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G. B. Spawn

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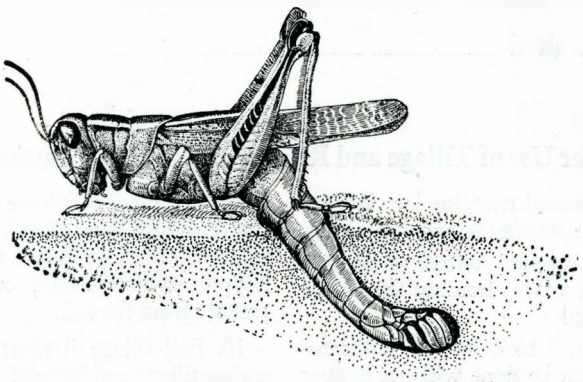

Two-striped Grasshopper: Female laying eggs.
Slightly more than natural size

Entomology Department
AGRICULTURAL EXPERIMENT STATION
South Dakota State College of Agriculture and Mechanic Arts
BROOKINGS, S. D., the Soil Conservation Service, cooperating

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Suggestions for Use of Tillage and Related Practices in Grasshopper Control

1. Examine fields and margins late in September to determine amount of egg deposition.

2. Consider soil erosion control as well as grasshopper control when choosing the tillage implement to be used.

3. Deep plowing, 5 to 6 inches, is recommended where it can be done without danger of soil blowing or excessive soil drying.

4. Tests tend to indicate that next in order of effectiveness are discing (various types); duckfoot type sub-surface cultivation; listing; and, straight blade type sub-surface cultivation.

5. Cultivate with a spring-tooth harrow late in fall or early in spring to reduce hatching of 'hoppers in alfalfa fields, (9, p. 32).*

6. Thoroughly disc any cultivated land which remains idle through summer and fall. These may be "'hopper hot-beds."

7. Till fields immediately after harvest to create unfavorable soil conditions for egg laying. Use trap strips, then till them late in the fall. See page 9.

8. Avoid the practice of "stubbling in" a crop without prior tillage treatment.

9. Any type of tillage which disturbs the surface 2-inch layer of soil, if done at the proper time, will serve to reduce the number of grasshoppers which would otherwise hatch and emerge from the soil.

10. Fall tillage is most effective, but early spring tillage can be used to advantage.

11. If State fall egg survey indicates 'hopper outbreak the following year, plan to plant immune, resistant or early maturing crops.

12. In headlands, fence rows and edges of pastures and range adjoining fields, the **timely** use of poison bait is recommended. Poisoning is most effective while 'hoppers are small and before they scatter out from their hatching grounds.

13. Plan control campaigns in advance. If grasshoppers are numerous in the summer start the following fall to control the next year's crop of insects.

14. Control campaigns are more effective when conducted on a community basis.

*See "Literature Consulted," page 16.

Tillage Methods in
Grasshopper Control

By Gerald B. Spawn*

During the past 90 years of agricultural history in South Dakota, 41 have been years in which grasshoppers in localized areas were present in numbers sufficient to do considerable damage to crops. During 17 of these 41 years grasshoppers have been a serious pest of agricultural crops over a large part of the state.

These insects, in South Dakota alone, have destroyed millions of dollars worth of cereal, forage and truck crops in each of the past several years, the loss figure of $42,303,030 being given for the five-year period of 1937-41, inclusive.† For this same period South Dakota Crop and Livestock Reporting Service (12) gives the figure of $151,906,000 as the total value of cereal, forage and truck crops harvested, (exclusive of buckwheat, small fruits and berries). In this case gross income includes cash income plus the value of the product used for feed, etc., on the farms where the product was produced (12). On this basis then, grasshoppers caused a loss of slightly over 21 percent of the value of cereal, forage and truck crops during the five-year period mentioned.

The fact that grasshoppers destroy crops to such an extent is reason enough why they should be considered a major insect pest. However, their attack on crops and the resulting financial loss to Great Plains farmers, ranchers and truck gardeners is not the entire story of loss brought about by these insects.

Increased soil erosion in fields in certain parts of South Dakota has been directly traceable to grasshopper damage. In years of extreme grasshopper abundance numerous fields, particularly of corn, have been completely denuded of vegetative cover and laid bare to the winds as a result of grasshopper invasions. Fields of small grain, especially if planted late in the spring or sown with a late-maturing variety, occasionally have suffered a smiliar fate, although usually not to the extent of complete removal of cover. Attempts by Soil Conservatoin Service personnel to regrass badly blown fields in certain parts of the Great Plains area have been defeated at times by grasshoppers which ate the grass shoots as fast as they came through the soil. Thus, in parts of the Great Plains area, grasshoppers are recognized as one of the major problems of successful farming, soil conservation and range and pasture management.

It has been known for some time that certain cultural methods help hold grasshoppers in check. It is generally conceded that certain types of tillage, completed late in the fall after the eggs have been laid or early in the spring before the eggs start to hatch, will bring about a decrease in the numbers of grasshoppers produced on a given area of ground. However, available data indicates that to date little work has been done in evaluating the different tillage methods on the basis of the actual numbers of young 'hoppers which emerge from the variously tilled areas.

The North Dakota Agricultural Experiment Station apparently has most nearly approached this as an ideal in studies of the effect of spring (and some figures on fall) tillage methods on grasshopper populations, (3) and (4). The conclusions were based on a survey of the tilled areas and the untreated check areas for numbers of young 'hoppers found per square foot after hatching had taken place.

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†These unpublished data were furnished by G. I. Gilbertson, Entomologist, Extension Service, South Dakota State College, Brookings, South Dakota.

The South Dakota Agricultural Experiment Station project was undertaken in an attempt to obtain comparative value figures for various tillage methods from the standpoint of destruction of grasshopper eggs, prevention of hatching of the eggs, and prevention of egg deposition. The project was started in the fall of 1939.

Because of the hazards of grasshoppers to soil conservation projects and because of the effect that tillage might have upon soil and moisture conservation, this work was done in close cooperation with the Soil Conservation Service. The cooperation of the Soil Conservation Service was very valuable to the South Dakota station on this project.

Recommendations to Date and Other Work Done

For the past 12 years various tillage methods have been recommended to aid in the control of grasshoppers by the destruction of their eggs.

Moldboard plowing has been highly recommended with deep plowing, 5 to 6 inches, apparently more effective than shallow plowing, 2 to 2½ inches, (1, 2, 3, 4, 5, 6, 7, 9, 10 and 11). This method should be used only in areas where plowing can be done without serious danger of soil blowing or of excessive soil drying.

The duck-foot cultivator, when used as a shallow-tillage implement, has recently been acclaimed as the best implement for use in treating stubble fields for grasshopper control, (9, p. 32), while in North Dakota it gave poor control, (4, p. 9). Other workers, (1), have recommended its use.

Tillage by means of either the wheatland plow or by the regular single or double disc has been advised for grasshopper control, (1, 3, 5, 7, 9 and 10).

Harrowing either with spike or spring-tooth harrow has been recommended for grasshopper control in certain instances, such as in afalfa fields of several years standing, (1, 7, 9, and 10).

Fall tillage, except possibly in the case of deep plowing, is considerably more effective than is spring tillage. This statement is verified by the results of the North Dakota work (3 and 4), which was conducted over a period of three seasons of spring and two of fall tillage on the problem.

Even though recommendations for tillage in grasshopper control have been made for a number of years, up until 1939, no attempt had been made to obtain figures by which a comparison of the effectivness of the various methods were possible. Both the South Dakota and the North Dakota studies were begun in that year.

Facts of Importance in Planning for Grasshopper Control

The Most Injurious Kinds of Grasshoppers. Most grasshopper damage to cereal, forage, and truck crops, and to gardens in South Dakota is done by three (and occasionally by a fourth) species of grasshoppers. For several reasons it would be extremely difficult to say just which one does the most damage. In the first place, the abundance of certain species will vary with different years. Secondly, some species hatch earlier than others and as a consequence may damage different crops. Early-maturing crops may and often do reach a stage where they can be harvested before suffering any damage by the later hatching species. In years of grasshopper abundance late gardens and late-maturing vegetables may suffer severe damage from the first three species discussed in the following paragraphs.

The two-striped grasshopper, *Melanoplus bivittatus* (Say), is usually between 1 and 1¾ inches in length and is yellowish to yellowish-brown in color. It has two bright yellow stripes extending lengthwise over the back from behind the eyes to the tip of the first pair of wings, (10). This species hatches early and adults have been recorded by July 10. This grasshopper, then, may do considerable damage to small grain and later to corn and alfalfa.

The differential grasshopper, *Melanoplus differentialis* (Thomas), is about the same size as, or slightly larger than, the two-striped. It "is usually of a bright yellowish-green color, un-

striped, and more or less marked with black. In some specimens the black color is more extensive, while in a small percentage of the locusts it is the predominant color," (10). In South Dakota this species usually hatches from two to three weeks later than does the two-striped 'hopper. It then, may damage later-maturing varieties of small grain and when abundant does serious damage to corn. It may also do serious damage to alfalfa, especially to the seed crop. Both of the above mentioned species may be bad in flax.

The lesser migratory locust, or grasshopper, *Melanoplus mexicanus* (Sauss.), is one of the smaller species. It is more slender than the two mentioned previously and is from ¾ to 1¼ inches in length. The first pair of wings is marked with definite dark spots, (10). This is an early-hatching species and when abundant it may do serious damage to small grain, alfalfa and flax. The damage to corn by this species is usually not as important as that done by the two-striped and differential grasshoppers, although at times it may greatly reduce the yield by eating off the silks and thus reducing the opportunity for successful pollination.

Formerly considered one of the most detrimental species of grasshoppers in South Dakota, the red-legged locust, *Melanoplus femur-rubrum* (De Geer), now plays a minor role as a pest. This species is much the same as the lesser migratory locust in size and appearance but the front "wings are unspotted, or if dark spots are present, they are indefinite and small," (10). This is a later-hatching species and is one which may be found late in the fall. Locally it may do quite a bit of damage to alfalfa seed crops, to fall planted small grain and to fall planted grass, in regrassing programs.

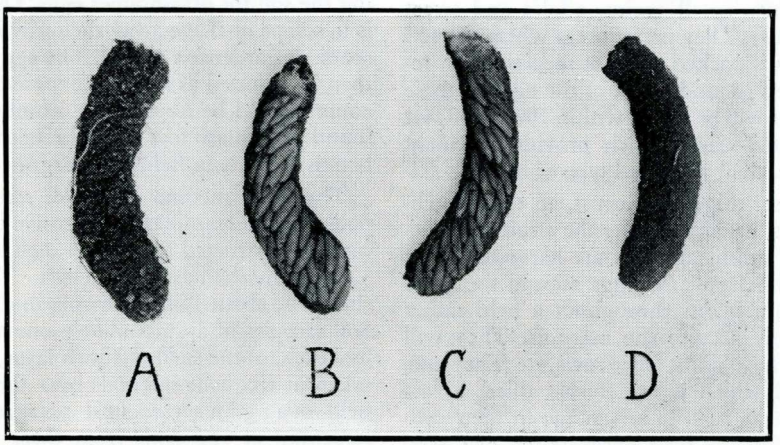

Fig. 1. Egg pods of two-striped grasshopper. A, D—egg pods intact. B, C—egg pods with portion of covering removed to show arrangement of eggs. (After Gilbertson and Severin.)

When the Eggs Are Deposited. These four species of grasshoppers pass through the winter in the egg stage. Considering the four kinds as a group, egg laying will ordinarily start in the latter part of July and continue until the first few hard frosts although most of the eggs usually have been laid by the latter part of September. The earlier hatching species are naturally the first to become adults and to lay their eggs. Each female will normally produce from 2 to 5 egg pods. The egg pods of the differential and two-striped grasshoppers are large (Fig. 1) and commonly contain from 60 to 100 eggs per pod. The pods of the lesser migratory and red-legged grasshoppers are usually considerably less in diameter and have a thinner coating of soil around the eggs, and are shorter than the pods of the larger species. They contain an

average of about 25 eggs per pod. The lesser migratory locust, under laboratory conditions, has been known to lay up to 10 egg pods, (11, p. 22).

Following the completion of egg laying, and with the approach of frosty fall nights, the adult grasshoppers die.

Where and How to Look for the Eggs. The two-striped and differential grasshoppers prefer grassy areas of not too heavy sod for their egg laying activities. Roadsides and ditch banks, fence rows, headlands, edges of pastures, cultivated land which has been allowed to lie idle for a year or more, weed patches, and similar areas are usually ideal places for these grasshoppers to deposit their eggs. However, they frequently lay their eggs in the edges of stubble fields, around the bases of corn and cane plants, and in alfalfa fields. Places selected for egg laying by these two species are "always near and usually border the preferred foods, such as corn, small grains, alfalfa and sweet clover," (10). They prefer areas where the soil is fairly well packed and not so loose as in recently tilled ground. Most of the eggs of these two species will be found within 100 to 150 feet of cultivated crops which provide succulent vegetation, their preferred type of food.

The lesser migratory locust, an early hatching species, usually reaches the adult stage before small grains and flax are harvested. This species will deposit its eggs around the bases of the grain plants throughout a field rather than mainly around the margins. They will also lay in headlands, fence rows, etc. They, too, prefer soil which is not freshly tilled, a fact which can be used to advantage in their control, (see Tillage for Concentration of Grasshopper Eggs, on page 9).

The red-legged grasshopper, hatching later in the season, is usually the last species to be seen in numbers in the fall. This species may be found depositing its eggs in grass areas such as those previously mentioned and is more likely than others, of the kinds in question, to be found in pasture areas. In years of its abundance this species may be found in numbers in stubble fields where volunteer grain provides food late in the season. These grasshoppers may also be found on idle or "go back" land and regrassed areas. Their eggs will usually be found in the immediate vicinity of such adult concentrations.

These four species usually lay their eggs no deeper than two inches in the soil, thus, it is not necessary to examine the soil any deeper than the surface 2-inch layer. Such areas as have been mentioned above should be examined late in September in order that the degree of egg infestation may be determined. Since the figures for determining the seriousness of egg infestation are given on a square foot basis it would then be well to make field examinations on the same basis. Use of either full square foot samples or two half-square-foot samples as a basis for egg pod counts is recommended. Smaller samples are likely to lead to inaccuracy in results of the count. The sample examinations should be made at fairly frequent intervals in areas where eggs are likely to be laid.

There are two common methods of examining the soil for grasshopper eggs. One method is to scrape or shave away the soil with a sharp spade or gardener's trowel. The egg pods may then be counted as they are exposed. Accurate count should be kept of the number of pods found per square foot and whether the examination is made in fields or margins.

The other method is that of screening the pods from soil samples. Inexpensive egg screens can be constructed from 1 x 4 inch boards and ¼-inch mesh hardware cloth. The frame should be about 15 by 20 inches in dimensions. Soil samples of approximately one-half square foot each, of the surface 2-inch layer, should be taken at frequent intervals over the field and field margins (see next paragraph). The screening of egg pods from these individual samples will enable one to figure the number of egg pods per square foot as an average. A common sand shovel, or round nosed shovel, can be used to obtain soil samples of about one-half square foot each.

How Bad Is the Egg Infestation. When the egg pod count has been obtained the figures may then be applied to the following chart for determination of the seriouness of the infestation. "Margins" should include all areas outside the cultivated land, such as headlands, fence rows, roadsides, edges of pastures, etc. "Fields" include any samples taken from with-

in the cultivated area. It is to be remembered that the percentage of damage which may be expected is an estimate, and actual damage may be more or it may be less, depending upon weather and other factors. This chart is a simplification of the one used by the Federal Bureau of Entomology and the State Extension Service in making the statewide grasshopper egg surveys.

Chart for Classification of Grasshopper Egg Infestations

Classification	Number of Egg Pods per Sq. Ft.		Estimated Percentage of Damage to Be Expected
	Field	Margins	
Non-economic	.25 to .37	2 to 3	0 to 5%
Light	.50 to .75	4 to 6	10 to 25%
Threatening	1.0 to 1.5	8 to 12	40 to 55%
Severe	2.0 to 3.0	16 to 24	70 to 85%
Very Severe	4 or more	32 or more	100%

As an example of the use of this chart, suppose that in a field there is an average of one pod per square foot (or one pod for every two samples of half a square foot each). This would just fall within the "threatening" classification and would indicate that one could probably expect from 35 to 45 percent damage to crops. A count of 1 pod per square foot in the margin would not even be considered to be of economic importance and less that 5 per cent damage would be expected. One must realize, however, that this chart applies only to local conditions in the case of one farm. When applied at intervals over a group of counties it gives an overall picture of the grasshopper situation to be expected for the next growing season, barring, of course, migration of grasshoppers from other areas.

Ways in Which Tillage Affects Grasshopper Eggs

There are several ways in which tillage treatments applied to grasshopper egg infested soil may serve to reduce the numbers of young 'hoppers which would otherwise be produced from the area.

Deep plowing (five to six inches) which has been recommended for use in areas where serious soil blowing is not to be feared, turns the egg pods over and buries them so deeply that if the eggs hatch at all the young 'hoppers are seldom able to reach the surface. This is especially true if the soil has had sufficient time, after the plowing, in which to become well packed. In South Dakota this is perhaps the principal way in which the eggs may be affected. It is an accepted fact that the surface layer of soil warms up more quickly than does the soil at a lower level. Temperature is a very important factor in the hatching of grasshopper eggs. When the temperature to which the eggs are subjected is lowered through the burying of the eggs, the development of the embryos within the eggs is slowed down. This extended period of time in the egg stage, even if hatching were to take place eventually, gives additional opportunity for other factors, such as molds, parasites and predators, to attack the eggs. These last mentioned factors may be even more important than the burying of the eggs, since Uvarov (13, p. 42) states that, "from the data at hand, it may only be concluded that a mere increase in the thickness of the layer of earth over the eggs can be scarcely of any influence." With heavier soils, especially, this statement possibly may be questioned.

Discing (by means of single, double, tandem, and one-way or disc plow treatment) serves to disturb the surface layer of soil. This treatment results in the exposure of certain numbers of egg pods, both broken and whole, to the drying effects of sun and wind, to predators and to parasites. Under natural conditions, without such disturbance, the eggs are quite well protected against injury due to weather. However, when the egg pods are exposed an entirely different situation prevails. According to Severin and Gilbertson (10, p. 13), "In hot dry weather the intact egg pods that were brought to the surface of the ground through discing and harrowing dry out within 48 hours. So dry do they become during this time that when one rubs them between the fingers they break up into a powder. The broken egg pods and the scattered eggs brought to the surface of the ground dry up even faster under these conditions. In cloudy cool weather, a correspondingly longer period of time will be necessary to destroy the eggs."

There are several species of insects, and near relatives, which are parasitic or predaceous upon grasshopper eggs. Disturbance of the soil and the egg pods may have a direct effect upon the availability of the eggs to some species or upon the ease with which the eggs are found by other species. Upon numerous occasions the author personally has observed, in the spring, clusters of red mites, *Eutrombidium trigonum* (Hermann) feeding on eggs brought to the surface by tillage. It is a well-known fact, however, that certain predators, (red mites, blister beetle larvae, bee fly larvae, ground beetle larvae, wireworms, etc.) will find the egg pods without the mechanical disturbance of the soil.

Rodents (ground squirrels, field mice, and other animals) eat grasshopper eggs which they find by digging in the soil. These animals, probably by means of their sense of smell, are able to locate egg pods with considerable accuracy. As many as 17 individual "diggings," presumably made by mice, have been observed in one square yard of soil surface. Around all but four of these was evidence that the animals apparently had found what they were seeking. Occasional scattered eggs and parts of pods were found in 13 of the "diggings."

Birds, too, will feed on grasshopper eggs. Exposed pods should be much more readily available to rodents and birds than pods which remain undisturbed in the soil.

Both spike and spring tooth harrows, under certain conditions, disturb the soil and the egg pods to the disadvantage of the eggs.

Sub-surface cultivation applied to fields in the Great Plains area, is usually done for the purpose of killing the fall growth of weeds which otherwise would transpire moisture from the soil. It is also used to put the soil into condition to receive and hold more moisture than otherwise would be held, because it loosens the surface soil. There are several types of sub-surface cultivation. The kinds used in the Great Plains area fall principally into two groups: (1) straight blade and (2) duck-foot or sweep type.

In the straight blade type, a blade 6 to 8 feet long and 4 or 5 inches wide, is mounted on a heavy framed machine so that it cuts or "shaves" through the soil at a predetermined depth. The blade may be set level, so that the soil is raised little, if any, or it may be set at an angle so that the soil will be raised and will break up as it "flows" across the cutting blade. From the standpoint or weed destruction the level position of the blade is efficient, but it apparently does not disturb the soil sufficiently to aid in the destruction of many grasshopper eggs. The machine is more effective for the latter purpose if the blade is set so that the soil breaks up as it flows across.

The duck-foot or sweep type of sub-surface cultivation may again be divided into two kinds: (1) narrow sweep and (2) wide sweep. In principle, these machines, with their V-shaped shovels or sweeps, may be used to give much the same effect as does the straight blade. The shovels may be set level or at an angle. The machine is much more effective against grasshopper eggs when the shovels are set to give a certain amount of actual cultivation or breaking up of the soil.

Listing, if done in the fall, has given indication of only fair control in heavy soils. Spring listing gave no control in the test conducted.

Considering tillage methods as a group there is always a certain amount of mechanical injury, breaking and crushing, to pods and the eggs contained within them. The actual amount of damage of this kind may be relatively slight. It is a factor worthy of mention, nevertheless, when we consider the aggregate of benefits derived from tillage.

Whatever may be the particular tillage method a farmer may choose to use, one important fact should be remembered. Thoroughness, in the use of tillage for grasshopper control, is of utmost importance. Care should be exercised to see that the surface layer of soil is disturbed sufficiently to bring about the destruction of the eggs. Every potential grasshopper producing area, which can be tilled, should be thoroughly treated.

A rather frequent comment, with respect to control campaigns, is, "What good does it do me to kill off my grasshoppers if my neighbor doesn't kill his? His will come over and eat my grain."

Cooperation, in a grasshopper control campaign is essential to the best interests of all farmers concerned. It should be remembered, however, that the 'hoppers which do the most

damage to cereal and forage crops, are usually produced right in the immediate vicinity. An individual farmer will benefit from control of local grasshoppers because damage to his own crops ordinarily will be reduced in proportion to the reduction of the 'hopper population. After grasshoppers start to migrate, later in the season, this statement will not hold true. By that time, though, early maturing small grain usually will have been harvested.

Farmers should not expect to obtain complete control of grasshoppers through tillage alone. Certain areas exist on most farms where tillage can be used only with considerable difficulty, if at all. In such areas the timely use of poison bait is strongly recommended. It is an important aid in obtaining the best results from grasshopper control efforts.

Tillage for Concentration of Grasshopper Eggs

In addition to its function as a factor in the immediate destruction of eggs, tillage has another important use in grasshopper control. Grasshoppers prefer firm, undisturbed soil for the deposition of the eggs, and they will avoid, if possible, areas of recently tilled, loose soil. This fact concerning their egg-laying habits can be used to advantage in the control program.

Stubble fields of small grain, tilled immediately after harvest, make undesirable egg laying areas. Eggs are not usually laid in loose soil. In addition, the killing of weeds eliminates what otherwise would have provided an ample food supply for the adult grashhoppers. These are probably the two most important factors in this respect.

It is recommended that stubble fields be tilled soon after harvest to create unfavorable egg-laying conditions. In connection with this tillage it is suggested that strips of soil about 15 or 20 feet wide, and upon which no early tillage is done, be left every 15 or 20 rods in the field. These strips will then serve as areas suitable to the grasshoppers for egg laying within a surrounding unsuitable area. Egg laying will then be concentrated on these untreated strips. Late in the fall, after the eggs have all been laid, the strips should be given a tillage treatment which will serve to bring about the destruction of a large percentage of the eggs. In this connection it might also be well to leave a border of untreated stubble 15 or 20 feet wide around the entire field, later to be treated in the same manner as the strips through the field. These are

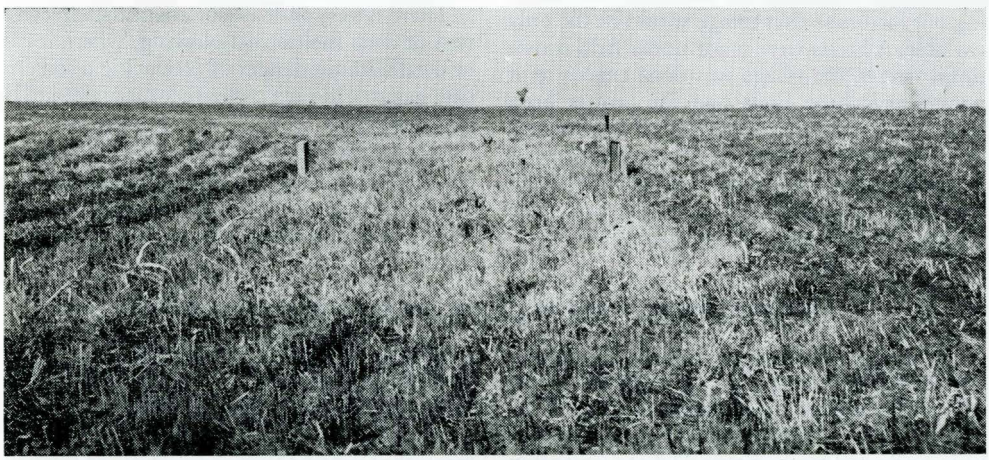

Fig. 2. Untilled strip in barley stubble. Remainder of field was duck-foot treated

the trap strips referred to in recommendation No. 7, inside the cover page of this bulletin. Such treatment will serve greatly to reduce the number of grasshoppers produced.

This method of egg concentration was used to advantage by Emmett Healey, of Chamberlain, South Dakota, in a field of barley stubble on his farm (Fig. 2). The field, except for the strips, had been tilled soon after harvest by the use of a small sweep, duck-foot sub-surface cultivator. From the non-tilled strips 162 soil samples of one-half square foot each showed an average of 3.31 egg pods per square foot. In the duck-foot tilled areas, between the tilled strips, 28 soil samples of one-half square foot each showed the average to be only 0.2 of an egg pod per square foot. The eggs were largely those of the lesser migratory locust. Late in the fall the strips were given a double disc treatment.

Fall Tillage Experiments

Fall tillage experiments in areas of heavy soil were conducted in the Winner, Reliance and Chamberlain districts. According to the Soil Conservation Service, the soil in these areas is of Boyd clay and clay loam. Fall tillage experiments in areas of light soil were conducted in the Brown-Marshall Soil Conservation District, which is headquartered at Hecla, South Dakota. The Soil Conservation Service classifies this soil as Valentine sand (a fine, "blow" sand) and Bearden sandy loam. The experimental plots were located, in different years, near Hecla, Britton, and Houghton, South Dakota. Experiments were conducted in one or two of the heavy soil districts and in one or two of the light soil districts during each year of the 5-year period covered by the studies.

Location of the experimental plots within districts depended upon the abundance of grasshopper eggs and the possibility of matching out factors so that tillage would be the only variable. All tests were made under field conditions, that is, the tillage was done exactly as it would have been done had the farmer been treating an entire field instead of a relatively small experimental plot. In this way the results obtained in the small scale experiments should have been no different than might have been expected from large scale operations.

The tests conducted gave an accurate figure for the percentage of control obtained for each tillage method during a particular year. The percentages of control given by various tillage methods, however, were not always the same from year to year. These differences were probably due to differences from year to year in: weather conditions following tillage; moisture content of the soil at the time of tillage; the covering of vegetation on the soil at the time of tillage application; and, other factors which would nevertheless be constant for any one year on all plots within a single field. Because of these differences, it was believed inadvisable at present to state definite figures for the percentage of control given by individual methods of tillage. Such figures should be available upon the completion of additional experiment on this particular problem.

There is very little doubt about the effectiveness of deep moldboard plowing, where it can be used without danger of producing a soil erosion hazard. In each experiment it proved to be most effective.

Effectiveness of other methods tended to take the following order: discing (various types), duck-foot type sub-surface cultivation, listing, and, straight blade type sub-surface cultivation.

Suggestions for Cropping Practices in Grasshopper Years

During years when grasshoppers are numerous certain cropping practices exist which can add considerably to the farmers' chances of obtaining a crop. The fall grasshopper egg survey, conducted by the South Dakota Extension Service and the U. S. Bureau of Entomology and Plant Quarantine, is a service to agriculture. While many farmers now use the survey maps, the figures might profitably be used by a much larger percentage. This survey is a forecast of grasshopper abundance for the next growing season. As such, it should form a basis

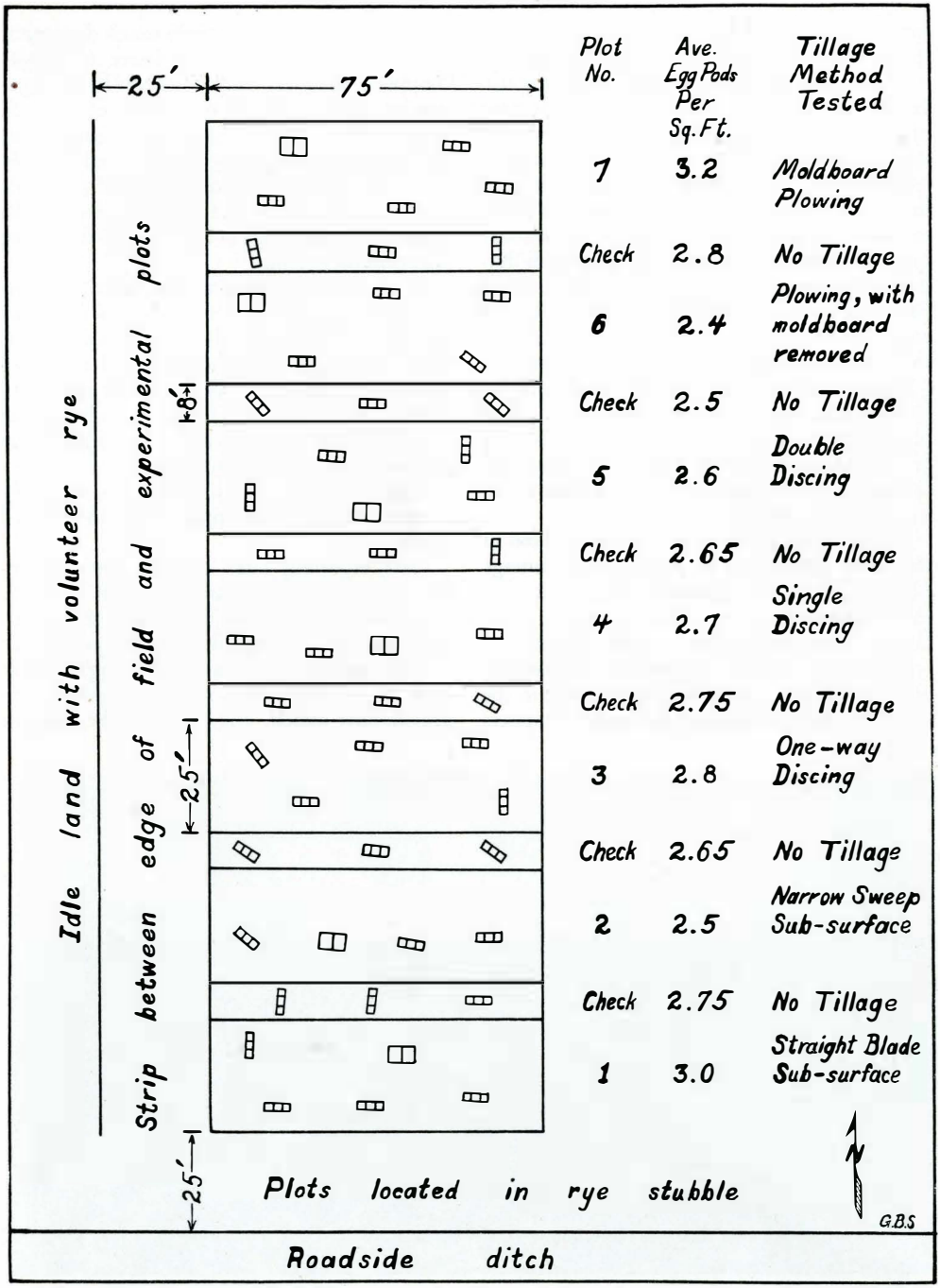

Fig. 3. Map of experimental plots of Ray Jarrett farm, three miles north and two-and-a-half west of Britton, S. D., 1940-41, showing location in field, random placement of cages, and other information. Tillage completed October 9, 1940

for the farmers' tillage and cropping plans for the current fall and the following spring.

This is true especially in areas where the survey shows from light to very severe depositions of grasshopper eggs. Even a light infestation may mean from 10 to 25 percent damage to crops. Under conditions of very severe infestations only the earliest of small grains are likely to produce a crop, unless rainfall conditions are most ideal. With an abundance of rainfall during the growing season grasshoppers may be very numerous and still do little damage to crops. With a scarcity of rainfall practically all the vegetation may be eaten to the ground.

Grain varieties advocated for use, in the following paragraphs, are suggested, by G. I. Gilbertson, entomologist for the Extension Service of South Dakota State College, to increase the chances of obtaining a crop under ordinary conditions in grasshopper years.

Of the small grain crops, barley is listed as the most susceptible to grasshopper damage (1, p. 7). Spartan, apparently because it is an early maturing variety, seems to escape grasshopper injury better than do other kinds.

Damage to winter rye depends considerably upon the species of grasshoppers present in the area. The differential and red-legged 'hoppers normally hatch too late to do much damage to rye. The two-striped and lesser migratory 'hoppers, however, may do considerable damage by chewing off the outer ends of the individual grains. As much as a half of each grain, and sometimes the entire kernel, is eaten. This, of course, reduces both the yield and the quality of the harvested crop. Grasshoppers may also damage the seedlings in the fall and the young plants in the spring.

Rival and Pilot wheats seem to be more resistant to grasshopper attack than do other varieties. Ceres is good but is susceptible to black stem rust. Thatcher, Reward and Marquis wheats appear to be decidedly more susceptible to grasshopper injury and should not be planted in 'hopper years in localities where grasshopper eggs are abundant.

Flax, although an important crop, is usually a poor risk in grasshopper years, in infested areas.

Oats, especially later varieties, are susceptible to injury. Early varieties, such as Early Burt, Brunker and Trojan, should be planted if grasshoppers appear likely to be a problem.

Cane and sorghums, after reaching a height of 8 to 10 inches, are relatively immune to grasshopper attack. Fig. 4 shows the contrast

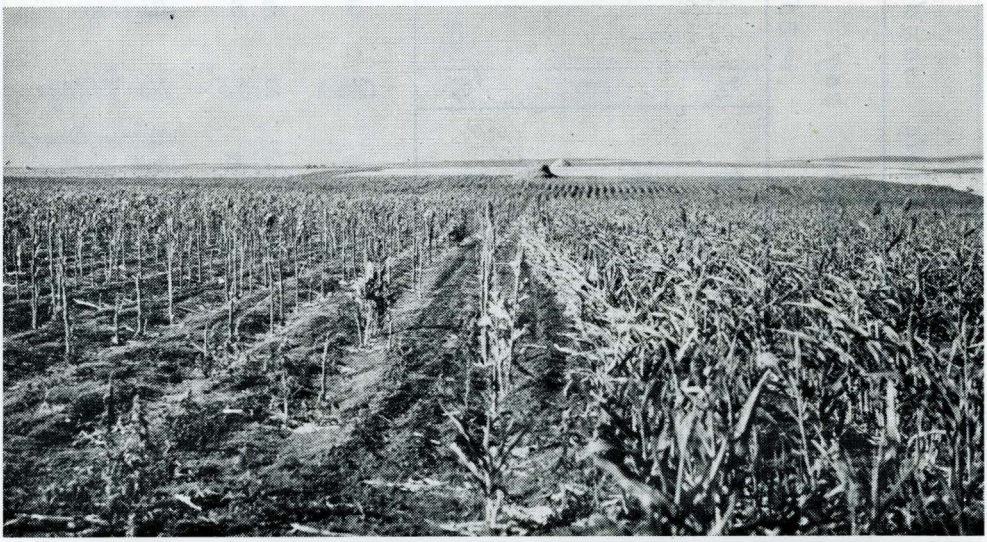

Fig. 4. A study in crop resistance to grasshopper attack. Corn at left is badly damaged; sorghum, at right, brought a good yield. Near Reliance, S. D., 1941

in 'hopper injury between corn, which is susceptible, and sorghum, which is immune. The example speaks for itself in advising which is the safer crop.

In an area in which the fall egg survey indicates that grasshoppers will be abundant the following year, the planting of corn is not recommended. If a farmer feels that he must plant corn, however, flint corn is recommended over dent varieties. Falconer, a flint-x-dent cross, seems to be fairly grasshopper resistant.

In planting small grain, the practice of "stubbling in" or drilling the seed into the previous years' stubble without prior tillage treatment, should be avoided. Grasshoppers may hatch over an entire field planted in this way and almost before any damage is noticed the crop may be lost.

Alfalfa fields of several years standing, which show an economically important number of egg pods per square foot, should be treated in the fall by means of a spring-tooth or spike harrow. This can be done without serious injury to the crowns of the plants and it aids in the reduction of local grasshopper populations.

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Appendix—Discussion of Experimental Methods Used

Trials were based upon the average numbers (by actual count) of grasshoppers which emerged per square foot from samples of the variously tilled areas. The figures thus obtained were checked against the actual count of 'hoppers which emerged per square foot from samples of untreated areas, which were left as check strips between adjacent tilled strips, (Fig. 3).

Areas were selected for study after several points of comparison had been considered. The procedure followed has been called, by workers in other fields, the method of natural experiments or matching factors. In this method an attempt was made to reduce to a minimum all the possible variable factors which otherwise might have existed between the tillage treated and the untreated, or check, areas. In other

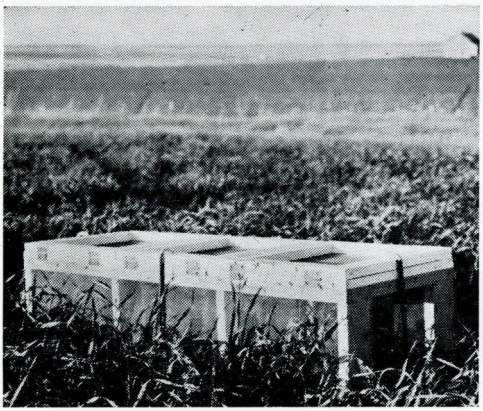

Fig. 5. Type of grasshopper emergence cage used in the South Dakota tillage experiments

words, areas were chosen, as nearly as possible, where all conditions were the same. Thus the tillage treatments applied to the experimental plots became the only important variable factor. This condition was set up as an ideal. Many areas examined failed to meet requirements and as a result they were not used in the experiments.

Grasshoppers of the group under consideration have a tendency to lay many more egg pods around the outer part of a field (100 to 150 feet of the field edge) than they do toward the center. The egg pods are usually not uniformly deposited over an entire field. With this fact in mind the experimental plots were usually located within 12 or 15 feet of the edge of the field. However, they were far enough from the edge so that no experimental tillage plot received any extra treatment due to the turning of machines. All tillage was done under field conditions, just as an entire field ordinarily would be treated.

The experimental tillage plots were usually from 20 to 25 feet wide and from 50 to 75 feet long. Between adjacent tillage plots a strip of untreated soil, 6 to 8 feet wide, was left as a check strip.

Small plots were used with the following points (the matching-out of factors) in mind:

(1) Egg deposition is more likely to be uniform over a series of small areas than over the same number of large areas.

(2) Soil drainage conditions are more likely to be the same over a small area.

(3) The egg parasite and predator factor is not likely to vary between strips of small dimensions whereas it may vary considerably over large areas. For these experiments this factor was considered to be a constant for the plots under study.

(4) The plots were chosen in such a manner that slope of the soil and exposure to sunlight were the same for all strips.

(5) Soil texture, within a given soil type, is less likely to differ between small plots than it is between entire fields.

In the fall of the year, after grasshopper egg laying had been completed, areas of as nearly uniform egg deposition as possible were chosen for study. These areas were selected on the basis of a preliminary egg survey. When an apparently suitable area was found it was staked off into suitable experimental plots. In each tillage plot thus marked off an intensive egg survey was then conducted. In this survey ten soil samples, of one-half square foot each, were examined and the egg pod counts were recorded. Dividing the total number of egg pods by 5 (the number of square feet of soil examined) gave the average number of egg pods per square foot in each tillage plot. By using the intensive survey, allowances could be made for slight variations in egg pod deposition.

Tillage practices chosen for study were then applied to the various plots. The tillage treatment for each plot was given to within 3 or 4 feet of the stakes which marked the boundary of the plot. In this way an untreated check strip was left between each two tillage plots. These check strips, at the time of the intensive egg survey, had been parts of adjoining staked-off areas. In view of this, the intensive survey figures for each two adjoining plots were averaged and the figure thus obtained was used as the number of egg pods per square foot in the check strip thus formed.

The following spring, prior to any hatching of grasshopper eggs, emergence cages (Figs. 5 and 6) were placed at random over the tillage treated land and the check strips. Each cage was held secure by four iron stakes, one at each side and each end. These cages had hinged doors at the top, were open-bottomed and were

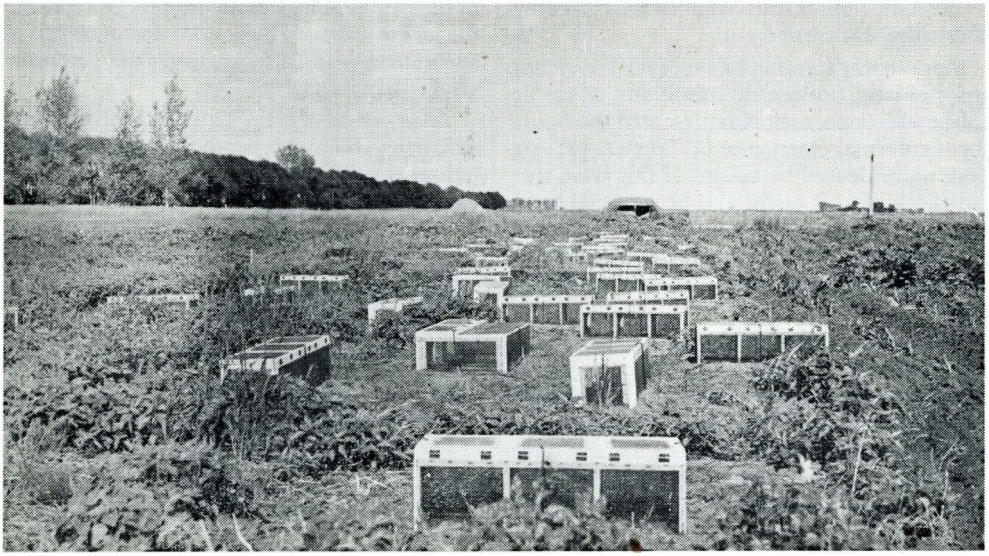

Fig. 6. Grasshopper emergence cages placed at random over experimental plots near Hecla, S. D., 1943

covered with 18 to 20 mesh bronze screen. They were constructed in two sizes. The smaller traps covered exactly 3 square feet and were screen partitioned into three compartments of one square foot each. The larger traps covered 6 square feet each. These were partitioned into two compartments of 3 square feet each. Incidentally, the small traps proved much more satisfactory. The cages effectively trapped all the young 'hoppers which hatched immediately beneath them.

Numbers were given the cages and the compartments in each. By counting the 'hoppers regularly, adding the totals for compartments and dividing this sum by the number of square feet of soil covered by cages in each strip, a figure was obtained for the average number of grasshoppers which emerged per square foot from each plot. Mathematical formulae were devised which could be used for each experimental area.

Let us consider first the check strips for the series of plots in one field. To simplify the explanation of the derivation of the formulae, the following letter designations were used:

A—Area, or number of square feet, covered by cages in each check strip.

A′—Total number of square feet covered by cages on all check strips.

P—Average number of egg pods per square foot on each check strip.

P′—Average number of egg pods per square foot assumed covered by cages on all check strips.

H—Total number of 'hoppers which emerged in cages on each check strip.

H′—Total number of 'hoppers which emerged in cages on all check strips.

Then,

AP—Total number of egg pods assumed covered by cages on each strip,

and,

(AP)′—Total number of egg pods assumed covered by cages on all strips.

These figures were obtained for all plots in every experimental area, in each of the two soil types and for each of the five years in which the studies were conducted. For all the check strips of experiments in each soil type, the following formula was used:

$$\frac{H'}{(AP)'} = X =$$

The number of 'hoppers which emerged per egg pod over the check areas.

With the figures thus obtained the following procedure was carried out:

Since in this formula H′ and (AP)′ were for strips of land, under field conditions, where no tillage was done, then X represented the figure for the normal emergence of 'hoppers per egg pod, uninfluenced by tillage. If this were true for check plots it could also be assumed to be true for all plots. This figure, X, was then used as a constant in ascertaining the expected uninfluenced hatch per square foot over the tillage areas.

To enable one to find the percentage of control given by a certain tillage practice, it was first necessary to know what kind of a hatch was to be expected if no tillage were done. To determine this for each tillage plot, the same procedure as outlined above was followed. The letter designations used for the various figures in the case of tillage plots were the same as for the check plots. Thus, A= the number of square feet covered by cages on the particular tillage strip in question, etc.

Then for all repetitions of one tillage practice, in a given soil type, the following computations were made:

$$\frac{(AP)'}{A'} = P'$$

and,

P′X=E=expected, uninfluenced emergence per square foot.

$\frac{H'}{A'}$=H″=Average actual emergence per square foot.

For the tillage plots, then,

$\frac{H''}{E}$ (100)=% emergence, and

100—% emergence = % control.

Literature Consulted

1. Gilbertson, G. I. and H. C. Severin. *Destroy grasshopper eggs.* S. D. Ext. Cir. 371. Dec., 1937.
2. Mills, H. B. and R. D. Mercer. *The use of tillage methods in grasshopper control.* Mont. Agr. Exp. Sta. Cir. 99. Oct., 1938.
3. Munro, J. A. *Tillage operations as affecting grasshoppers.* N. D. Exp. Sta. Bi-monthly Bul. 2:3-5. Sept., 1939.
4. Munro, J. A. and H. S. Telford. *Grasshopper control aided by tillage methods.* N. D. Agr. Exp. Sta. Bul. 309. Feb., 1942.
5. Parker, J. R., W. R. Walton and R. L. Shotwell. *How to control grasshoppers in cereal and forage crops.* U.S.D.A., F.B. 1691. April 1932.
6. Parker, J. R. *Fight grasshoppers by plowing stubble.* U.S.D.A., Cir. 302. Sept., 1933.
7. Parker, J. R. *Grasshopper control by tillage and seeding methods.* (Mimeo.), U.S.D.A., Bur. Ent. & Plt. Quar. E-452. Oct., 1938.
8. Parker, J. R. *Grasshopper outbreaks during the last 100 years.* (Mimeo.), U.S.D.A., Bur. Ent. & Plt. Quar., Div. Cereal & Forage Insect Investigations, Bozeman, Mont.
9. Parker, J. R. *Grasshoppers and their control.* U.S.D.A., F.B. 1828. June, 1939.
10. Severin, H. C. and G. I. Gilbertson. *Destroy the grasshopper eggs.* S. D. Agr. Exp. Sta. Bul. 267. Oct., 1931.
11. Shotwell, R. L. *A study of the lesser migratory grasshopper.* U.S.D.A., Tech. Bul. 190. July, 1930.
12. South Dakota Crop and Livestock Reporting Service. *South Dakota agricultural statistics, 1941 and 1942.* Office of Sec. of Agr., Pierre, S. D.
13. Uvarov, B. P. *Locusts and grasshoppers.* Wm. Clowes & Sons, Ltd., London, England, 1928.