in potato tubers, decaying organic matter in the soil, barnyard manure (11), peony bulbs (13), and cucumber plants under glass (14). It has been collected from leaf mold (12), and on one occasion the author collected both larvae and adults on an old bone buried in a potato field.

The author has observed it feeding upon and within the stems of young potato plants, on damaged onion bulbs in the field, and upon an injured parsnip root. However, the larvae were most commonly observed feeding upon potato tubers and seed pieces; hence, it is believed that the potato is usually the preferred food.

NATURE AND EXTENT OF DAMAGE

The damage done by the potato scab-gnat may become evident at either, or both, of two seasons of the year. It may appear in the spring when the insects attack the seed piece and occasionally the tender stem of the young plant, or it may occur later during the growing season when its presence is manifested by the wounds found on the new-crop tubers at harvest time. A still further, though less usual, type of injury is that which continues after potatoes are placed in storage. If the storage is kept dry and cool, this type of injury is not likely to occur.

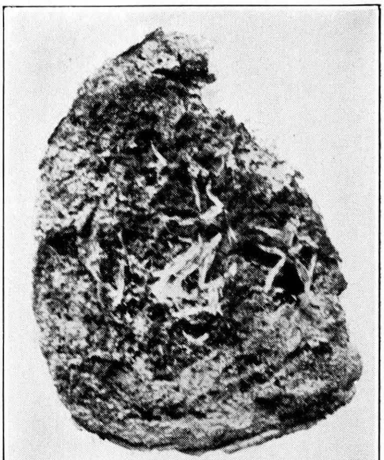

Fig. 3.—Seed piece destroyed by potato scab-gnat larvae. The elongate white objects are full grown larvae. Slightly enlarged.

When the damage is done to the seed piece in the spring, the stand may be reduced by the destruction of all of the flesh of the set, thus removing the source of nutrients for the sprout. This type of injury is shown in Figure 3. In one field under observation in 1926, at least 25 per cent of the stand was destroyed in this manner. When the infestation is less severe, only a portion of the flesh may be consumed. In this event a weak sprout which lacks vitality develops and, consequently, reduces the yield to a degree corresponding to the amount of the injury to the seed piece. This lack of thriftiness is illustrated by comparing illustrations A and B in Figure 4, the former showing a normal sprout and the latter a sprout from a severely injured seed piece. Sprout tubers were found very frequently to develop on sprouts from severely injured seed pieces.

It is characteristic of the insect to establish itself on the cut surface of the seed piece, although it frequently attacks the skin side. Figure 4 A illustrates the latter type of injury. In cases of heavy infestation, the stem of the plant may be attacked as well as the seed piece. Larvae have been found within and on the stem of the plant both below and above the surface of the soil.

The injury to the tuber crop may vary greatly, ranging from small scab-like abrasions on the skin to the formation of large, deep cavities in the tuber. Figure 5 A shows a potato bearing some of the smaller wounds. The degree of injury of this type varies from one wound per tuber to a number sufficient to involve the entire surface. Figure 5 A also depicts large, relatively shallow wounds. This type of damage is common. Large and deep wounds which frequently penetrate to the depth of 1 inch into the flesh of the tuber are shown by Figure 5 B and C.

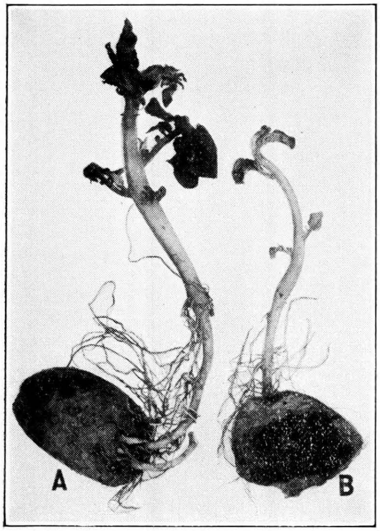

Fig. 4.—A—Normal sprout from seed slightly injured on skin side. B—Sprout from severely damaged seed piece, showing lack of thriftiness.

The wounds made by the potato scab-gnat may be differentiated with a fair degree of accuracy from the lesions caused by the common scab organism, *Actinomyces scabies* (Thax.) Güssow. Damage caused by common potato scab is described by Chupp (1) as follows: "In each case the corky ridges of the lesion are arranged more or less plainly in concentric everwidening circles". Wounds made by the potato scab-gnat show no evidence of concentric ridging; instead, the skin of the potato surrounding the wound remains normal to the edge. The deeper wounds are filled with a brownish refuse which has a tendency toward a spongy structure.

General surveys to determine damage caused by potato insects were conducted in the northern counties during late summer of 1926, 1927, and 1928. Two to four fields were visited in each of the counties included. In each of these fields 20 hills of potatoes were chosen at random. Each potato was examined and the findings recorded. Wireworms, the potato scab-gnat, and white grubs, named in order of their importance, were found to be responsible for practically all the insect injury noted. The findings of the survey are shown graphically in Figure 6.

On other occasions it has not been unusual to find fields in which 25 per cent or more of the tubers showed evidence of scab-gnat attack; for example, in 1931 damage was done to 60 per cent of the potatoes grown in certain experimental plots at Wooster.

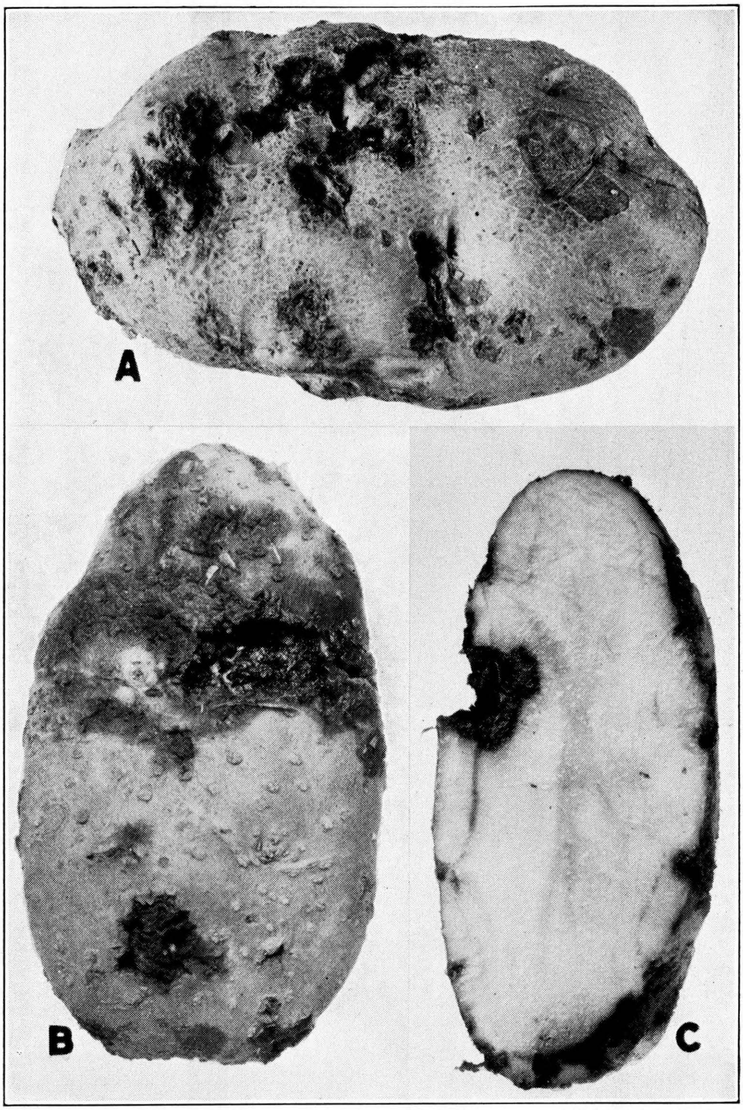

Fig. 5.—A—Both small and extensive, shallow wounds caused by the potato scab-gnat. B and C—Large, deep wounds caused by the potato scab-gnat

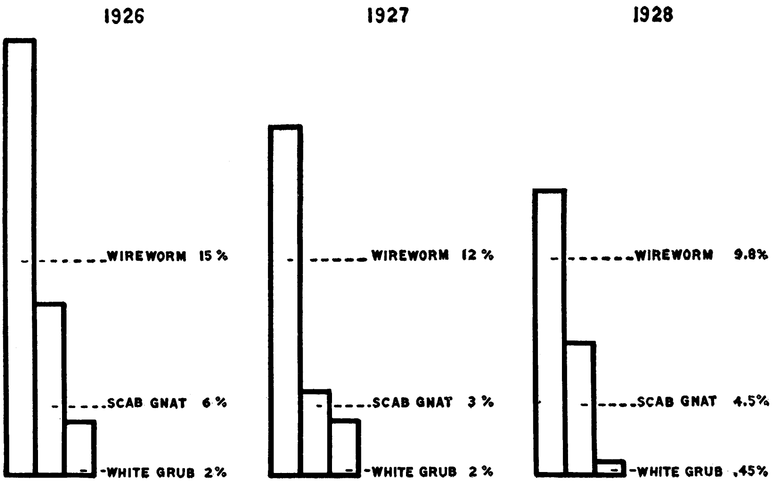

Fig. 6.—Degree of injury caused by three subterranean insect pests of the potato

METHODS OF DISPERSION

It has been shown that under favorable conditions the potato scab-gnat is able to pass the winter on seed potatoes in storage. The utilization of infested seed, therefore, must be an important method of dispersion. To determine the importance of this factor, certain plots at Wooster, apparently free from scab-gnat infestation since potatoes had not been grown previously thereon, were planted with seed which was known to be heavily infested; adjacent plots were planted with clean seed. The crops of the two series were compared at harvest time. Eighteen rows grown from infested seed produced a total of 962 tubers; of these, 124, or almost 13 per cent, were injured by the potato scab-gnat. Twelve rows planted with clean seed produced a total of 676 tubers, of which only four, or less than 0.6 per cent, were injured. In the former case, only 11 per cent of the rows was free from injury; in the latter, 66 per cent was free. This statement is made to emphasize the general distribution of the insect in the plots grown from infested seed.

It is possible for the potato scab-gnat to negotiate considerable distances through the soil, thus suggesting that clean seed may be infested after it has been planted or that the insect may spread underground from one hill to another. In determining this point, the following method was used: Glass tubes, ⅞ by 9 inches, were set in an upright position. A stopper was placed in the bottom of each, on which a piece of cut potato rested. The space above the potato was filled with soil to depths of 5 inches in some tubes and 7½ inches in others. The soil in some of the tubes was allowed to remain loose, and in others it was packed to different degrees of firmness. The potato scab-gnat in its various stages was confined in the space above the soil by means of a cheesecloth cover. The cork in the lower end was removed from time to time and the potato examined for infestation. In the majority of cases the first generation of the insect reached the potato, but in a few instances the infestation did not occur until the second generation had developed. No infestation occurred when the soil was packed in the tube above the potato.

CONTROL INVESTIGATIONS

SEED TREATMENT

Since it has been demonstrated that infested seed constitutes one of the means of disseminating infestations of this insect, seed treatment which destroys such infestations should be of value as a control measure. In Table 4 are shown the results following the use of corrosive sublimate, Semesan Bel, and hot formalin compared with no treatment. Although the differences

TABLE 4.—The Relation of Seed Treatment to Scab-gnat Injury

Treatment	1928		1929	
	Tubers produced	Injury	Tubers produced	Injury
	No.	*Pct.*	*No.*	*Pct.*
Corrosive sublimate	795	0.0	737	0.0
Semesan Bel	663	0.0	879	0.2
Hot formalin	509	0.0	823	0.0
No treatment	795	0.6	551	1.8

between the treated and untreated plots are not great, it is significant that practically no infestation occurred in the treated plots. This lack of significant differences between treated and untreated seed is due, no doubt, to the fact that slightly infested seed only was available for the experiment. No living insects could be found on any of the lots of treated seed.

CROP ROTATION

Crop rotation is of importance in the control of the potato scab-gnat. Although this conclusion has been drawn from a limited number of observations made during the surveys of 1926, 1927, and 1928, the indications are that the insect causes more damage where potatoes are grown consecutively on the same field than where some rotation is followed. Not only was the percentage of injury high but the number of fields showing infestation was also high, since in six out of the seven fields observed where potatoes had been grown consecutively injury was evident. Where sweet clover preceded potatoes in the rotation, the crop was seldom damaged by the potato scab-gnat. This point will be discussed further in the following section. Table 5 gives a summary of the fields for which rotation data were obtained.

TABLE 5.—Injury to Potatoes as Influenced by Preceding Crop

Preceding crop	Rank in humus production	Fields surveyed	Fields showing injury	Injury	
				Range	Average
		No.	*No.*	*Pct.*	*Pct.*
Sweet clover	1st	4	1	0- 3.5	0.9
Soybeans	4th	4	2	0- 5.5	1.5
Grass	5th	11	5	0-10.1	2.0
Clover	3rd	8	5	0- 6.7	2.4
Alfalfa	2nd	3	2	0- 6.7	2.6
Melons	10th	1	1	....	2.7
Wheat	6th	2	1	0- 9.2	4.6
Corn	8th	7	6	0-20.7	5.7
Potatoes	9th	7	6	0-45.0	13.6
Oats	7th	1	1	....	14.3

RELATIONSHIP OF SOIL ORGANIC MATTER TO SCAB-GNAT DAMAGE

Investigations have shown that the addition of organic matter to the soil reduces the amount of injury done by the potato scab-gnat. Plot work for the purpose of determining this relationship was conducted over a period of 3 years. The essential features of this experiment consisted each year of surface mulching one series of plots with 3 inches of straw; to another series, manure was applied and plowed under; and another series had no organic matter added.

The plot work of 1927 was of a preliminary nature, and only four plots of each treatment were included in the series. Each plot was 24 feet (eight rows) wide and 22.5 feet long, or approximately 1/80 acre in size. The greatest and only significant difference was found to exist between the plots grown under straw mulch and those where no organic matter was added, with more injury occurring under the latter conditions. Manure had been applied at the rate of about 10 tons per acre. This small amount had no apparent influence on the insect.

TABLE 6.—Relation of Soil Organic Matter to Tuber Injury by Potato Scab-gnat

	Treatment	Average injury	Treatment	Average injury	Difference in degree of injury	Odds that results are not due to chance
		Per cent		*Per cent*		
1927 1/80-acre plots	None	5.76	Straw mulch	2.84	2.92	20.1 to 1
	Manure	5.70	Straw mulch	2.84	2.86	11.4 to 1
	None	5.76	Manure	5.70	0.06	1.0 to 1
1928 1/129-acre plots	None	5.60	Straw mulch	0.13	5.47	9999.0 to 1
	Manure	1.30	Straw mulch	0.13	1.17	63.9 to 1
	None	5.60	Manure	1.30	4.30	29.7 to 1
1929 1/121-acre plots	None	6.33	Straw mulch	0.70	5.62	43.2 to 1
	Manure	4.49	Straw mulch	0.70	3.79	24.6 to 1
	None	6.33	Manure	4.49	1.84	2.6 to 1

In 1928, the series was expanded to include eight plots of each treatment. All of the plots in this test received an application of ground limestone in the spring. Where manure was used, it was applied at the rate of 20 tons per acre. The plot size was reduced to 15 feet (five rows) wide and 22.5 feet long; each plot contained 1/129 acre. The results show that a straw mulch gave the best protection. They also show that manure at the rate used offered a considerable degree of protection. The most severe injury occurred where no organic matter had been added.

In 1929, in order to adapt the experiment to new implements the plot size was again changed to 16 feet (six rows, 32 inches apart) wide and 22.5 feet long. These plots contained 1/121 acre. During the year manure at the rate of 20 tons per acre failed to give the desired protection, and no significant difference in injury between the manured plots and those which received no manure was to be found. Straw mulch again provided the best protection.

A summary of the three seasons' work on the effect of the treatments on the insect is given in Table 6. The data have been analyzed statistically by methods given by Fisher (4).

Yield records were taken of the potatoes grown under the different treatments. A summary of the 3 years' work is shown in Table 7.

It is of significance to note that the treatment which produced the cleanest potatoes also produced the highest yield. In this experiment straw mulch protected the crop from injury to a greater degree than did the addition of manure, but the yields did not vary significantly, excepting in 1927, when the light application of manure did not materially affect the yield.

TABLE 7.—Influence of the Addition of Organic Matter on Yield

	Treatment	Average yield per plot	Treatment	Average yield per plot	Difference of average yields per plot	Odds that results are not due to chance
		Lb.		*Lb.*	*Lb.*	
1927 1/80-acre plots	None	239	Straw mulch	298	59	82.3 to 1
	Manure	245	Straw mulch	298	53	82.3 to 1
	None	239	Manure	245	6	1.6 to 1
1928 1/129-acre plots	None	105	Straw mulch	128	23	1666 to 1
	Manure	122	Straw mulch	128	6	5 to 1
	None	105	Manure	122	17	624 to 1
1929 1/121-acre plots	None	62	Straw mulch	92	30	Over 9999 to 1
	Manure	89	Straw mulch	92	3	4.2 to 1
	None	62	Manure	89	27	Over 9999 to 1

Organic residue from crops preceding potatoes is of value in preventing tuber damage by the potato scab-gnat. When potatoes followed crops which returned the largest amount of organic matter to the soil, scab-gnat injury was relatively low; but, when the preceding crop was one that returned a small amount of organic matter to the soil, the damage was higher. In Table 5 the 10 crops under consideration are ranked in the approximate order of their ability to add organic matter to the soil. The percentage of fields producing injured potatoes was lower in those fields ranking highest in humus production than in those ranking lowest. This is probably the reason why fields on which sweet clover had been grown previously produced potatoes which were injured only to a slight degree.

The addition of organic matter to the soil does not appear to be inimical to the insect's development. In the early part of the season the potato scab-gnat seems to prefer the cut surface of the seed piece to the organic matter in the soil; but later, if organic matter is abundant, this seems preferred to the growing tubers.

SOIL REACTION IN RELATION TO POTATO SCAB-GNAT ACTIVITIES

Hopkins (9) determined that *Pnyxia scabiei* was tolerant to alkaline soil conditions. During 1927, 1928, and 1929 attempts were made in Ohio to test the value of this factor in relation to the control of the insect. The plot sizes referred to in the previous section of this paper were used in this experiment. Forty-eight plots were used in 1927, 48 in 1928, and 60 in 1929.

Each year certain treatments were applied to the series of plots in order to adjust the reactions in such a manner that plots ranging from low to high pH values were represented. Limestone was applied to increase the alkalinity (increase the pH value) and inoculated sulfur was used to increase the acidity (decrease the pH value). By these methods a range from pH 4.3 to pH 7.8

was obtained. The soil reaction was determined by use of the Morgan Soil Testing Outfit. Data were taken on the degree of injury to the tuber crop by the insect and the yields of potatoes. Inasmuch as sulfur is employed quite commonly as an insecticide, the thought presents itself that a direct killing influence might have resulted from this material in the soil. The maximum quantity used was 1000 pounds per acre; and, since this is equivalent to only 1 pound to 2000 pounds of the surface 6⅔ inches of soil, it would seem that this extreme dilution of the sulfur would exercise no direct effect on any stage of the scab-gnat.

For each of the 3 years of this experiment, the percentages of injury when compared with the pH value of the various plots show that, excepting in 1927, a distinct and significant correlation existed between the two. The results are summarized in Table 8. The data indicate that the insect is able to tolerate a high degree of alkalinity but is unfavorably affected by acidity brought about by the addition of inoculated sulfur. The insect was not completely controlled by decreasing the pH value of the soil since some of the tubers from the plot having a pH value of 4.3 were damaged.

TABLE 8.—Relation of Soil Reaction to Injury

Year	Range		Correlation coefficient	Odds that results are not due to chance
	pH value	Injury		
		Pct.		
1927	4.5–6.0	1.1–10.1	.35	5.67 : 1
1928	4.3–6.9	0.0–11.9	.50	Over 3,333,332 : 1
1929	4.6–7.8	0.0–21.1	.41	Over 3,333,332 : 1

When the yields of the plots were correlated with the pH values, it was found that the yield was materially reduced as the acidity of the soil increased; and, when these data were subjected to statistical analysis, it developed that this correlation was emphasized for 1928 and 1929 but did not appear significant in 1927. This relationship is shown in Table 9.

TABLE 9.—Relation Between Soil Reaction and Yield

Year	Range		Correlation coefficient	Odds that results are not due to chance
	pH value	Plot yield		
		Lb.		
1927	4.5–6.0	184–366	.13	Equal
1928	4.3–6.9	79–160	.69	Over 3,333,332 : 1
1929	4.6–7.8	9–116	.60	Over 3,333,332 : 1

When given free choice of laboratory media having graduated pH values, *P. scabiei* larvae have a tendency to select a reaction approximating pH 5.0. Only a few selected more acid conditions, but a considerable number selected a more alkaline reaction. The experiment on which these statements are based consisted of six agar blocks of different pH values, 1 inch long, ½ inch wide, and ½ inch deep, poured side by side without intervening partitions in an ascending series of pH values from pH 3.0 to pH 7.8. Closely fitting upright sides confined the insects on the surface of the blocks. Twenty-five to 30 larvae were distributed on the agar, and the containing vessel was placed in a dark, moist chamber for a period of 48 to 60 hours. The larvae wandered about on the surface of the agar for a while, then settled down, and began feeding. It is assumed that the place of recovery of a larva represented the optimum pH value for that insect. The final placement of the larvae is given in Table 10.

TABLE 10.—Larval Reaction to Media with Adjusted pH Values

pH value	Number larvae recovered							
	Series							
	1	2	3	4	5	6	7	Total
3.0	5	0	0	0	2	0	0	7
4.0	10	4	5	1	2	0	0	22
5.0	6	9	5	9	7	17	3	56
6.0	0	9	1	5	6	0	4	25
7.0	1	4	3	2	5	0	0	15
7.8	1	0	4	5	3	1	1	15
Total	23	26	18	22	25	18	8	140

For some unaccountable reason 10 larvae were recovered from the pH 4.0 block in Series 1. It is evident that an error of some sort must be held accountable for this result, since it is wholly out of line with all the other reactions of the series, as well as with the performance of the insect under field conditions.

CONTROL BY SUBMERSION

As has been indicated previously, Speyer (14) reported that *P. scabiei* was controlled in greenhouses in England by flooding the infested beds with water for a period of 12 hours. To test further the effectiveness of this method the writer placed 30 larvae in a small glass vessel containing tap water and kept it at room temperature. All larvae at once sank to the bottom. The experiment began on February 23, 1927 and continued until March 24. The rate of death of the submerged larvae was as follows:

Days of Submersion	Number Larvae Alive
0	30
1	28
2	27
3	19
5	15
8	15
9	10
11	5
13	4
15	1
28	1

Since the record indicates that 9 days of complete submersion were required to cause the death of 66⅔ per cent of the larvae and one remained alive after 28 days, it would appear that this procedure would have little practical value in the control of this insect. Moreover, very few Ohio growers are equipped for flooding their fields, and very few fields are sufficiently level or the soil of such a character that flooding would be possible. Finally, growing potatoes will not tolerate flooding for any extended period of time.

METHOD OF PLANTING

Since it has been demonstrated that the potato scab-gnat cannot penetrate packed soil, an effort was made to utilize this factor as a control measure. In 1928 and 1929 two series of plots were used, both of which received identical treatment throughout the season, excepting that the plots of one series were packed with a cultipacker immediately after planting and the soil of the other series was allowed to remain loose. The potatoes in both series were not cultivated until the plants were well up and the weeds became so numerous that it was necessary to cultivate. In this experiment, packing the soil did not appreciably decrease the amount of damage caused by the insect, but it must be remembered that during both 1928 and 1929 potato scab-gnat was not destructively abundant. Had this experiment been conducted during a season when the insect was prevalent, it is possible that the difference in degree of damage between the plots would have been substantially more pronounced. However, in the contemplated practical utilization of this suggested control measure, consideration should be given to the fact that sprouting and growing potato plants soon loosen the overlying soil and thus afford possible access to the plants by the egg-laying scab-gnat adults. On the other hand, if the soil is packed, this should afford a considerable degree of protection to the seed pieces.

To adopt this control measure would interfere, of course, with the common practice of early and frequent cultivation so commonly followed as a weed control measure.

GENERAL SUMMARY

The potato scab-gnat has been definitely recognized as a potato pest since 1895. Two serious outbreaks have occurred in Ohio, the first in 1910 and the second in 1926.

This insect is generally distributed in Ohio and has been found in several other states from Missouri to New York and West Virginia to Michigan.

The potato scab-gnat is not easily observed in its natural habitat because of its small size and its habit of concealing itself. The larval stage is the one most frequently found.

The insect may overwinter in the field or on stored potatoes. In storage, it tolerates any temperature suitable for potatoes but is most active if both temperature and humidity are relatively high.

Insofar as it has been observed, the potato scab-gnat is almost free from natural enemies. One species of centipede has been found to consume large numbers of the larvae.

The insect feeds upon a variety of materials, but the potato is the only crop which the author has observed to be injured by it. Injury to this crop may be to the seed piece, to the tender, growing stems of the plants, or to the tuber crop. When the seed piece is attacked, the stand may be reduced or the vitality of the plant which grows from the injured seed piece may be impaired.

The damage done to the tuber crop is usually confined to a low percentage of the total yield but is important in that it occurs in some degree year after year. Occasionally, a high percentage of the crop may be damaged. The extent of injury occurring to a potato may be slight and confined to a small area, or it may be so severe that the entire surface may be affected. Wounds of large area and as much as 1 inch in depth have been found.

Treatment of seed with corrosive sublimate or hot formalin will destroy all insects present at the time the work is done.

Potato scab-gnat injury is more severe when potatoes are grown more than 1 year in succession in the same field.

Potatoes grown in soils in which the organic content is high or when straw mulch is used in the cultural practice are less susceptible to damage than when smaller amounts of organic matter are present.

The activities of the potato scab-gnat are favored by soil reactions above pH 5.0 and are inhibited by lower reactions. Laboratory tests also have shown that the larvae select media with a reaction at or above pH 5.0 in preference to more acid conditions.

Potato scab-gnat larvae are able to live for a considerable length of time when submerged in water. Of the larvae subjected to submersion tests, 66⅔ per cent lived for 9 days.

Migration through loose soil from the surface downward or from one hill of potatoes to another can be accomplished by the potato scab-gnat.

SUMMARY OF CONTROL MEASURES

Preferably, potatoes free from scab-gnat injury should be used for seed; but, if such are not available, the seed should be treated with corrosive sublimate or hot formalin according to the standard recommendations for controlling common potato scab.

Potatoes should not be grown for 2 or more years in succession in areas where scab-gnat injury has occurred.

Cultural practices and cropping systems which return the maximum amount of organic matter to the soil afford a considerable degree of protection.

The soil should be maintained at a reaction of pH 5.0 or slightly above. This may be done by avoiding heavy liming programs, or, if the reaction is high, it may be reduced by applying sulfur or other chemicals. The latter procedure, however, is attended with some risk and should not be attempted without careful study.

Fortunately, the most useful measures applicable to scab-gnat control follow the commonly recognized better practices for potato culture.

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