A G Robinson

PROCEEDINGS OF THE

ENTOMOLOGICAL SOCIETY OF MANITOBA

VOLUME 11 1955

Proceedings of the

ENTOMOLOGICAL SOCIETY OF MANITOBA

Vol. 11 1955

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	1955	1956
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Members 1955

W. R. Allen, Entomology Laboratory, Brandon, Manitoba.

W. L. Askew, Entomology Laboratory, Brandon, Manitoba.

C. F. Barrett, Entomology Laboratory, Brandon, Manitoba.

B. Berck, Entomology Laboratory, 724 Dominion Public Bldg., Winnipeg, Manitoba.

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J. P. Eastwood, Velsicol Corporation, 700 Kellogg Ave., Ames, Iowa.

W. Fox, Chipman Chemicals Ltd., 1040 Lynn Ave., Winnipeg, Manitoba.

B. Furgala, Dept. of Entomology and Economic Zoology, University of Minnesota, St. Paul 1, Minnesota.

F. J. Greaney, Line Elevators Association, 765 Grain Exchange Bldg., Winnipeg, Manitoba.

R. H. Handford, Entomology Laboratory, Box 210, Kamloops, B.C.

W. Hanec, 484 Polson Ave., Winnipeg, Manitoba.

A. F. Hedlin, Forest Biology Laboratory, Indian Head, Saskatchewan.

R. J. Heron, Forest Biology Laboratory, Winnipeg, Manitoba.

J. S. Howden, Green Cross Insecticides, 110 Sutherland Ave., Winnipeg, Manitoba.

W. G. Ives, Forest Biology Laboratory, Winnipeg, Manitoba.

J. S. Kelleher, Entomology Laboratory, Brandon, Manitoba.

R. R. Lejeune, Forest Biology Laboratory, Victoria, B.C.

*A. V. Mitchener, 911 Windermere Ave., Fort Garry, Manitoba.

J. A. Muldrew, Forest Biology Laboratory, Winnipeg, Manitoba.

J. A. McLeod, Dept. of Zoology, The University of Manitoba, Winnipeg, Manitoba.

L. D. Nairn, Forest Biology Laboratory, Winnipeg, Manitoba.

R. M. Prentice, Forest Biology Laboratory, Winnipeg, Manitoba.

S. Pugh, Chipman Chemicals Ltd., 1040 Lynn Ave., Winnipeg, Manitoba.

H. P. Richardson, Entomology Field Station, Experimental Farm, Morden, Manitoba.

D. R. Robertson, Provincial Apiarist, Legislative Bldg., Winnipeg, Manitoba.

A. G. Robinson, Dept. of Entomology, The University of Manitoba, Winnipeg, Manitoba.

W. Romanow, Entomology Laboratory, Brandon, Manitoba.

E. P. Smereka, Forest Insect Laboratory, Box 490, Sault Ste. Marie, Ontario.

T. Smith, 631 Henderson Highway, Winnipeg, Manitoba.

E. J. Stansfield, 917 Riverwood Ave., Fort Garry, Manitoba.

J. R. G. Sutherland, Dept. of Zoology, The University of Manitoba, Winnipeg, Manitoba.

A. J. Thorsteinson, Dept. of Entomology, The University of Manitoba, Winnipeg, Manitoba.

W. J. Turnock, Forest Biology Laboratory, Winnipeg, Manitoba.

*J. B. Wallis, 468 Niagara St., Winnipeg, Manitoba.

G. L. Warren, Forest Biology Laboratory, Winnipeg, Manitoba.

F. L. Watters, Entomology Laboratory, 724 Dominion Public Bldg., Winnipeg, Manitoba.

P. H. Westdal, Entomology Laboratory, Brandon, Manitoba.

H. R. Wong, Forest Biology Laboratory, Winnipeg, Manitoba.

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*Life member.

Addenda

W. Krivda, Riverton, Manitoba.

D. J. Petty, Plant Protection Division, 722 Dominion Public Bldg., Winnipeg, Manitoba.

ENTOMOLOGICAL SOCIETY OF MANITOBA FINANCIAL STATEMENT

FOR YEAR ENDING DECEMBER 31, 1955

Receipts:		
Balance in Bank, Dec. 31, 1954		$ 45.99
Members' dues, 1955		72.00
Members' dues, 1956		81.00
Registration for 1955 fall meeting	$ 16.00	
Fall banquet	61.55	77.55
Donations:		
Sherwin-Williams Co.		15.00
Sales of Proceedings:		
N.V. Swets & Zeitlinger (Amsterdam, Holland)	10.26	
University of Manitoba (for Stechert-Hafner Inc., New York, U.S.A.)	10.00	
Students Book Corporation (Pullman, Washington, U.S.A.)	10.00	30.26
		$ 321.80

Expenditures:	
Subscriptions to Entomological Society of Canada	$ 120.00
Taylor Co. -- covers for 1955 Proceedings	17.88
Banquet expenses	79.70
Bank service charge	1.67
Willson Stationery -- receipt book	1.95
Balance in hand December 31, 1955	100.60
	$ 321.80

Audited and found correct - January 10, 1956

W. Romanow

P. H. Westdal

Proceedings of the

ENTOMOLOGICAL SOCIETY OF MANITOBA

Vol. 11 A society to foster the advancement, exchange, and dissemination of entomological knowledge 1955

INTRODUCTION

With this issue of the Proceedings, we begin our second decade of publication of papers presented at meetings of the Entomological Society of Manitoba.

We have always encouraged the presentation and discussion of topics of current entomological interest. Such topics generally have a wider appeal than specialized research papers. To select subjects that interest only a few members might tend to separate rather than unite the membership of our Society. By preserving the type of program developed and by striving to improve its quality, our Society can continue to flourish and make a worthwhile contribution to the science of entomology.

For the convenience of our members, subject and author indices for Volumes 1 to 10 have been included in this volume.

All members, I am sure, will wish to join in extending our thanks to Professor A.G. Robinson for the time and effort he has contributed as Editor of the Proceedings during the past two years. Dr. W.R. Allen has been elected as the new editor and will no doubt receive from the members the support accorded his predecessors.

On behalf of the membership it is a pleasure to acknowledge the stenographic assistance given by the following laboratories: Forest Biology Laboratory and Stored Product Insect Laboratory, Winnipeg; Entomology Laboratory, Brandon.

F. L. Watters,
President.

THE SPRING MEETING

The Business Session

A business meeting of the Entomological Society of Manitoba was held at The University of Manitoba, Department of Entomology, April 15, 1955. Mr. F.L. Watters presided.

The minutes of the fall meeting held November 19, 1954, were read and adopted on a motion by R.M. Prentice and A.J. Thorsteinson.

The Treasurer's report was presented by T.V. Cole. The Society has no outstanding debts and a bank balance of $67.00.

The Editor-Librarian's report was presented by Professor A.G. Robinson. He reported that the Society was ready to receive for publication in the Proceedings, papers other than those presented at the spring and fall meetings of the Society. The Editor-Librarian proposed writing Dr. Glen and Dr. Prebble asking for a contribution number for all papers published in the Proceedings.

It was reported that a request had been received for a complete series of back copies of the Proceedings and the question of selling price was discussed. After a number of motions and amendments it was moved by J.B. Wallis that the selling price for back copies be left to the Editorial Board. Seconded by D. Robertson. CARRIED.

W. Turnock reported for the Common Names Committee that one common name had been submitted for approval.

The President reported that the Executive had investigated and abolished the Insecticide Committee.

On a motion by W.R. Allen and T.V. Cole, P.H. Westdal and W. Romanow were appointed auditors for 1955-56. CARRIED.

The meeting adjourned at 12 a.m. on a motion by F. Watters and W. Ives.

Scientific Business

The scientific session of the spring meeting convened in the Department of Entomology, The University of Manitoba, on the afternoon of April 14. The program was completed on the following morning.

The paper reading session provided a good variety of subjects of general interest to the group. The papers prepared and presented by Messrs. J.R.G. Sutherland, W.J. Turnock, W. Romanow, F. Birt, and F. Watters follow.

Dr. R.D. Bird showed color pictures of insects taken with the equipment that had been demonstrated to the group at the April 2, 1954, meeting at Brandon. The fine close-ups shown of insects and native animals and birds amply demonstrated the adaptability and effectiveness of the Exakta VX when used with the Heiland Strobonar V.

A film on biting flies in Northern Canada, prepared under the direction of the Veterinary and Medical Entomology Unit, Ottawa, was shown on the afternoon of April 15.

In the evening the members attended a banquet at "The Homestead" and enjoyed the 1954 Grey Cup film.

THE ROLE OF ARTHROPODS IN VIRUS DISSEMINATION

by J.R.G. Sutherland
Department of Zoology
The University of Manitoba

INTRODUCTION

Virus develops only parasitically and intracellularly in metabolizing cells. In order to propagate successfully, a virus must be able to make contact with a susceptible tissue. It must penetrate or bypass the mechanical barriers presented by external surfaces of plants and animals, and frequently must also bypass non-susceptible internal structures. It must overcome such degree of internal resistance as may have been inherited, or acquired either actively or passively by the host organism. In order to continue propagation, it must multiply and be liberated in a viable condition and in such a way as to make effective entrance into a new susceptible host.

The outcome of virus infection in a host organism may range from complete destruction of the virus to the death of the individual host or decimation of the population. In either of these extreme cases the maintenance of a virus reservoir would be difficult, particularly if the effect should be attained rapidly. On the other hand, if the rate of destruction of the virus or onset of death in the host should be slow, or if the course of the disease should be mild or even asymptomatic, a highly productive reservoir might be established and maintained, provided other ecological factors did not operate to reduce host density below a critical level.

It is usual to think of plant and animal viruses primarily in economic terms and to focus attention on the diagnosis, prophylaxis and treatment of the diseases they produce. Success in this field is naturally measured by the degree of protection that is afforded man, animals or crops against a given type of infection.

Let us consider briefly the factors that contribute toward the success of virus as a pathogen, using continued transmissibility as a criterion.

HOST RANGE AND VARIATION

Most viruses are pathologically specific for a few host species that are usually closely related taxonomically or closely associated ecologically. A few show single species specificity, and some others may cause recognizable disease in a wide range of unrelated organisms. There is no doubt that viruses are specifically pathogenic for certain tissues, at least in vertebrates.

When considering alternative hosts it may be hard to decide whether one is dealing with a plant, arthropod or vertebrate virus, for the designation is usually derived from the host that shows definite disease symptoms most clearly or most commonly. Perhaps a more practical approach would be to distinguish the primary host in which a reservoir can be best maintained under the most adverse of ecological conditions. This will usually be the one that suffers the least damage from the virus parasite and thus offers it the best chance of success in continued propagation.

Variation is frequently observed in viruses in nature, particularly among those pathogenic in plants, and adaptability under experimental conditions is a striking attribute of viruses. Superficially it may seem that this is brought about through the virus being able to change spontaneously according to the demands of the host, and to transmit the characters acquired in the process. On the contrary, the observed adaptations depend on the fact that an inoculum may contain many billions of virus particles with a mutation rate that will vary with conditions, but will probably be similar to those known to occur in plants and animals. Adaptability and survival in higher organisms depend on selection involving the coincidence, in single individuals, of a complex of suitable characters, which subsequently cross and segregate. An adapted strain of virus, however, is probably the genetically identical progeny of a single successfully mutating particle selected from among individual billions of unchanged entities and thousands of unsuccessful mutants.

This adaptive faculty has an important bearing on virus host specificity, although it is complicated by host susceptibility and type of response, both of which are determined genetically and are subject to modification in some degree by environmental factors. In animals the phenomenon of immunity, brought about by the formation of virus antibodies, is an important factor in regulating pathogenicity in individual cases and virus dissemination in the population. No similar reaction has been shown to occur in plants, but viral interference is often observed to give protection against a virulent strain, when a milder strain preempts susceptible tissues. It is possible that this condition may in turn influence dissemination, if any differential should exist among the many factors affecting the transmissibility of the two strains.

PLANT VIRUSES

Four methods of virus transmission are practical in economic plants: 1) by vegetative propagation including grafting; 2) by seed infection; 3) by soil infection; 4) and by sap inoculation. Modern plant sanitation practice tends to prevent vegetative transmission by the rejection of diseased material. The passage of virus through seed is exceptional and sporadic, though according to BAWDEN (1950) it is not negligible in the legumes. Soil transmission was thought at one time to be attributable merely to the presence of stable virus particles in the soil or in plant debris, but the work of McKINNEY (1946) suggests that it may be accomplished instead by soil-inhabiting organisms.

Inoculation may take place during mechanical injury resulting from friction between neighbouring plants or in cultivation, but in any event so much tissue damage may be involved or the inoculum may fall so far short of susceptible cells that the virus cannot propagate. Sap inoculation using needles frequently fails with viruses that are regularly transmitted in nature by insects. The requirements for successful sap inoculation seem to include the ability to place the virus within reach of susceptible tissues, in a condition and in a concentration suitable to permit multiplication.

The immobility of plants rigidly circumscribes the area in which a virus reservoir may be maintained, unless some form of inoculation is available to aid in dissemination of the pathogen. Even then the efficiency of an inoculating agent may be limited by the freedom and amplitude of its movements, its frequency of contact with infective and susceptible hosts, and its ability to place a virus effectively near susceptible tissues. Because of their mobility and fecundity, their dependence on plants for food, and the structure of their mouth-parts, many insects are well adapted to minimize these limitations.

Once a focus of virus infection has been established by any means, dispersal and maintenance outside the immediate area will usually be accomplished by insects. In a list of 32 representative virus diseases of plants, LURIA (1953) indicates 26 as transmissible by insects, two of them by mechanical means as well. Of the remaining six, four are recorded as being spread only mechanically and two through the soil. Control of one of these last, the wheat mosaic virus, has been achieved by the use of soil insecticides, leading to the conclusion that an animal vector may be involved (JOHNSON, 1945). BAWDEN (1950) considers that "...most [plant] viruses depend for transmission on the activity of insects, [and] though conditions under which plants are grown may influence susceptibility to infection, ...environmental conditions that affect the multiplication and movement of insects are usually most important in determining distribution."

BAWDEN also gives a list of 76 insect species that are involved in the transmission of more than 80 distinct virus strains. Of these, 65 have piercing and sucking mouth-parts and 11 the biting type. Some of the viruses have several known vector species and a few of the vector groups, notably the aphids and leafhoppers, are capable of transmitting several viruses or strains in nature. Most viruses that have vectors with biting mouth-parts also have a sucking mouth-part vector, but turnip yellows mosaic virus seems to be unique in having biting mouth-part vectors only.

Virus may be non-persistent or persistent in an insect vector. Transmission of the former kind has been shown not to be purely mechanical, for it is common experience in experimental work that insects with similar sized stylets and apparently similar feeding habits do not transmit a given virus with like efficiency. Moreover, prestarved individuals are more efficient vectors in most cases than are those that have previously fed on infective plants. Maximum efficiency in non-persistent transmission is limited to a period of minutes in many cases, usually the absolute limit is a few hours. The duration of infectivity may vary with virus and vector, and 24 hours is usually taken as the time standard for separating non-persistent and persistent categories. However, time variations within these categories seem to be determined principally by the virus, for the time element is relatively constant regardless of the test insect used, even in those species able to transmit viruses of both types.

WATSON (1946) has suggested that non-persistent virus may be inactivated by some inhibiting principle present in large quantities in a vector after it has fed continuously but absent or nearly so in starved specimens. BLACK (1939) has demonstrated the presence in insect extracts of inhibitors that prevent infections with inocula which otherwise are readily infective. HOGGAN (1933) and other workers have shown that inhibitors having a similar effect occur in plant juices. It seems that inhibiting substances of plant origin may be simply imbibed during feeding but are disposed of fairly rapidly by the insect provided the gut is not overloaded. At any rate, the non-persistent type of virus transmission is characterized by the absence of a latent period regardless of the duration of infectivity, and usually increased feeding time results in reduced infectivity.

Persistent viruses have three main attributes in common: 1) prestarving a vector does not increase its efficiency; 2) lengthened feeding time tends to increase both efficiency and duration of transmissibility; and 3) there seems to be a latent period after feeding on a virus source, before the end of which transmission cannot take place.

Several theories have been advanced to account for this apparent "incubation period" in an insect vector. It has been proposed that the latent period may be necessary for the activation of the virus within the vector, that it may undergo multiplication, that time may be needed to dispose of inhibitors extracted from the plant along with the virus particles, or that the virus must reach a position in the insect from which it can be reinoculated effectively into a new host. All four propositions have both supporting evidence and objections, and it may be that varying combinations of them may explain observed events in different vector-virus combinations. At least in some cases the virus must penetrate the gut wall and pass through the haemolymph to the salivary glands before transmission can occur. STOREY (1933) has shown that the maize streak virus is transmitted in nature only by individuals of the jassid Cicadulina mbila Naude that carry the dominant allele of a gene pair which permits the virus to pass through the gut wall, while homozygous recessives are non-infective. If the gut of a genetically non-infective leafhopper is punctured before or soon after feeding, it becomes capable of transmitting the virus. It seems probable that the ability of a virus to become persistently infective in a vector depends partly on the nature of the structure of the virus particle and partly on that of the insect gut wall; these two factors combined constitute a primary limitation of vector efficiency.

No case appears to have been substantiated of virus inoculation into plants from insect faeces. BLACK (1941) has transmitted aster yellows virus by inoculating Cicadula sexnotata Fall. with extracts from infective hoppers after 24 hours in vitro and STOREY was equally successful in making Cicadulina mbila infective by injecting sap from plants showing maize streak symptoms, though the same inoculum failed in mechanical transmission trials. MARKHAM and SMITH (1949) found that all the field vectors of turnip yellows mosaic virus as yet recorded had biting mouth-parts and lacked an oesophageal valve. They concluded that regurgitation of virus particles may be necessary for infection to take place. The latent period of 24 hours in this case may represent the mean time required for regurgitation, or the time necessary for virus activation or multiplication, or for the removal of inhibitors.

WATSON (1940) challenges the idea of a latent period on the grounds that ejection of virus particles by feeding insects is not a continuous process. It is her view that prolonged feeding on a source of infection of the persistent type may increase the virus content of a vector and hence the rate of intermittent ejection from the salivary glands. She holds that the chances of effective transmission are thereby increased in an infective population, and that since individual insects vary in the onset and duration of their infectivity under similar conditions, the so-called latent period represents the time during which all potentially infective individuals in a population begin to approach a maximum probability of effective transmission in relation to these three variants.

Few viruses appear to be transmitted to progeny of vectors of plant pathogens through the egg. Two exceptions have been proven, those of the rice stunt virus through the jassid Nephotettix apicalis Motsch. (FUKUSHI, 1935) and the clover club-leaf virus through the jassid Agalliopsis novella Say. (BLACK, 1950). In the latter case the virus was passed experimentally through 21 generations and remained infective, indicating that multiplication must have taken place, otherwise the virus dilution would have been of the order of 10^{26}.

Virus plant pathogens are likely to be disseminated more efficiently by insect vectors than by mechanical means for one or more of the following reasons:

(a) the viruses may be present in great dilution in plant extracts and may require multiplication before becoming infective,

(b) they may inactivate readily and need the speed and protection of a vector to reach a new host in an infective condition,

(c) they may be accompanied in plant extracts by inhibitors of plant origin that need removal before successful inoculation,

(d) they may require conditioning or activation of some other kind in the insect body before becoming infective, or

(e) they may have to be introduced into specific tissues in order to propagate successfully.

By all known standards, insects seem to be more efficient than any alternative means in nature of disseminating virus plant pathogens, regardless of the exact mechanism by which this effect is achieved in each instance.

ANIMAL VIRUSES

Virus studies in vertebrates are made difficult by the complexities of anatomy, physiology and ecology of the organisms involved and particularly the barrier mechanisms that protect animal hosts from virus invasion.

In vertebrates, viruses may cause epithelial lesions or lesions of the central nervous system, or neoplasms, or they may appear as generalized infections often with catarrhal symptoms and sometimes involving one of the foregoing conditions as a side-effect. The mobility of animals renders them more subject than plants to direct or indirect contagion. Infective virus particles may be present in exudates, secretions or excreta or in the blood of infected individuals and may be transmitted in these media to new hosts under suitable conditions.

Entry may be effected through the respiratory tract in airborne droplets or solid particles, particularly when susceptible hosts are closely confined with infective ones, although this method of spread is now known to be generally less effective than was formerly believed. Ordinary day-to-day reaction to the environment may lead to infection, by ingestion with food or water, by inoculation through skin injury, or in coitus. The method of transmission of a virus in nature and its efficiency will depend primarily on the type of infective material produced in the host and the ease with which it may reach susceptible tissue in a new host. Limiting factors will include the probability of contact between infective and susceptible individuals, either directly or indirectly through the agency of an inanimate object or an organism, and will depend on the density and degree of movement and dispersal in both host and vector populations. HOCKING (1953) has pointed out that, theoretically, no disease transmission can take place by winged vectors unless their flight range is greater than the reciprocal of the square root of the host population per unit area, provided transovarian passage of the pathogen does not occur. KETTLE (1951) has shown that the relation between flight range and population density in insects is not constant.

To be infective an inoculum must be able to pass the primary or epithelial defences of the host body by some means, and at least some of the virus particles must be able to survive early reaction by the secondary or parenteral defences. The degree of resistance of an individual to disease production by a given virus may be the result of selection or it may have been acquired through active response to infection. In nature, passive immunity may be conferred by the passage of antibodies to a foetus _in utero_ or through colostrum to the newborn. By comparison, virus interference in animals seems to be insignificant in its effect on the natural production of disease although it can be induced experimentally.

Unlike plants which may recover symptomatically and still retain an infective concentration of virus, vertebrates often seem to bring about total destruction of a pathogen by means of neutralizing antibodies. In other cases it has been shown that antibodies do not necessarily destroy all infective virus particles (SABIN, 1935) leading to the conclusion that prolonged immunity may be attributable to the continued presence of virus. On the other hand it has been suggested (LURIA, 1953) that post-infective changes may take place in antibody-producing cells which enable them to continue production for varying periods or to respond quickly to a new infection by the viral antigen.

Virus parasites that induce disease in vertebrates do not appear to cause recognizable disease symptoms in arthropods, and _vice versa_. The principal similarity among the viruses that have been recorded as pathogenic in vertebrates is the presence of an _eclipse phase_, in which the titer in a host falls rapidly below that of the inoculum and then increases to a maximum typical for the virus concerned.

In certain viral infections, immunity appears to be established locally as the virus spreads through a tissue. At this time antibodies cannot be detected in the general circulation. LURIA (1953) postulates that "...immunity results from an alteration of the infected cells, following infection by a route that does not lead to their destruction." Since viruses exist intracellularly it also seems possible that they may continue to propagate in a tissue while the surrounding fluids contain considerable quantities of antibodies (HAGAN and BRUNER, 1951). LURIA (1953) further states that "...circulating antibodies are ineffectual against the spread of viruses that are transported along nerve fibres. By the time the symptoms of a virus disease manifest themselves, most of the cells that are going to be infected already contain virus and protect it from circulating antibodies." HORSTMANN et al. (1954) discuss observed instances of the early appearance of viremia in symptomatic poliomyelitis cases and asymptomatic contacts, that are followed by the prompt development of antibodies in the blood. They believe that this situation supports the hypothesis of primary extraneural growth of the virus.

It may well be that the success of a virus in producing a disease depends on the speed with which neutralizing antibodies, of varying origins, are developed and moved into position to protect susceptible tissues.

An examination of the discussions of the major virus diseases of domestic animals by HAGAN and BRUNER (1951) indicates that all those classified as causing skin lesions have infective exudates, that oral transmission is considered normal in nature, and that viremia has been demonstrated in most of them at some phase in the course of the disease. It is probable that arthropods of ectoparasitic habit and others such as muscoid flies play some part in the dissemination of these viruses. It also seems possible that blood-sucking arthropods may have a more essential role in the maintenance of reservoirs of viruses that cause a high mortality in livestock.

Most of the neurotropic viruses (loc. cit.) are said to produce viremia at some stage and to involve arthropod vectors in a biological role. Exceptions are rabies, transmitted through the saliva of a long range of species, and pseudorabies which appears to be inoculated into bovines, canines and felines through minor abrasions, from swine and rodent reservoirs within which it is contagious. This type of situation does not preclude the involvement of blood-sucking vectors, but if they exist they do not seem to be essential to virus maintenance.

Within the group of virus diseases showing a generalized type of infection, often accompanied by a catarrhal condition at some time and locus, both viremia and an arthropod vector have been proven in many instances. But in the past natural dissemination has been ascribed to ingestion because of the presence of the infective exudates. For example, oral transmission of the fowl plague virus is readily carried out, but as this does not fully explain the epizootic pattern, ectoparasite vectors are suspected of furnishing an alternative means.

Among the viruses involved in producing neoplasms, there is evidence that those of the avian leucosis complex may require blood feeders as vectors, whereas the lymphomatoses seem to be infective through the egg only, and the mammalian papillomas appear to be disseminated by direct and possibly indirect contact. Myxomatosis is highly lethal in the European rabbit (*Oryctolagus cuniculus*) but not in the hare *Lepus europaeus* nor in marsupials. Advantage is being taken in Australia of this differential reaction as a measure of biological control of the first mentioned species. Transmission of the virus is known to occur readily through contact with copious infective discharges from the body openings of diseased specimens. For several years after the first introduction of the virus into Australia the spread of the disease was slow, and in many instances virus liberations ended in apparent failure. However, from 1950 onward myxomatosis has been characterized in the southeastern part of the continent by waves of epizootics in widespread areas with very high mortality rates. RATCLIFFE et al. (1952) have found a significant correlation between the epizootic performance of the myxoma virus and the abundance of Culex annulirostris Skuse, and at least three other culicids. Several ceratopogonid species are also suspected of playing a part in its dissemination.

Information now available suggests that the ecological and biological factors affecting the success of a virus in a vertebrate host are very complex and that transmission by a blood-sucking vector may often be necessary to the maintenance of a virus reservoir. There is no evidence of alternating forms of reproduction in vertebrate and invertebrate hosts, but dissemination by a mobile blood-feeder seems to be obligatory for some viruses, and possible in some circumstances in others. An arthropod may be necessary in transmission because it is the only physical means available to span a gap in time or space; it is the only means of obtaining an inoculum and of keeping it in an infective condition; it is essential for the effective placement of virus in relation to susceptible tissues; or it is needed to raise the titer to an infective level.

Multiplication of viruses in arthropod vectors has been shown to occur in the North American encephalitides, dengue and several other diseases. BLANC and CAMINOPETROS (1929) found dengue virus to persist in Stegomyia mosquitoes for up to 174 days after feeding, and it is probable that a single infective blood-meal may make many vector individuals infective for life. But not all arthropods that feed on vertebrate hosts are able to transmit virus, and viruses are usually more or less specific for vector complexes. Natural transmission from one generation to another through the egg seems to be rare, though the virus of St. Louis encephalitis has been transmitted experimentally for two generations in the egg of the chicken mite (Dermanissus gallinae) (SMITH, 1946). These facts coupled with ecological considerations mean that a successful experimental vector may not be important or even capable of transmission under natural conditions.

Many viruses affecting vertebrates display "incubation periods" in their arthropod vectors, resembling the latent period in persistent plant viruses. MERRILL and TENBROECK (1935) repeated STOREY'S (1933) gut-puncturing operation with Aedes aegypti and caused specimens to transmit Eastern equine encephalomyelitis virus, though they had been unable to do so before the puncture. This is a further indication of the biological role of the vector in insect transmission. Virus has also been shown often to be present in all parts of infective mosquitoes, and McLEAN (1953) found this to be true for Murray Valley encephalitis and *Culex annulirostris*. He concluded that the virus multiplies in the cells of the stomach and midgut walls and is then liberated into the haemolymph.

Multiplication *per se* was also demonstrated by McLEAN in *C. annulirostris* and ten other culicine species, with the presence of an "incubation period" which he termed *eclipse phase*, as in vertebrates; amount of virus increased 100-fold. It would seem that the eclipse phenomenon in vectors may occur because of the time necessary for a virus to proliferate and to disseminate through the haemolymph and reach the salivary glands in an infective concentration. It remains to be proven how similar the mechanism of eclipse in vertebrates and arthropods may be, but present evidence suggests that members of the two groups are merely alternative hosts for given viruses, suffering different degrees of pathological condition because of their different genetic tendencies toward resistance.

If this were so, it would provide at least a partial explanation of the absence of recognizable disease in infected arthropods yet the presence of patent symptoms in alternative vertebrate hosts, and the apparent natural selection of resistant types among man and animals in areas of virus disease endemicity. It might also help explain the frequent discovery of "new" viruses in fringing ecological zones and in transplanted populations. Non-pathogenicity in arthropods and low pathogenicity in vertebrates should contribute toward the successful survival of a virus and high mortality in either should have the reverse effect. Although vector-borne viruses can be inoculated experimentally from vertebrate to vertebrate and arthropod into arthropod, the probability of this taking place in nature seems minimal. In birds and mammals it would depend on infection through injuries sustained mainly in fights and accidents, but the known difficulties with experimental techniques tend to discredit the idea. Observed feeding habits of proven vector species make it even more unlikely that an appreciable rate of natural transmission may take place between individuals of the species.

Five pertinent queries arise from this brief and necessarily superficial consideration of the role of arthropods as disseminators of virus in vertebrates: 1) is an arthropod vector capable of supplementary biological transmission in instances in which there are clearly other means of spreading the virus causing economic disease? 2) is virus maintenance in arthropods possible or even essential during off-phases of epidemic diseases of this type? 3) is a blood-sucking vector the most efficient means of transmission in nature, regardless of the presence of infective secretions and excretions, provided viremia of a suitable duration occurs? 4) may the sporadic occurrence of severe clinical cases in diseases characterized by a high proportion of subclinical infections and frequent natural transmission by contagion, be attributable to occasional transfers of viremic blood, with consequent penetration of the primary defences and invasion in time of the parenteral defences? 5) may viruses become adapted and vectors and vertebrate hosts become selected progressively, so that all three reach a condition of mutual tolerance, with the other links of the cycle, or become reduced together or separately below a density critical for continued virus transmission?

CONCLUSIONS

There is abundant evidence of the fact of biological transmission of virus disease agents by arthropods. In the studies of transmission cycles during the past half century, more and more viruses of economic importance have been shown to owe their survival and continued propagation to invertebrate vectors, principally insects. It seems significant that within the past fifteen years three major epizootic virus diseases have been demonstrated to be transmissible by blood-sucking insects. The North American encephalitides have been proven to be insect-borne in nature, Murray Valley encephalitis has been shown to comply with BURNET'S (1952) minimum epidemiological requirements as an arthropod-borne virus. While myxoma virus has become adapted to some form of dissemination by species of the local insect fauna among pest rabbits in Australia.

Many plant viruses are dependent on insects for transmission in nature.

EKLUND (1953) believes that although many alternatives have been proposed to the mosquito-virus-vertebrate cycle of the encephalitides, none has been fully proven, and that at the present state of knowledge it is not even possible to say definitely that an alternative type of cycle is necessary. This idea might reasonably be extended to include viruses other than those causing the encephalitides, and to other potential insect vectors. Even if other obvious means of transmission of a virus exist, it would seem advisable to extend studies of dissemination to include arthropod vectors as possible contributors to the maintenance of virus reservoirs, particularly if epidemic outbreaks and the pattern of their development cannot always be completely and consistently explained in terms of contagion.

It would not be easy to formulate a general rule by which to distinguish a primary host species of a virus. The situation may be in a continual state of flux, now remaining relatively constant and then altering with appreciable speed, with a consequent variation in the stability of a virus reservoir as mutant strains arise and as hosts of differing degrees of susceptibility and vulnerability to them make up changing proportions of the total population.

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THE CLIMATES OF NORTH AMERICA

by W.J. Turnock
Forest Biology Laboratory
Winnipeg, Manitoba

The climates of North America are unrivaled in the world in their dramatic changeability, the great differences between them, and, with the exception of the Pacific coast climates, their inconstant, sometimes violently erratic, character. The climates of the various regions of North America are controlled by the movements of air masses that pass over them from different source regions and the frontal disturbances that arise along the air mass boundaries.

An air mass is a body of air that has remained over a uniform topographic surface long enough to acquire an equilibrium between the lower levels of the air and the ground surface. Air masses tend to have uniform horizontal distributions of temperature and pressure. The relatively uniform surfaces such as oceans, level plains and plateaux, deserts, and ice sheets, where air masses may form, are known as air mass source regions. Depending on the surface over which they form, air masses may be dry and warm, dry and cool, moist and warm, or moist and cool. Since any air mass carries with it characteristic properties when it leaves its source region, a recognizable range of airmass weather occurs within it. Although the air mass, and consequently the airmass weather, undergoes considerable modification depending upon the direction and speed of travel, and the terrain beneath it, they generally persist in a recognizable form over a considerable period in space and time. Thus tropical maritime air, which is warm and moist when it leaves its source region in the Caribbean and Gulf of Mexico, becomes somewhat cooler and drier as it moves up the Mississippi valley, but it remains much warmer and moister than any other type of air that invades the eastern Canadian prairies.

As the air masses move across the continent they come in contact with other air masses with different properties. The transition from the characteristic weather of one air mass to another is generally abrupt and zones of discontinuity are readily detectable. Along these borders, areas of low pressure often form. Parts of the zone of discontinuity between the air masses develop into frontal systems.

Frontal weather is associated with these systems and produces changes in weather that are more marked, but also more transitory, than those associated with air masses. Cold fronts occur where a cold air mass replaces a warmer one, and warm fronts where the reverse occurs. Each is associated with characteristic cloud formations and weather patterns. Two storm belts cross the continent along the major air mass boundaries.

The air masses affecting North America are polar continental (cP), polar maritime (mP), tropical maritime (mT), and continental (C). Figure 1 shows the source regions of these air masses in winter and summer and the general directions of their movements across the continent. The air masses may be characterized in the following general way with regard to temperature and moisture: cP - cold and dry, mP - cool and moist, upper air drier, mT - warm and moist, C - dry and usually warmer than the areas into which it moves.

The areas dominated by the four different air mass types fluctuate with the seasons, particularly between winter and summer, as shown in Figures 1 and 2. On the basis of the combined winter and summer patterns, the North American continent may be divided into eight regions, as in Figure 1. The boundaries of these regions are constantly fluctuating apart from their seasonal trends. Short term fluctuations are due to penetration of an air mass into the area normally dominated by another. These penetrations vary both in the depth of penetration and the time they dominate the area. For example, cP air, normally dominant over the Canadian prairies in the winter, commonly pushes southward to the mid-central states where it may remain dominant for periods up to a week. Less frequently, a strong outflow of cP air pushes southward behind an active cold front (the Texas 'norther') into the Gulf of Mexico, bringing snow, freezing rain, frost or cold weather to latitudes that are normally frost-free. Conversely, the very heavy, relatively warm snowfalls that occur in February and March over the eastern Canadian prairies are caused by a northward expansion of warm moist mT air forming a warm front in contact with the cold cP air.

The boundaries of the air mass regions also fluctuate annually. For example, the average boundary between cP and mT air in the summer lies almost straight west from the Gaspe through Lake Superior to southern Manitoba. During some summers mT air only rarely reaches Manitoba and Lake Superior while other years it is the dominant air mass over southern Manitoba and the north shore of Lake Superior.

The climates of the North American air mass regions (Plate I) may be briefly characterized as follows:

1. cP - winter and summer. Northern Alaska and most of Canada, excluding the western cordillera, southern prairies, St. Lawrence valley, and the Maritimes. Frontal activity consists of weak occluded systems with scattered light precipitation which pass regularly through the region. The winters are cold and dry, with little snowfall except near the southern boundaries where it is associated with passing frontal systems. In summer precipitation is somewhat heavier along the southern boundary, but in general it remains high in frequency but low in intensity. The frost season is prolonged and intense; the growing season short.

2. cP - winter, mT - summer.
   a. Southern Alaska. The winters are short and cold for the

PLATE I

Fig. 1. Climatic regions and prevailing air-mass types, winter and summer. Arrows show winter pattern of air-mass movements. Dashes show major storm belts in summer, crosses indicate changes of path during winter.

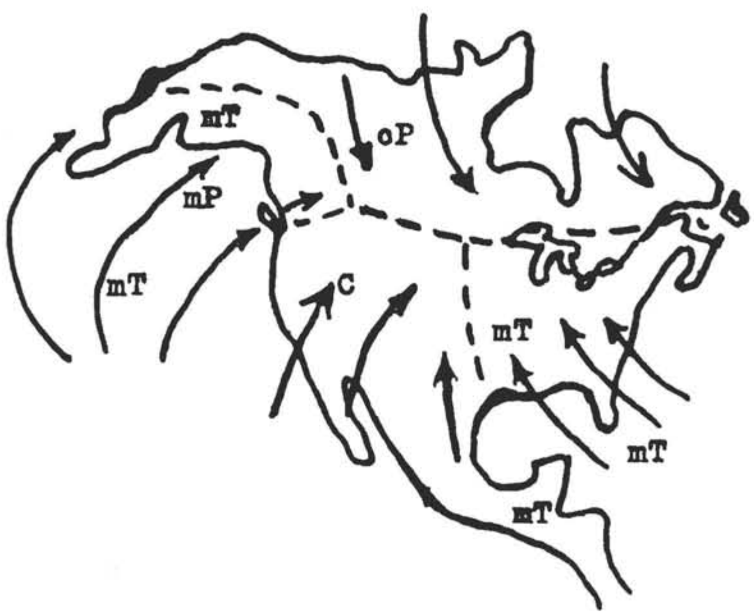

Fig. 2. Prevailing air-mass regions of North America in summer, showing source regions of air masses, arrows showing summer pattern of movements. Dashes show the major storm belts.

latitude and are characterized by frequent occluded frontal systems from Siberia, which bring much cloudiness but little snowfall. The prevailing winds are north to northeasterly. In summer mT air, somewhat cooled and very moist after a long passage over the western Pacific, enters the area from the west as the warm sector of frequent frontal systems. Cloud cover is thick, persistent, and frequent. High intensity rains occur, particularly on the coastal mountains. Summers are long and warm for the latitude.

b. Eastern Great Lakes, St. Lawrence valley, and the Maritimes. Winters cold and with frequent light snowfall from occluded fronts. Heavy snowfalls are more frequent than in Alaska as mT air regularly extends northward close to the area and occasionally penetrates to give January thaws. Summers are dominated by mT air in the warm sector of frequent frontal passages. Rain is very frequent and intense. The summers are long and warm for the latitude.

3. mP - winter, mT - summer. British Columbia. The growing season in this region is long and cool; the winters short and mild on the coast but cold at higher altitudes. Precipitation is high in frequency but low in intensity throughout the year. In winter, precipitation accompanies the frequent occluded fronts from the Pacific, while in summer mT air and warm fronts give frequent precipitation on land and a high fog frequency over the cold offshore Alaska current.

4. mP - winter, C - summer. Washington and Oregon. The winter climate is dominated by frequent frontal passages which give regular rains and high fog frequency at the coast. The winters are mild on the coast but cold at higher altitudes. In summer the C air gives clear dry weather with infrequent, low intensity rains.

5. C - winter and summer. Western and southwestern United States. Generally dry throughout the year. Precipitation is low in frequency and intensity and very variable from year to year and place to place. Precipitation generally accompanies a flow of mT air from the Gulf of Mexico or the Pacific Ocean.

6. C - winter, mT - summer. A wedge including southeastern Manitoba to eastern Oklahoma and east through the 'prairie peninsula' to eastern Indiana. This area has winters characterized by relatively frequent but very low intensity precipitation with occasional heavy snow or rainfall accompanying invasions of cP and mT air. Frequent storms, cold snaps and thaws occur, particularly in the central portion. The summers are generally hot and humid, with high frequency but low intensity rains, caused by thermal lifting of the moist mT air. Occasional cold fronts entering the area give heavy rainfall.

7. mT - summer and winter. Southeastern United States. Summer rains are generally of the high frequency, low intensity type caused by thermal and orographic uplift. Occasional cold fronts entering the area result in extremely high intensity rains, the highest in the world, due to a combination of warm, wet, mT air, cold cP air, and turbulence caused by surface

heating. In winter frontal rains are more common and occasionally cP air invades the area, giving freezing rains and frost.

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ECOLOGICAL STUDIES ON GRASSHOPPERS IN THE RED RIVER VALLEY

by W. Romanow
Entomology Laboratory
Brandon, Manitoba

With the advent of agriculture in Manitoba, large areas of open grassland were converted to cultivated farmland. This disturbance of the native habitat resulted in a marked change in the distribution and abundance of the native grasshopper species. Those species that bred in sod and were specific feeders have become limited in their distribution. They are not a problem in cultivated areas but are still economically important on rangeland. Species that found cultivated plants and the new environmental conditions favourable became more abundant and widespread.

Breaking up of native sod and growing of grain crops has probably benefited *Melanoplus mexicanus mexicanus* (Sauss.). Though many of the former breeding areas of this species have been destroyed, the conditions created have proved favourable, as this species shows a preference for stubble fields for oviposition and grain crops always provide an abundant supply of food. However, *M. m. mexicanus* is a species of the short-grass prairie and prefers light soil and arid conditions and is therefore seldom a troublesome species in the Red River Valley.

Melanoplus bivittatus (Say), a species of the long-grass prairie, is the most abundant species in the Red River Valley and has probably become more widely distributed on the prairie since the land came under cultivation, as is evident by its choice of oviposition sites. This species prefers crowns of ditches, drift soil, field margins, and abandoned fields. These habitats were at a minimum under natural conditions.

Camnula pellucida (Scudd.), the second most abundant species in the Red River Valley, has also been favoured by changes that have taken place. Overgrazing of ranges and retention of native sod along roadsides and fields provide excellent sites for oviposition. These favourable habitats are smaller than under natural conditions but their proximity to the crop has increased the economic importance of the insect.

In the early days most of the area in the Red River Valley was low, wet prairie. When the land came under cultivation much of the area was drained, resulting in a change from a wet grass prairie to a tall grass prairie.

In the last 15 to 20 years most of the native vegetation in the Red River Valley has been destroyed. Roadside sods consist mainly of brome grass or Poa spp., with traces of Agropyron repens (L.) Beauv. The dominance of brome along roadsides appears to be the result of seeding to brome rather than plant succession. Patches of Poa spp. are common on roadsides on which brome is dominant. In the older stands of brome, Poa spp. appear to be succeeding brome and indications point to an eventual climax of Poa spp. along these roadsides.

Roadsides recently disturbed have been invaded by annual weeds and there are various stages of succession.

Mechanization has resulted in practically no livestock being kept and many of the pastures have been broken up. Many fences have been removed and fields are generally cultivated to the edges of the drainage ditches. This practice has created a drainage problem, as the ditches become plugged by soil carried from the fields during spring run-off and heavy rains. In some areas farmers are considering a return to the old practice of retaining a strip of sod along the edge of the field to overcome this problem. There has been a fairly extensive road-building program, resulting in further removal or disturbance of habitats.

Breaking up of pastures, working of fields to the edges of the ditches, and road building have probably destroyed many potential breeding sites of C. pellucida but not necessarily those of M. bivittatus. These practices have destroyed many ditch crowns, which are favoured by M. bivittatus as oviposition sites, but the conditions created have partially compensated for this.

In the past several years of low grasshopper populations, M. bivittatus has remained the most abundant and widely distributed of the economic species in the Red River Valley. The bulk of the population has occurred primarily along roadsides that have been recently disturbed and are in the early stages of succession. Several factors contribute to the ability of this species to maintain itself in this habitat during unfavourable years and possibly build up and spread to other areas during favourable years.

M. bivittatus has a variety of egg-laying sites. In wet years when the population is at a low level this species probably becomes more selective in its choice of oviposition sites. The conditions created along disturbed roadsides provide excellent sites. The soil is usually loose and simulates drift soil, highly favoured by M. bivittatus.

The changes that have taken place in the last 10 to 15 years have reduced egg-laying sites of C. pellucida. However, the return to seeding a sod strip along the edge of the field may in time restore these breeding sites. Also, many of the roadsides that have been seeded to brome may in time be succeeded by Poa spp. and create more sites favoured by C. pellucida.

A project was initiated at the Brandon laboratory in 1954 on the effects of the destruction and modification of habitats as a result of present-day agricultural practices on the population trends of the two economic species M. bivittatus and C. pellucida in the Red River Valley.

Seven years' data (1935-1941) for work previously carried out at Arnaud are available. Arnaud was the first study centre established by the Entomology Division, Canada Department of Agriculture, for "intensive study of the economic grasshoppers in typical environments where previous outbreaks have been known to occur". The study of this area was to be a long-term project, the object of which was "to determine the biological and environmental factors which cause extensive fluctuations in grasshopper populations, with the practical end in view of being able to predict or prevent grasshopper outbreaks" (1).

The Arnaud study centre along with other areas provides an opportunity to study the two economic species under changing environmental conditions and also to utilize the data already obtained at Arnaud. The investigations will include studies on the seasonal history of C. pellucida and M. bivittatus in the different habitats and detailed studies of the habits of all stages of the grasshoppers.

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COMMERCIAL APPLICATION OF INSECTICIDAL RESEARCH

by F.C. Birt
Chipman Chemicals Limited
Winnipeg, Manitoba

The title given me for this paper was "Commercial Application of Insecticidal Research". This title has presented several problems as to the approach you wish taken to this subject. I am not sure just who chose this particular title, but I am sure that he had some specific aspect in mind when choosing it. However as it has been given to me to deal with, and I am mainly interested in sales and extension of agricultural chemicals, I shall try to approach it as it affects others in similar positions.

Much has been written in recent years on the subject of insecticidal research of one type or another. When we consider it from a commercial aspect, we usually think of insecticides rather than natural means of control of insects. Therefore, I feel this paper should deal with insecticides and how commerce uses the information given them by research in this particular field.

Since the discovery of DDT and its introduction, we have had a rapid development of new insecticides. They are almost too numerous to list. Many of these have been selected for their possible value by the laboratories of large chemical companies' research divisions where trained teams of specialists, made up of chemists, entomologists, physicists, mathematicians and numerous other specialists and technicians, screen possible combinations of materials or by-products produced by their companies for new uses. If they obtain anything of interest from any one of the samples they are examining, it is set aside for further examination and development or rejected, depending on how it shows up for the purpose for which it has been selected.

In many cases agricultural chemicals have been rather poor second cousins in many of these programmes. As this new field of agricultural chemicals opened up, more and more companies became interested in the possibility of finding new outlets for their production, especially immediately after World War II. In general they were more interested in some other main field of endeavour and their agricultural departments were rather small. However, a change now is taking place and greater interest is developing in this field.

With populations increasing and the demand for agricultural products, particularly food, expected to increase, all products that will help to protect our crops will have ever-increasing demand. For this reason greater emphasis is being placed on the development and perfection of new and better agricultural chemicals. Furthermore, it has been definitely proven in the last ten years that there is a definite place in agriculture for these products and farmers are now accepting them as every-day tools in their way of life.

For this reason, the technical personnel in the agricultural chemical divisions of commercial organizations is being increased. Some companies no longer just screen chemicals to see if they have a use, but their teams are making surveys of existing problems in all parts of the world to find what the chief problems are, and chemicals are being designed to fit the needs required. They are no longer trying to adapt existing chemicals to specific uses.

You are all familiar to some degree with the development of a chemical from the first few ounces prepared in a laboratory to the time it is released to the public for sale. It is during this period that the insecticidal research takes place, for at this time something must be known of the insecticidal properties of these samples, their toxicity, and adaptability to formulation and handling. It could be rejected if it falls down in any of these. Its insecticidal properties, of course, must fill a need. If it is too highly toxic, it will probably be rejected. If it is too expensive to produce or does not lend itself readily to formulation or handling in the field, it will also be discarded. If it clears all of these points, then it must be produced in a pilot plant in sufficient quantity to determine its value in the field.

This is the period when widespread tests must be carried out under close observation by entomologists, in every possible location, to see if similar results can be obtained at all points and to discover as far as possible how many insects this particular chemical will control. It is at this time that help must be obtained from the entomological laboratories, experimental stations, universities and other extension agencies carrying on work of this type. Often this is not only done by the company producing the basic material, but also by other companies who may in the future be interested in formulating the material for their local market. Once this work has been carried out, and if the original beliefs in the chemical have been proven and substantiated by accredited organizations, the product will be ready for registration. It has been estimated that the total research and development cost of a successful chemical is one and one-half million dollars. This of course is before the chemical is in production.

It is at this point of development that I feel my paper should begin. A new chemical has been turned out and approved. Most of the necessary insecticidal research has been carried out and the product is satisfactory to present to the public. In other words, the scientists in the industry say to the development boys, "Here it is, this is what it will do, you sell it" and then another stage in its development has to be got under way.

If the first steps have been carried out, then most of the personnel in extension positions know of this chemical and are in a position to assist or even recommend it for special uses before it would normally be expected to be taken out in large quantities.

An outbreak of grasshoppers greatly assisted in the introduction of several chlorinated hydrocarbons a few years ago. These products proved themselves to be highly efficient if used according to the information that had already been determined by the companies and government agencies working closely together in the early days of the development of these products. The value of this co-operation was proven as these chemicals behaved almost exactly as expected when they were put into the field to be used by numerous untrained operators.

However, this is an emergency type of operation. Often we are concerned with pests that have been with us for years. They cause great damage year after year but not always in exactly the same location and there is no accurate way of forecasting the extent that they will attack in any one season. They may not cause damage at all, due to weather conditions, even though they may be in a location in large numbers. This is somewhat true of a number of our soil insects. In cases like this, a control with an insecticide may be known and the information available. This information must be carried to the final user, who, in many cases, will not realize what losses he is suffering or may not realize that he even has the problem.

This can be done in a number of ways. One is to use an extensive and expensive advertising campaign, which is becoming more and more popular as the public are becoming more and more appreciative of agricultural chemicals. This was not the case a few years ago when the first of these chemicals were being introduced and new techniques had to be accepted by the users.

Another method is by demonstration. Here numerous demonstrational plots must be laid down on the users' locations and in as many areas as possible, in order to show the value of the chemical in these areas. Where possible these tests should be supervised by experienced personnel, the results should be registered and the improvement in the crop recorded. Then the information should be made available to the farmers in the area. This is a most interesting type of extension but limited to specific problems that can be handled in this fashion; they require a great deal of organizational preparation and co-operation on the part of all interested parties, particularly if the areas of infestation are large, because it is impossible for any one agency to do a thorough job on its own.

Past experience has shown that this is possible; here in Canada we are fortunate that our Federal and Provincial Departments are always willing to assist commercial enterprises in developing new chemicals or techniques that will be of value and assistance to our farmers and other basic producers.

Other chemicals for more specific uses, for example, greenhouse fumigation, household pests, and forest insects, have to be handled by different methods designed to fit each particular field. All of these are developed and promoted on the basis of the information produced from insecticidal research. Therefore, it is only fair to say that insecticidal research is basic to the commercial application of an insecticide.

ENTOMOLOGICAL ASPECTS OF BULK GRAIN STORAGE IN THE PRAIRIE PROVINCES

by
F. L. Watters
Entomology Laboratory
Winnipeg, Man.

On the prairies, normal grain storage capacity has been taxed during the past five years by a series of above-average harvests. Farmers and commercial grain handlers have been forced to use many types of temporary storages. Some of these are unsuitable for storing grain for protracted periods. This has brought entomological problems. To appreciate the significance of these problems we must know something of the habits and life-histories of the insects involved, their control, and something of the physical nature of bulk grain.

Stored grain is threatened by a group of insects that have become specialized for feeding on dried seeds and grain dust. These insects are capable of causing serious losses, especially in tropical countries, where high year-round temperatures, coupled with inadequate storage facilities, promote infestations. On the Canadian prairies the entomological problems are somewhat reduced by cold winters, which cool most bulks of grain below the temperature at which many grain-infesting insects are active. Nevertheless, certain species survive the winter and have caused serious losses to individual farmers and commercial grain handlers.

Common Stored Grain Insects

Grain-infesting insects are sometimes grouped according to their feeding habits. The so-called borers are equipped with strong jaws that enable them to attack sound kernels. Another group, the "Bran bugs", are incapable of feeding directly on whole grains but rely for food on fragments left by borers. A third group are the fungus feeders; these insects are attracted to, and feed on, microorganisms that develop on "tough" (14.5 to 17.5 per cent moisture content) or damp (above 17.5 per cent moisture content) grain.

The most destructive group of stored product insects are the borers. The granary weevil, *Sitophilus granarius* (L.), is the most important of these in Canada. It is a dark-coloured beetle about three-sixteenths of an inch long. The head of the adult is extended to form a snout that bears strong jaws, used for chewing holes in kernels. The female beetle chews a small hole in the kernel, lays an egg in the cavity, and seals the opening with a gelatinous fluid. The small, legless larva that hatches feeds on the germ and endosperm inside the kernel. At a temperature of 68.9°F. and a moisture content of 70 per cent, the duration of development is 45 days (Richards, 1947). Grain with a moisture content of 10 per cent does not support populations of *S. granarius*. On the prairies, this insect has been found at only a few points in southern Manitoba.

The rusty grain beetle, *Laemophloeus ferrugineus* (Steph.), is widely distributed in the southern regions of the prairies. The most northerly point reporting an infestation is Prince Albert, Sask. Infestations on farms and in commercial storages have centred around Lethbridge in Alberta and Weyburn, Moose Jaw, Regina, and Rosetown in Saskatchewan. In Manitoba, most infestations have occurred at points south of the trans-Canada highway between Winnipeg and Brandon.

The adult is a flattened beetle with an oblong shape, about a sixteenth of an inch long. The antennae are about half as long as the body. The female beetle deposits her eggs in small crevices, fractures, or holes in kernels of grain. The larvae hatch in 3 to 4 days and enter the kernel through microscopic fractures in the seed coat over the germ region. The time taken to complete development depends on the temperature and moisture content of the grain. Rilett (1949) states that at 90°F. and with a grain moisture content of 15.2 per cent it takes 20.5 days for a newly emerged larva to complete its development. With the same moisture content at 70°F. the period of development is increased to 64.2 days. The adults emerge from the kernels and mate when only 1 to 2 days old; oviposition commences shortly afterwards. A small patch of "tough" grain is apparently necessary for this species to start an infestation. Once established, the insects are able to maintain an infestation in grain with a moisture content of 11 to 13 per cent. The adults can fly when the temperature is above 80°F. and this is an important factor in its wide distribution.

The confused flour beetle, Tribolium confusum Duv., is a typical member of the "bran bug" group. This insect is found throughout the world and occasionally infests warehouses and grain storage facilities in the Prairie Provinces. It is an important pest of cereal processing plants in Canada. The adult is reddish-brown and about an eight of an inch long. The average adult life is from six months to a year although individuals live for as long as three years and nine months. The oviposition rate is related to temperature and relative humidity. The average female lays 400 to 500 eggs when conditions are ideal. Most of these are laid during the first six months in varying numbers up to 15 daily. The adults deposit eggs loosely in wheat or grain dust. The eggs hatch in 5 to 12 days into slender, yellowish-white larvae that grow to a length of three-sixteenths of an inch. The rate of development depends on temperature and relative humidity. At a relative humidity of 75 per cent and a temperature of 63°F. the eggs hatch but no larvae complete development; at 72°F. they complete development in 61 days and at 91°F. they take 17 days. It has been calculated that over one million progeny could be produced by one pair in 150 days under ideal conditions (Gray, 1948).

The hairy spider beetle, Ptinus villiger (Reit.), is mainly a pest of warehouses in which bagged flour is stored, but it also occurs in stored grain. Eggs are laid among grain kernels from about April 15 to August 1. The eggs hatch in two or three weeks. The larvae cement a number of kernels together and feed inside the clusters. It takes about 3 months to complete development from the egg stage at 68°F. During winter the larvae go into diapause when exposed to field conditions. Adults that emerge during summer and fall do not oviposit until March when kept at 50°F. Oviposition commences several weeks earlier if adults are exposed to 35°F. for two weeks and then kept at 50°F. Adult survival during winter is higher on wheat than on patent flour.

The saw-toothed grain beetle, Oryzaephilus surinamensis (L.), sometimes occurs in stored grain. It gets its common name from the 6 toothlike projections on each side of the prothorax. The adults are flattened, brown, and about a tenth of an inch long. They usually live for about 6 to 10 months but some live for as long as 3 years. Females lay an average of 170 eggs during their lifetime. The eggs are deposited loosely between kernels, in crevices, or in farinaceous material. Larvae emerge in 3 to 5 days and feed on broken or damaged kernels and on grain dust. They become full-grown in two weeks during summer and then form a cocoon from grain dust and fragments. The life-cycle takes about 24 days at 81°F. and 72 days at 70°F. (Freeman, 1951). This beetle has been known to breed in grain having a moisture content of 9 to 10 per cent.

There are several species of beetles that feed on micro-organisms in "tough" or damp grain. Among these is the foreign grain beetle, Ahasverus advena (Waltl.), of the family Silvanidae. This is a small reddish-brown beetle similar in size and general appearance to beetles of the family Cryptophagidae. In addition, beetles of the family Lathridiidae occur in "tough" or damp grain stored on the prairies. Species of these three families of insects are commonly called fungus beetles, and they are often found in grain that is heating.

Mites frequently infest grain that is "tough" or damp. Tyroglyphid mites give grain a sweet, minty odour, which disappears when the mites die. They feed on the germ of wheat and are often associated with heating grain. Acarus siro L. is the mite causing most damage in Canada. Germination and food value of wheat infested with mites is likely to be low. In bulk grain, mite infestations are usually confined to surface areas where moisture has condensed from translocation.

Tyroglyphid mites are easily recognized by having legs darker than the rest of the body, short hairs, and slow movement.

Two other species of mites often found associated with tyroglyphids in stored grain are Glycyphagus cadaverum Schr. and Cheyletus eruditus Schr. G. cadaverum is slightly larger than A. siro, has longer hairs, and moves about rapidly. It feeds primarily on grain dust. C. eruditus is larger than A. siro or G. cadaverum and moves more slowly. It feeds on the other two species and is therefore considered beneficial. C. erúditus often becomes more abundant than the other two species during late summer. During winter when the surface of bulk grain becomes "tough" or damp, A. siro is predominant, G. cadaverum occurs in fewer numbers, and C. eruditus occurs infrequently. Solomon (1946) has reported similar seasonal changes in population densities of grain mites in Britain. There, C. eruditus becomes more abundant than Tyroglyphus farinae (L.) or G. destructor Schr. during summer and autumn. During winter and spring T. farinae becomes more abundant than the other two species.

Mites are exceedingly susceptible to desication because they respire through the body surface and have no mechanism to control water loss. Therefore, infestations may be controlled by drying the grain. In addition to removing moisture required for development and survival, the physical handling of grain through grain driers is a controlling factor because mites are easily injured.

Moths are infrequent pests of bulk grain stored in the Prairie Provinces. The adults because of their wing structure are unable to penetrate deeply into grain and infestations remain near the grain surface. The larva is the only stage that feeds on the grain. It has strong jaws and feeds on both the germ and the endosperm of wheat.

The Indian-meal moth, Plodia interpunctella (Hbn.), is one of the two species of moths found in stored grain on the prairies. It is easily recognized by the reddish-brown colour of the outer two-thirds of the fore wing; the inner third of the wing is a light grey colour. The wing expanse is nearly three-quarters of an inch. Females lay 100 to 300 eggs. In warm weather, the eggs hatch in about a week and full development is completed in 6 to 8 weeks. Heavy infestations may be indicated by extensive webbing of wheat kernels by the larvae.

The meal moth, Pyralis farinalis L., is larger than P. interpunctella, having a wing spread of 1 inch. The fore wings of the adult have two wavy, transverse white lines on a background of light brown with dark-brown patches. The larvae are larger than those of P. interpunctella. They spin tubes of silk that enclose them except for an opening near the mouth. When they reach a length of about 1 inch they leave the tubes and spin cocoons, in which they form the pupal stage. They complete development in 6 to 8 weeks. In general, this insect attacks only grain that is damaged or slightly out of condition.

Types of Storage

Our entomological problems in stored grain are closely related to the types of storages used. Most infestations occur when surplus grain is stored in unsuitable buildings. Old granaries that have not been used for several years, machine shops, and barns are often filled with grain. Many of these buildings are not weatherproof and, as a result, "tough" and damp areas develop near leaking walls or beneath roof holes; moulds begin to grow and the grain becomes more susceptible to insect infestation.

Open crib shelters are sometimes used to store surplus grain. These are often constructed from snow fencing lined with building paper or from lumber. The capacity is usually from 500 to 1000 bushels. Losses usually occur when no provision is made for protecting the grain from ground moisture and rain.

Most grain in commercial storage in the Prairie Provinces is held in elevators with capacities from 20,000 to 85,000 bushels. The average capacity is about 30,000 bushels. A grain elevator contains, on the average, about 20 bins that are used to store different varieties and grades of grain. Additional space at elevator points is provided by annexes holding 20,000 to 50,000 bushels. The annex may be filled by gravity through a spout leading from the top of the elevator, or by an overhead auger. Newer annexes have screw conveyors running the length of the building at floor level and grain can be readily moved from individual bins into the elevator when necessary. Annexes without screw-conveyors are emptied by gravity through ports near the floor. Portable augers are used to unload grain at floor level.

Physical Nature of Bulk Grain

The physical state of grain is subject to change during the storage period. Temperature and moisture content are the dominant physical factors affecting bulk grain. Since grain has a low thermal conductivity the temperature at the centre of a bulk of 20,000 bushels does not change as much as the temperature at the periphery. During winter, whenever a temperature differential is established, water vapour surrounding the warmer grain near the central region moves towards the cooler grain at the surface. This phenomenon is called translocation of water and has been demonstrated in the laboratory by Anderson et al. (1943). Translocation occurs more rapidly when the temperature gradient is steep. Often, this results in surface grain becoming "tough" or damp. Under these conditions micro-organisms become active, moulds develop, heating begins, dormancy is broken, and sprouting occurs. This may be followed by formation of a surface crust that will prevent the escape of water vapour and cause further deterioration within the grain bulk. Insects and mites are almost always present to aggravate the situation.

Grain stored in 1000-bushel granaries is cooled to uniform temperatures during winter and translocation does not occur. "Tough" or damp grain at the surface can usually be traced to roof leaks.

Figure 1 shows temperatures, taken in mid winter in Manitoba, of a small bulk of grain (800 bushels) and a large bulk of grain (25,000 bushels). The temperatures of the small bulk are lower and more uniform than those of the large bulk.

Biological Factors

Stored grain is a living material and, like most living things, it uses oxygen and gives off carbon dioxide, water, and heat. When grain is dormant these processes are hardly measurable. Dormancy can be broken, however, by increasing the moisture content above about 15 per cent. In large bulks of grain this can happen through translocation of moisture or by roof and wall leaks. Moulds develop and grain respiration increases. The heat produced accumulates faster than it can be dissipated because of the low thermal conductivity of the grain. The final stage is reached when the grain sprouts, dies, and rots.

Insects can also cause bulk grain to heat. When they feed and grow, the heat they produce accumulates and raises the grain temperature. Insect development and reproduction are accelerated in warm grain but when their optimum temperature is exceeded they are likely to move into cooler grain and so extend the zone of infestation and heating. Immature stages of insects inside kernels are, of course, unable to move into cool grain. They remain and continue to produce heat.

Oxley (1948) has suggested that "damp grain heating" occurs under the following conditions: The moisture content is greater than 15 per cent, the temperature is between 108°F. and 144°F., and insects are usually, but not necessarily, present. "Dry grain heating" is characterized by a moisture content of 11 to 15 per cent, a grain temperature approaching but not exceeding 108°F., and the presence of insects.

Sometimes "dry grain heating" caused by insects may lead to "damp grain heating". This may occur when grain with a moisture content between 15 and 18 per cent becomes infested with insects. Before infestation, the grain may be dormant but the heat produced by the insects will cause micro-organisms beneath the bran coat of the kernel to respire and "damp grain heating" will be induced.

Locating Infestations

Several methods are used for locating infestations in bulk grain. Surface infestations may be found by sieving samples taken from various places, and checking grain temperatures. Deep samples of grain may be obtained with a torpedo probe. This device consists of a brass tube about 2 inches in diameter, 6 to 15 inches long, pointed at one end. It can be shoved into the grain to various depths by means of extension rods. The tube is opened at the desired depth and filled with grain. The samples can then be withdrawn and sieved for insects. Adults can readily be found but it is more difficult to detect immature stages within kernels. When hidden infestations are suspected, the grain is incubated for a month or more to allow time for the adults to develop and emerge from the kernels.

A quicker method of determining the presence of immature stages of weevils in grain has been developed by Milner et al. (1950). The grain sample is immersed in a staining medium of alkaloid berberine sulphate for 1 minute. The plugs over the egg holes in the kernels fluoresce in the dark when exposed to ultra-violet radiation, and are readily sorted out.

An ingenious method for detecting infestations deep in a bulk of grain has been developed by Howe and Oxley (1944). This consists of measuring the carbon dioxide content at points in the grain bulk. Because the carbon dioxide produced by insects is greater than that by grain, the extent of an infestation can readily be determined.

An X-ray method for detecting hidden infestations has been developed by Milner et al. (1950) and is now in commercial use in the United States, where sanitation standards, set by the Food and Drug Administration, operate in buying and selling grain. X-ray photographs are taken of grain samples, and it is a simple matter to detect immature stages within the kernels.

Adams et al. (1953) have described a method to detect hidden infestations with electronic equipment. A high-gain audio amplifier with a low noise level is used in conjunction with a sound-proof box. A sample is withdrawn from the grain bulk and placed in the box along with a suitable microphone. The sounds made by the immature stages are amplified and fed into a loud speaker. It is possible to differentiate between larvae and pupae by the frequency of the sounds emitted. The low-frequency sounds are made by the movement of larvae and pupae within the kernels, and the high-frequency sounds are made by larvae when they chew.

Recently an electronics company in the United States has developed an audio amplifier for detecting the presence of insects in bulk grain without withdrawing samples. This instrument was designed for locating termites in the timbers of houses and other buildings. Small-scale tests have recently been carried out in bulk grain by Craig. A sensitive microphone is inserted into the grain bulk and insect sounds transmitted to the amplifier can be detected by earphones. The effective range of the instrument is said to be 3 to 4 feet.

At the Winnipeg laboratory a method has been devised for detecting surface infestations without taking samples. In this work use is made of the attraction by many species of stored product insects for water. In tests, jars of water placed in bulk grain have yielded numbers of Laemophloeus ferrugineus, Cryptophagus spp., psocids, staphilinid beetles, and the hymenopterous parasite Cephalocinctus waterstoni Gahan.

Control

A number of measures may be applied either to prevent grain infestations or to limit their severity. The following preventive measures may be applied before harvest. First, granaries should be cleaned and made weather and rodent-proff. Second, the floors and walls should be sprayed with a suitable insecticide. Third, the grain should not be harvested "tough" or immature, for then it is more likely to become infested.

Grain may be protected from serious infestation during storage by treatment with a suitable insecticide as it is being binned. Pyrethrins-piperonyl butoxide in the form of of powder is effective against the cadelle, Tenebroides mauritanicus (L.); the saw-toothed grain beetle, Oryzaephilus surinamensis; Laemophloeus spp.; the rice weevil, Sitophilus oryza (L.), and the granary weevil, Sitophilus granarius (Wilbur, 1952). The insecticide usually remains effective for about 8 months. Tests at the Winnipeg laboratory indicate that pyrethrins-piperonyl butoxide is less effective against the granary weevil, the rusty grain beetle, Laemophloeus ferrugineus, and the confused flour beetle, Tribolium confusum, when the moisture content exceeds 15 per cent. It is more effective when the grain moisture content is at or below about 12 per cent. In general, wider use of protective dusts is limited largely by economics. The treatment is usually more expensive than fumigation and many farmers and commercial grain handlers are inclined to rely on good storage practices to prevent infestations.

Infestations by beetles and mites in stored grain have been controlled by cleaning the grain during cold weather. It is difficult to lower grain temperature sufficiently to obtain a quick kill of insects. However, oviposition and larval development of most stored grain insects are greatly retarded when the grain temperature goes below 50° F.

Fumigants are used widely to control insects in stored grain. They are usually applied as liquids that vaporize to form gases toxic to insects and mites. The effectiveness of a fumigant depends not only on its toxicity but on its ability to penetrate the grain mass. Penetration of fumigants is reduced in grain that is "tough" or damp, or contains a high proportion of dust and weed seeds. This reduced penetration is caused by absorption into the commodity and to compensate for this the applied dosage must be increased.

Fumigants may be applied to bulk grain at the surface, or below the surface through pipes. They can also be poured on the grain as it is being binned.

When fumigants are applied to the grain surface all cracks, doors, ventilators and spout openings should be sealed to prevent the gas from escaping. During winter the grain may be too cold to vaporize fumigant applied at the surface. It may then be necessary to apply the fumigant through pipes pushed two feet or more into the grain. This method may also be used to fumigate infested "hot spots" below the grain surface.

Chloropicrin was used extensively in the Prairie Provinces during World War II. It was applied through short probes just below the grain surface, and gave satisfactory control against mites and insects (Gray, 1948). Another fumigant that is applied at points on the grain surface contains 30 per cent methyl bromide and 70 per cent ethylene dibromide. This mixture may be used to fumigate grain stored in 1000-bushel granaries by opening the containers and pressing the open ends into the grain. The surface of the grain should be covered with a tarpaulin or building paper to confine the vapours and assist penetration.

Larger bulks of grain of 25,000 bushels or more can best be treated by fumigants applied from above the grain. One commonly used fumigant consists of 7.2 per cent ethylene dibromide, 27.7 per cent ethylene dichloride, and 64.9 per cent carbon tetrachloride. It is essential to use a power sprayer when fumigating grain bulks of 25,000 bushels or more. This facilitates application from outside the building, and thus the personal hazard is reduced.

A bronze gear pump used in conjunction with a 3.5 h.p. gasoline engine is suitable for applying large quantities of fumigant from above the grain surface. A stirrup pump may be used to apply fumigant to grain stored in 1000-bushel granaries.

Methyl bromide, a fumigant with superior penetration properties, may be applied from pressurized cylinders to shallow open containers placed on the grain surface. The liquid volatilizes to form a gas that sinks into the grain. A plastic tarpaulin placed over the surface limits the escape of vapour. An advantage of this method is that the methyl bromide may be applied safely from outside the building.

Fumigants are hazardous to use and adequate safety precautions should be followed during application and handling. Respirators with appropriate canisters should always be worn when entering buildings that are under fumigation. Protective clothing should be worn when there is any likelihood of spillage.

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A. 800 Bu. Granary

26.0	19.5	22.0	22.0	24.0
23.5	18.75	22.0	22.0	22.0
22.0	18.75	22.0	21.5	21.5
21.5	18.75	22.0	20.5	21.5
19.5	17.75	22.0	20.5	21.5
19.5	17.75	22.0	22.0	21.5

8 ft. (height) × 10 ft. (width)

B. 25,000 Bu. Annex

35.6	39.2	41.0	35.6	40.3	42.0	37.4	33.8	40.3
31.5	33.8	35.0	36.8	39.2	42.0	37.4	33.8	33.8
32.0	35.6	38.5	39.2	42.8	42.8	39.2	35.0	33.8
33.8	37.4	40.3	42.0	44.0	44.6	39.2	35.6	32.0
33.8	38.5	40.3	42.0	44.0	44.6	38.5	33.8	30.5
32.0	42.8	38.5	41.0	44.0	42.8	36.8	33.8	28.7
29.7	46.0	35.0	37.4	39.2	40.3	35.0	32.0	26.8
27.8	30.5	32.0	33.8	35.6	36.8	32.0	30.5	25.0
30.5	27.8	31.5	32.0	33.8	35.0	31.5	29.7	26.0

18 ft. (height) × 22 ft. (width)

Figure 1. Temperatures of bulk grain (°F.). Readings in A taken in plane through middle of granary 1 ft. apart vertically and horizontally. Readings in B taken in plane through middle of annex, 2 ft. apart vertically and horizontally.

THE ANNUAL MEETING

The Business Session

The business session of the eleventh annual meeting of the Entomological Society of Manitoba was convened in the Department of Entomology, The University of Manitoba, at 10.30 a.m., November 4, 1955. The President, F.L. Watters, was in the chair.

The minutes of the spring meeting were read and adopted on a motion by R.M. Prentice and T.V. Cole.

At the opening of the meeting W.A. Reeks, formerly of the Fredericton laboratory, and now Officer-in-Charge, Forest Biology Laboratory, Winnipeg, was welcomed to the Society by F.L. Watters.

The Society was reminded of the vacancy in the Nominating Committee due to the recent transfer of R.R. Lejeune to the Victoria laboratory. W. Fox was nominated by G. L. Warren to fill this vacancy, seconded by R.J. Heron. CARRIED.

The Treasurer's report was read by T.V. Cole. The Society was reported as having no outstanding debts. The Treasurer stressed the need for prompt payment of dues. T.V. Cole moved adoption of the report. Seconded by H.R. Wong.

The Editor-Librarian's Report was presented by A.G. Robinson. He reported the sale of two complete series of 10 volumes of past proceedings. A letter in reply to a recent request to Drs. Glen and Prebble concerning contribution numbers for articles appearing in the proceedings, was read to the Society. Both Dr. Prebble and Dr. Glen gave negative replies to this request. A.G. Robinson resigned as Editor-Librarian.

A Report of the Common Names Committee was read by W.A. Reeks for W.J. Turnock, Chairman of the Committee. It was pointed out that concepts of the functions of the Committee varied between regional societies, some feeling that common names should be given to all common species of economic importance, while others felt that the list of common names should be limited to major economic species. The policy of the Manitoba Society for 1955-56 would be to take a liberal outlook in adopting common names. That is, insect species that appear frequently in reports or papers warrant the assignment of common names. Those presenting names should give strong support for the name. Lack of strong defence is the main reason for rejection. Forms are available through Professor Mitchener for submission of common names. It was recommended that Regional Committee members make a serious effort to submit some names for approval in 1956. Professor Mitchener, now Chairman of the Canadian Committee on Common Names, further stressed the need of strong support for all common names submitted.

The Report of the Nominating Committee was presented by A.V. Mitchener. The Nominating Committee met and recommended that the 1955 slate of officers be continued for 1956. W.R. Allen was nominated for the office of Editor-Librarian. The Committee recommended that after 1956 the offices of Past President, President, and

Vice President be held for only one year, and that the Nominating Committee should be elected by the executive one year in advance. A.V. Mitchener moved adoption of the report. Seconded by R.J. Heron.

Other Business. Moved by A.V. Mitchener that the place and time of the I.G.P.C.E. meeting in the summer of 1956, be left to the executive. Seconded by A.G. Robinson. CARRIED.

The meeting adjourned at 12 a.m.

Scientific Business

The scientific sessions were held in the Department of Entomology, The University of Manitoba, on the afternoon of November 3 and on the following morning. Dr. J.R. Weir, Dean of the Faculty of Agriculture and Home Economics, welcomed the members to the campus.

The program featured a series of papers on grasshoppers. Professor A.V. Mitchener and H.E. Wood presented an historical account of the control methods and organization of control campaigns in Manitoba since the turn of the century. Professor Mitchener took a congent look at the recurrence of grasshopper outbreaks and found a definite pattern. Also, he sought the muses and has distilled for us, from many vintage years, an Acridological verse. W. Romanow reviewed the grasshopper survey system used in Manitoba, showing the developments made in recent years, and mentioned the purposes for which it is designed. We are much indebted to D.S. Smith for his up-to-date account of researches in grasshopper nutrition and to L.G. Putnam for sharing with us the observations he made on grasshopper and locust control during his recent trip to Europe and Africa.

The texts of these papers follow.

On the evening of November 3 the members enjoyed a banquet at Motel 75. J.B. Wallis gave an interesting after dinner talk on "Entomologists I Have Known" and Dr. R.D. Bird entertained with a series of fine color slides on animals and birds.

A HISTORY OF GRASSHOPPER CONTROL IN MANITOBA

A.V.MITCHENER

Professor Emeritus of Entomology
The University of Manitoba, Winnipeg.

These many years we've waited till
These hexapods have had their fill
It's time we struck more timely blows
Against these pests, our ancient foes.

A.V.M.

The records of the occurence of grasshoppers in Manitoba extend back to 1799. Probably grasshoppers had invaded this area from time to time, long before then when their native American breeding ground far to the south-west had failed to supply sufficient during the dry years. The writer has recorded some of the historical background of these invasions of the Rocky Mountain grasshopper, _Melanoplus spretus_ Uhler in a paper to be found in the _Report of the Entomological_ Society of Manitoba, Vol. 9, 1953. To provide some additional emphasis on the importance of these visitations the writer quotes the following from hitherto unpublished personal correspondence (dated November 17th. 1919) from Most Reverend Samuel Pritchard Matheson (1852-1942), a former chancellor of The University of Manitoba.

" The year 1865 was very dry and I think the three following years were so too. - - - I remember the first coming of the grasshoppers. I was working in a potato field in East Kildonan when suddenly the light of the sun seemed to become blurred and when we looked up we saw the upper air filled with some particles which almost hid the light of the sun. After lunch when we came out to the field again, it was covered with grasshoppers and they were simply mowing down the grain. We tried to beat them off, but it was in vain. Soon everything was desolate.

" I recall how in the autumn of that year every black spot of earth and especially the hard roadside (and over the hard road itself) was covered with those creatures sticking themselves into the ground and depositing their eggs. I remember how next spring as soon as it was warm, the tiny young ones began to appear till the whole surface of the ground was gray or brown with them. I remember how they floated down the streams of the creeks into the rivers, and how the fish swarmed and seemed as if they all congregated up from the Lake. By angling, we could catch hundreds in a day, and when we could not eat them all, we fed them to our pigs. I remember how the hens were so fat that they could hardly walk and how the yolks of the eggs were red like blood. I remember how on several days a half holiday was given to us boys of St. John's College School on condition that we would spend part of our time shovelling into barrows and wheeling into the river loads and loads of the creatures which had piled up two feet deep in passages between the buildings and in holes along the fences, where not being able to get away, they smothered each other, and became most offensive and unsanitary. I remember seeing an old French halfbreed drawing loads of them in a dump cart from around the bastions of the old Fort, and dumping them into the river near the junction of the Red and the Assiniboine. I remember how later on in the summer, after they had eaten everything, they suddenly rose into the air on one fine day and flew away with the wind, to our great joy and relief."

The Rocky Mountain grasshopper was responsible for the sporadic outbreaks which occurred in Manitoba up until near the end of the nineteenth century and although suggestions such as burying the eggs by plowing, digging the eggs up to receive a government bounty, burning grass, using heavy rollers on the young, and driving young into straw which would then be burned, had been made, no insecticide had been recommended for poisoning them, since at that time people were no doubt unfamiliar with the use of insecticides.

Dr. James Fletcher, Dominion Entomologist and Botanist, Experimental Farm, Ottawa, reported the presence of numerous injurious grasshoppers in southern Manitoba in 1900, but grasshoppers had been troublesome during the two previous years. This outbreak continued until 1903. For the first time, the native species, Melanoplus packardii (Scudd.), Melanoplus mexicanus mexicanus (Sauss.), Melanoplus bivittatus (Say), and Camnula pellucida (Scudd.) were almost entirely responsible for the damage, although some Melanoplus spretus Uhler were present. This was the beginning of a series of outbreaks of species native to Manitoba and the end of the appearance of the Rocky Mountain grasshopper in this province. Since native species had become involved, more attention was given to control. Baits were used for the first time during this outbreak. Norman Criddle, Treesbank, Manitoba, later Entomologist in Manitoba for the Government of Canada recommended that a bait consisting of paris green mixed with fresh horse droppings, salt, and water, be scattered on the ground where grasshoppers were numerous. This bait was effective, but was used to a limited extent and it was soon supplemented by a bran bait that was widely used by the farmers.

This bait consisted of the following: Paris green, 1 part; salt, 1 part; bran, 11 parts; and water, "as much as the stuff will hold". Paris green was supplied by the Manitoba Government without charge to all farmers who would use it to control grasshoppers on their own farms. Farmers were advised to spread this bait in as small lumps as possible. "One pound of Paris green should make enough mixture to spread a strip two miles long by 15 yards wide". A trowel or thin piece of iron was suggested as an instrument for spreading the bait. Dr. Fletcher reported to Dr. William Saunders, Director of Dominion Experimental Farms, Ottawa, December 29th., 1900, that "Everybody who tried this remedy now swears by it". Melanoplus mexicanus mexicanus (Sauss.) and Camnula pellucida (Scudd.) were the two most common species in 1900. Additional control measures, recommended by Dr. Fletcher, consisted of using hopperdozers and of plowing land to bury the eggs.

In the Sessional Papers for the Legislative Assembly of Manitoba under the date of November 30th., 1900, the Noxious Weed

Inspector, Charles Braithwaite, reported to the Minister of Agriculture that "We had over 300 dozers in operation this year." He also stated that, "Many farmers have plowed their stubble ground and others intend to do so early in the spring. Many are intending to leave strips unseeded adjacent to vacant lands and afterwards seed them for green fodder."

Apparently a minor grasshopper outbreak occurred through the years 1909-1913. The report of the Dominion Entomologist for 1909, mentions that Melanoplus mexicanus mexicanus (Sauss.) and Melanoplus femur-rubrum (Deg.) "were injurious in certain sections of Manitoba where the Criddle Mixture proved a very effective and at the same time simple remedy." Hopperdozers were used and the plowing of stubble land was recommended. In a similar report for 1910 speaking of blister beetles he says, "their prevalence in such numbers may be correlated possibly with the abundance of grasshoppers and locusts which were similarly reported as injurious to cereals in Manitoba." Although no mention is made of grasshoppers in the Dominion Entomologist's reports for 1911 and 1912, in 1913 he states that in "southern Manitoba considerable loss was occasioned from ravages of locusts particularly in light sandy areas and ... wherever applications of the Criddle Mixture were made little damage was caused by the locusts." The public accounts of the Province of Manitoba for the year 1911 show an item of expenditure of $159.90 for Paris green, which presumably was for grasshopper control. From all of these reports it seems evident that there was an outbreak of grasshoppers covering approximately the years 1909 to 1913.

The third Manitoba outbreak of native grasshoppers of the present century began in 1919 and continued through 1923. A poisoned bait known as the Kansas Mixture was used widely during this outbreak. It consisted of bran 100 pounds; Paris green or white arsenic, 5 pounds; lemons, 12 to 15 fruits; black strap molasses, 2 gallons; and water, 14 gallons. Another bait consisting of bran, 100 pounds; white arsenic or Paris green, 4 pounds; salt, 2 pounds; and water, 14 gallons was also used. Lemons were omitted from this bait not only because many casual and regular visitors to the mixing stations expected to quench their thirst with fresh lemonade, but because imported fruit for grasshoppers seemed rather a luxury when they would eat a bait which did not contain lemons. Mr. T.C.D.Boon, of Goodlands, Man., who had charge of the second largest mixing station in Manitoba in 1920, reported that: "The Kansas Mixture appeared to give the best results generally, although the other mixture (referring to the salt-bran mixture) did very good work in places."

A continuous effort, by means of experimental work, was made to reduce the cost of the bait. This resulted in Mr. Criddle's recommendation that dry sawdust be substituted for half the bran used in each batch of bait. So the "Manitoba Bait" recommended in 1921 consisted of bran and sawdust, half and half 100 pounds; salt, 6 pounds; white arsenic (crude) 4 to 5 pounds; and water, about 11 gallons.

Mixing station operators had found that the fine particles of Paris green that floated in the air inside the mixing stations were more annoying than those of white arsenic whose particles were heavier, but of similar toxicity pound for pound, to the grasshoppers. More than one mixing station operator became ill from breathing the air-laden Paris green dust and one man in particular was unable to continue work for several weeks. White arsenic was also preferred because it was much cheaper than the Paris green. It came in small oak barrels and one prank played on a newcomer arriving at a mixing station was to ask him to move a keg containing white arsenic to another location on the floor. These small barrels were about two feet high and when full of white arsenic weighed around 600 pounds. Many a stalwart son of the soil got the surprise of the day when he tried to move a keg.

At first the mixing of the bait ingredients was done by hand by farmers at home and later at mixing stations, but the need for bait became so extensive, and the work so great, that a mechanical mixer was devised at Waskada. This consisted of a stationary metal drum with revolving mixing rods, geared to and powered by a gasoline engine. This was capable of turning out many tons of mixed bait daily. Soon these mechanical mixers were in widespread use in the Province. As soon as the damp bait was dumped from the mixing machines, it was shovelled into bags which were piled on the floor of the building. More than one wandering straw boss was attracted to a soft seat on a pile of bags and suffered rather uncomfortable results later, due to the toxic contact effect of the poison.

Throughout this campaign, farmers spread the bait by hand broadcasting, from a pail. Gloves were recommended or the hands could be protected by oiling them frequently with machine oil. At first the baits were put out early in the morning but later when the demand became almost overwhelming they were scattered at all times of the day; as far as could be observed, the results appeared to be the same. In 1920, more than one and one-half million pounds of prepared bait were distributed from the eight most active mixing stations in south-western Manitoba with the greatest demand occurring on June 15. That the bait was very effective was unquestioned by 99 percent of the farmers who used it.

Early in the campaign certain difficulties were encountered which delayed baiting operations. Progress depended upon men with original ideas, but it was important for them to know all the aspects of the problem to be solved. In one place local pressure was responsible for holding up recommended control measures while an attempt was made to spray the egg beds with kerosene, with two gallon hand operated compressed air sprayers, which were relatively new at that time. Equipment used in Winnipeg to heat asphalt pavement when making repairs was taken out into the country and an attempt was made to bake the ground containing grasshopper egg pods. Both of these attempts were given up when it was realized that the problem was much too big for these methods, even if they were effective. At one town a mechanic much respected locally, attempted to build a row of oil burners attached to a machine to be drawn by horses over ground infested with grasshoppers. When it was discovered that the grasshoppers were frightened away from the machine as the horses advanced through them, the mechanic tried to push the machine with the horses, but the steering problem defeated that idea.

One full week was wasted in that territory before the use of baits was resumed. Some thought that doubling the recommended amount of poison in the bait would double its effectiveness. One man came for bait with a double-decked wagon box and used a scoop shovel to scatter it. It was necessary to be decidedly firm and limit the amount of free bait that he could take away.

Hopperdozers had been used in the 1898-1903 campaign and they appeared again, but the baits were so effective that relatively few farmers continued to use them any length of time. Some scattered straw on land containing egg beds and burned it at the time the hoppers emerged. Some such scenes were photographed, but there was a delay with the photography on one occasion when a specimen of Melanoplus bivittatus Say became imprisoned inside the writer's folding camera and before the starving insect was discovered it had eaten several holes in the bellows.

It was not until 1931 that the next grasshopper outbreak (1931-1935 inclusive) began with a widespread but relatively light infestation. The "Manitoba Bait" containing slightly less poison and salt was used again by the farmers who purchased their own supplies. In 1932 the Manitoba Government anticipated a very destructive outbreak and agreed to supply the ingredients used in the bait. Liquid sodium arsenite for the first time replaced the crude arsenic or paris green. Enough liquid sodium arsenite solution was used to provide two pounds of As_2O_3 to each 100 pounds of mixed dry bran and sawdust, salt was still added. In some cases malt sprouts were used to replace bran with excellent results. The grasshoppers involved throughout the outbreak were the same as those encountered in the previous outbreak, Camnula pellucida (Scudd.) being the most abundant. The experience gained in the 1919-1923 campaign proved to be of great value and the mixing, distribution and application of the bait was carried on, as formerly, throughout the outbreak.

The first grasshopper egg survey in Manitoba was undertaken during the autumn of 1931 by The Government of Canada under the direction of Mr. Norman Criddle, Dominion Entomological Laboratory, Treesbank, Man. As a result of this survey, a map of Manitoba was prepared indicating the relative extent and abundance of egg deposits. Egg surveys have been undertaken by the Federal Entomologists each year since that time and provide a very valuable forecast of probable outbreak conditions, expected for the next year.

Experiments carried out in the Department of Entomology at The University of Manitoba resulted in leaving salt out of the modified "Manitoba Bait" in 1933. In 1932 this item alone had cost the Manitoba Government more than five thousand dollars. In 1934 the bait formula was changed to two parts of sawdust to one part bran. Malt sprouts, oat feed, flour and brewers' grains were also used as carriers for the poison. In 1935 the standard bait was further modified so that three parts sawdust were used to one part bran.

The areas involved in the outbreaks of 1932, 1933, 1934, and 1935, were approximately similar in extent, ranging from 1,300 to 1,600 square miles, but the severity of the outbreak diminished markedly in 1935. This was the most severe outbreak of native grasshoppers in Manitoba's history. Very little poisoned bait was needed in 1936. The outlay by the Manitoba Government for the bait ingredients alone for the four years was approximately one-quarter million dollars. To this must be added a similar cost to the municipalities for local expenses.

Although a few farmers used baits during 1936, 1937, and 1938, the infestations were only of local importance. We may consider these years as the period between widespread outbreaks and the shortest such interval between grasshopper outbreaks during the first half of this century. During the summer of 1938 migrations of winged grasshoppers from North Dakota and Saskatchewan were observed and the egg survey that autumn indicated trouble for the following year.

In 1939 the native species of grasshoppers previously mentioned were widespread and destructive and continued in outbreak numbers, requiring government organization and support in controlling them through 1942. Poisoned baits were still recommended. Liquid sodium arsenite was used almost exclusively but the carrier was changed to sawdust and cheap flour. During the course of this outbreak the results of egg surveys conducted the previous year, by the Federal Entomologist at Brandon, were used to prepare posters showing the areas of infestation and the intensity of damage to be expected. These posters emphasized the importance of plowing to bury the grasshopper eggs, early seeding and seeding in clean summer fallow. Mechanical bait spreaders were recommended where large areas were involved but hand spreading was advocated where the infestation was more limited. Farmers were advised to locate egg beds and poison the young grasshoppers as soon as they hatched, to reduce damage. There were approximately a total of two and one-half as many municipalities and fifteen times as many farmers, involved in the 1931-1935 outbreak as during the 1939-1942 occurrence.

For the next five years grasshopper populations were at a low point and no control campaigns were undertaken. In 1948 a beginning was made in controlling the next outbreak which continued until 1952. Control was soon changed from the use of poisoned baits to the use of poisoned sprays applied to vegetation upon which the grasshoppers fed. At first chlordane was used at the rate of 12 ounces of the chemical mixed with the amount of water the sprayer would deliver per acre. Later this was decreased to 8 ounces of chlordane per acre. Toxaphene was used to a similar extent. These poisons were largely replaced during the progress of the outbreak by aldrin which was used mostly at the rate of two ounces of actual chemical per acre.

Weed sprayers, which by 1948, were in widespread use in Manitoba, were used to apply the poison to level areas such as fields. The Buffalo turbine was used to spray roadsides and other uneven areas which could not be serviced with the farm weed sprayers. In order to apply the correct amount of chemical per acre it was necessary to know the capacity of each spray tank, the amount of spray the machine would deliver per acre and the amount of actual toxicant in each gallon of the commercial insecticide.

From the beginning of this century, entomologists have continued to impress upon our farmers the importance of employing suitable farm practices to reduce grasshopper infestations. Different species of grasshoppers select different locations on a farm for egg laying, such as short grassed areas along fences or in old pasture fields or in stubble fields. The farm cultural practices suggested include summerfallowing to prevent egg laying, plowing and cultivating to destroy the eggs, growing crops least likely to be injured by grasshoppers and seeding as early as possible in the season. These recommendations have not changed and are now as important as when they were first made.

Weather plays a very important part in grasshopper outbreaks. In general hot, dry weather favours grasshoppers in any season. Conversely, wet, cool weather is unfavourable. During the period of years under review predators and parasites have played an important part at times in reducing the grasshopper population. Vast flocks of Franklin's gull, Larus franklini L. in many instances devoured countless numbers of the grasshoppers. The larvae of the grasshopper bee fly, Systoechus vulgaris Loew destroyed many grasshopper eggs during the various outbreaks. Larvae of the caragana blister beetle, Epicauta subglabra (Fall) and others, reduced the number of grasshopper eggs substantially during some years. The larvae of a ground beetle, Percosia obesa Say occurred in many egg pods. The red grasshopper mite, Eutrombidium trigonum (Herm.) occurred on grasshoppers and in their egg pods in the ground. A braconid, Scelio calopteni Riley parasitized the eggs. One of the most effective restraints on grasshoppers, especially Camnula pellucida (Scudd.) was a disease caused by Empusa grylli Fr. At times, this caused the virtual disappearance of that species over large areas.

CONCLUSIONS

1. Native species of grasshoppers even with the changing conditions are likely to continue to occur in outbreak numbers in Manitoba in the future and seriously damage crops.

2. Much more emphasis should be placed on teaching farmers to look for, to recognize and then spray poison on those farm areas where grasshopper populations are starting to build up at the beginning of an outbreak period. Although much could be done to reduce injury on an individual farm by the owner, much more would be accomplished if action were undertaken promptly throughout whole areas where the grasshopper egg survey indicated probable or possible trouble. This control should be undertaken before the local situation reaches a state of economic importance. Such early control would at least slow down and reduce the local increase in grasshopper populations.

3. More interprovincial and international co-operation is needed to control those grasshoppers such as Melanoplus mexicanus mexicanus (Sauss.) and Camnula pellucida (Scudd.) which may migrate long distances.

SUMMARY

1. It is difficult to be definite as to when each grasshopper outbreak began and when it drew to a close. The principal criterion used has been based on the years when the Manitoba Government has been involved in providing assistance to farmers. Based on this and other published information and personal experience, the information in Table 1 is of interest.

TABLE 1

Manitoba Grasshopper Outbreaks

Outbreak Years Inclusive	Duration of Outbreak	No. Years Comparatively Free of Grasshoppers Since Previous Outbreak.	No. Years Between Beginnings of Outbreaks.
1898 - 1903	6 years	First Recorded Outbreak of Native Grasshoppers in Manitoba.	
1909 - 1913	5 "	5 years	11 years
1919 - 1923	5 "	5 "	10 "
1931 - 1935	5 "	7 "	12 "
1939 - 1942	4 "	3 "	8 "
1948 - 1952	5 "	5 "	9 "
Averages	5 "	5 "	10

For the first half of this century we have had a grasshopper outbreak approximately every ten years and these outbreaks have lasted on an average of half that time with a similar period when grasshoppers were of relatively little economic importance.

2. The native species of grasshoppers became important about the beginning of this century and occurred in approximately descending order of importance throughout the first half as follows: <u>Camnula pellucida</u> (Scudd.), <u>Melanoplus mexicanus mexicanus</u> (Sauss.), <u>Melanoplus bivattatus</u> (Say), with some <u>Melanoplus fermur-rubrum</u> (Deg.) and <u>Melanoplus packardii</u> Scudd., and a few other native species of minor importance.

3. Based on cost, effectiveness, availability and ease of handling, the poisons used have changed during this period through Paris green, crude arsenic, liquid sodium arsenite, chlordane and aldrin.

4. The carriers for the poisoned baits have b[illegible] horse manure, bran, bran and sawdust, flour and sawdust, shorts and sawdust and malt sprouts, all of which were moistened with water.

5. Attractants used in the baits were salt, lemons, blackstrap molasses and amyl acetate. Eventually no attractant was used as grasshoppers could be killed without it.

6. Bait spreading was done with a shingle or wooden paddle,

by hand broadcasting and by mechanical spreaders. Most of the bait was scattered by hand broadcasting in the successive campaigns. During the last outbreak weed sprayers were employed to spray vegetation upon which the grasshoppers were feeding.

7. Cultivation of the land to prevent egg laying and plowing the ground to bury and prevent eggs from hatching, have been and still are recommended to reduce the grasshopper infestations.

8. Weather played an important part in the seasonal emergence of hoppers, the seasonal period of maximum crop injury, the number of eggs laid and duration of each outbreak.

9. Franklin's gulls were the most important Avian predators although turkeys and hens ate many grasshoppers.

10. The grasshopper bee fly, blister beetles, ground beetles, the red grasshopper mite and scelio have been important predators and parasites of the eggs.

11. An empusa disease, when weather was favourable, was very effective in killing countless numbers of grasshoppers at times, especially Camnula pellucida (Scudd.).

ACKNOWLEDGMENTS.

In addition to the sources of information mentioned in this article, the writer has consulted many bulletins and circulars published both by the Canadian and Manitoba Governments. He has also had access to unpublished memoranda compiled by Mr. H. E. Wood, Publications and Weeds Branch, Manitoba Department of Agriculture and Immigration, from 1932 to the present.

The writer has been able to recall many details of these various outbreaks as he has been associated with grasshopper control in Manitoba since 1918 when he first became entomologist at the Manitoba Agricultural College, which in 1924 became the Faculty of Agriculture and Home Economics of The University of Manitoba, Winnipeg.

A Grasshopper Idyl

A.V. Mitchener

The Rocky Mountain locusts it appears
No longer come in any year;
But native species have taken over
To feed on fields of grain and clover.

The clans that make the greatest fuss
Belong to genus <u>Melanoplus</u>;
But our <u>Camnula</u> is another foe
That also brings its toll of woe.

A rhythmic scheme of nature brings
The fearsome whirr of locusts' wings.
They lay their eggs in the solid ground
Or in other likely places found.

In early spring, in the month of May,
The hoppers hatch and forthwith they
Begin to feed on fields of grain,
And loss of growth exceeds the gain.

At one time baits were used to kill
This loathsome plague, but now
The farmers spray their growing crops
To stop the insect's nimble hops.

Grasshoppers have their troubles too,
But these we think are far too few.
With predators and parasites
They surely spend unpleasant nights.

Franklin's gulls attack by day,
Beetles and flies and who can say
What weather does or if <u>Empusa</u>
Is more important than <u>Percosia obesa</u>.

To summerfallow, to disk and plow,
We warn our farmers do this now.
Yet other things should be done
To have earlier control of outbreaks won.

Spray small areas on every farm
Before the grasshoppers do their harm;
At the first approach of the cyclic years
Get to action as they appear.

These many years we've waited till
These hexapods have had their fill.
It's time we struck more timely blows
Against these pests, our ancient foes.

My friends, I am quite sure of this
That even though some years we miss,
These pests will surely come again.
We must protect our farmers' grain.

THE EVOLUTION IN GRASSHOPPER CONTROL ORGANIZATION IN MANITOBA

-H. E. Wood - Manitoba Department of Agriculture-

Grasshoppers have menaced, at recurring intervals, considerable areas of Western Canadian farm lands; damage was reported shortly after the establishment of the Red River Settlement in 1812. Since 1901 the Government of Manitoba co-operated with Municipalities and aided financially in the control and eradication of this pest, as have the other Provincial Governments of Western Canada. In this paper the changes and developments that have occurred in grasshopper control campaigns since their inception are discussed.

Control Measures Start With Localized Grasshopper Outbreaks

The year 1900 was the first occasion when poisoned bait was used to combat grasshoppers in Manitoba. In that year an outbreak of grasshoppers occurred in the Treesbank-Wawanesa district. Poisoned bait, probably the first to be used in Western Canada, was prepared by adding 1 pound Paris green to 25 pounds bran and dampening the mix. In 1901, the Manitoba Government aided in control by distributing over 1,000 pounds of Paris green to farmers. This was the occasion when the "Criddle Mixture" was introduced; fresh horse droppings were substituted for bran. In the same area an outbreak of grasshopper occurred from 1911 to 1913 and Norman Criddle tried sawdust as a carrier with encouraging results. It was not until the widespread grasshopper outbreak of the 1920's on the Canadian Prairies that poisoned baits were used on a large scale.

Control Becomes Well Organized During 1919-1923 Campaign

The extensive and alarming grasshopper threat over considerable sections of the Canadian Prairies from 1919 to 1923 found all three Provincial Governments active in assisting with the direction of control measures. The governments as well aided financially by supplying the ingredients used in the preparation of the poisoned bait. In the peak year of infestation 1921, nearly a third of the farmed land was infested with grasshoppers in Manitoba.

Quite early in this control campaign it became necessary to set up central bait mixing stations, one or several in most of the municipalities involved. The Government purchased and assumed the cost of having the bait ingredients delivered to convenient points within the municipalities. The preparation of the bait and its allocation to farmers was the responsibility of each municipality.

Policy and the plans for carrying out control measures in this grasshopper outbreak were agreed upon at a meeting held at Napinka May 20, 1920. Government representatives, meeting with reeves and councillors of the several municipalities affected agreed to wage a strenuous fight against the pest and to follow the suggested Government policy as outlined at the meeting. Each municipality operated as a unit with the reeve in charge, while the councillors looked after control details within their wards. Each farmer was responsible for control measures on his own land as well as the half of the adjacent road allowance. The municipality was responsible for hiring the help needed for baiting vacant land. It was at this meeting that the Government was requested to assume the full cost of bait ingredients, rather than half the cost as first announced.

The Napinka meeting was followed by organization meetings in each municipality. Mixing stations were established and the campaign was soon in full swing. Mixing station operators were advised as to methods of spreading bait in order that they could instruct farmers. Government inspection of mixing stations was made regularly, and the manner in which bait was being used in the field and its effectiveness were observed. The campaign of the '20's may be considered as the pattern on which later campaigns were modelled.

In 1919 the bait was mixed with a shovel. By 1920 a mixing machine run by a gasoline engine was developed. This had a horizontal drum which was stationary when the mixer was in operation. Eight stirring rods revolved inside the drum and made a very thorough job of the mixing. These mixing machines were made locally and were located in mixing stations established in villages within the infested area. This type of mixer proved very satisfactory, and with minor changes was used very generally in later campaigns until bait was superceded by poison sprays.

The report of the 1920 grasshopper control campaign records the following points of interest:

> "On June 15, 185 farmers called for and received from one mixing station 39,800 lbs. prepared bait."

> "Grasshopper baits were used very extensively throughout the infested area with excellent results."

> "The savings in value of crop through control measures was estimated to equal over 17 million dollars."

Control Measures of the 1930's

Western Canada's most widespread and serious grasshopper outbreak occurred in the early 1930's. It was not unexpected because the Dominion Entomological Branch issued, in the Fall of 1931 and each year thereafter, a forecast map on which the area and degree of infestation was indicated. These forecast surveys were to prove invaluable to those charged with organizing and operating control measures.

To meet the threatened grasshopper outbreak, the Manitoba Grasshopper Committee was appointed by the Provincial Government in 1931. It was chaired by the Deputy Minister of Agriculture and comprised, the officer in charge of the Dominion Entomological Laboratory, Brandon, and the Professor of Entomology of The University of Manitoba. A representative of the Manitoba Department of Agriculture - the writer - served as secretary and was the manager of control operations. The Committee met from time to time and was responsible to the Government for policy and the general direction of the control campaigns.

As in previous campaigns the rural municipality was the basis of organization. Very early in 1932 Councils were contacted and the necessary steps in organization were outlined by the Department of Agriculture representative. Municipalities arranged for one or more mixing stations depending upon the area to be served, the probable intensity of campaign, and the rail or road service, etc.

The Manitoba Government again provided the ingredients for the poisoned bait. Liquid sodium arsenite was used exclusively as the poison. It was shipped from Winnipeg by rail or truck, in returnable steel drums. Salt was dropped from the formula after 1932. A mix starting with equal parts of bran and sawdust was varied as the campaign progressed. It became necessary to supplement bran by substituting shorts, oat feed, malt sprouts and low grade flour. The percentage of sawdust was increased to the point that at the end of the campaign as little as one part flour to twelve of sawdust was used to make a satisfactory bait. Such changes effected a considerable saving to the Manitoba Government.

Based upon the outbreak forecast by the annual egg Survey, limited quantities of the materials required for poisoned bait would be moved to mixing centres before the grasshopper eggs hatched. The supplies were purchased and moved into the munucipalities on short notice, often in response to telephone orders. This made the campaign sensitive to daily changes in local conditions or weather. The hot and dry summers of the 1930's were conducive to the development and spread of grasshoppers. With minor exceptions it was possible to keep mixing stations constantly supplied with bait ingredients.

Municipal authorities met their responsibilities by appointing a campaign manager and manning mixing stations that were usually on trackage. Almost without exception the one or more mixing machines at each station were powered by gas engines. Delivery of bagged bait was made to farmers, when they called at stations or bait-delivery centres, on the basis of the acreage to be treated. Quite early in the campaign it became necessary to limit the outgo of bait that was supplied without cost to the actual requirements of the farmers because they gave indications of using it so freely, that it would not be possible to keep stations supplied with materials. Records were kept of bait supplied each farmer. In general bait was spread by hand, but toward the close of the campaign homemade spreaders were coming into use.

The handling of a very poisonous material, such as sodium arsenite and the resulting bait, presented hazards to both man and beast. Some station operators suffered ill-effects from the poison, a few could not work with the chemical and had to be discharged. Very few farmers were affected. In all, some two hundred cattle and horses were killed. In nearly every case this resulted from carelessness or thoughtlessness in leaving the bait unprotected, rather than from spreading bait in field and pastures as recommended for grasshopper control.

The peak of the outbreak was reached in 1934 when 80 of the 117 rural municipalities in Manitoba were affected by grasshoppers.

Sixty-five municipalities operated 103 mixing stations, the others secured bait from neighboring municipalities. Bait was supplied from 278 points. That summer, 122 carloads of bran, etc., 254 carloads sawdust and 34,242 gallons liquid sodium arsenite were used. A total of 13,737 tons of bait was delivered to farmers. Total cost to the Government was $102,159 to municipalities, $102,160. The cost of bait per seeded crop acreage averaged 3 cents or about 10 cents per acre baited.

Crop losses in 1934 were estimated as follows: wheat, 1,112,000 bu.; oats and barley, 4,501,000 bu. As a result of control measures the saving affected was estimated as: wheat, 6,216,000 bu.; oats and barley, 7,350,000 bu. In monetary value the loss $2,748,000 - the saving $7,347,000. Municipal officials and farmers generally agreed that the control campaigns of the 1930's were of great benefit.

In Manitoba the control campaign ended rather precipitously and sooner than had been anticipated in 1935. This was accounted for by a widespread outbreak of Empusa grylli Fr. following a period of wet weather with high temperatures when hatching was well advanced. Even with the best of management, the salvage of unused materials at the close of a grasshopper control campaign presents problems. Where initial shipments were largely unused the matter of disposing or storing of poison, sawdust, bran, etc., became a major task. Stocks of liquid sodium arsenite were stored locally and the following year most of it was brought together and shipped by tank cars to the neighboring Province where control measures were still necessary. By late summer complete disposal had been made, at prices in line with the cost of the materials.

Localized outbreaks of grasshoppers, required limited control measures in the years 1939-1942. However, it was not until 1948-1951 that Manitoba was to experience another grasshopper infestation that required extensive control measures.

Radical Changes in Control Measures Take Place in the 1948-1952 Campaign

While poisoned bait was again used in 1948, chlordane sprays were found very effective on young hoppers feeding on grass or grain. Thereafter, chlordane along with several other hydrocarbon chemicals as sprays were to be used exclusively. The introduction of a poison spray solution coincided with farmers purchase of sprayers for weed control. And material that would replace the laborious and unpopular method of hand or machine spreading of bait, and that proved more effective, received immediate farmer acceptance. As this control campaign drew to a close in 1952 chlordane, aldrin, dieldrin and toxaphene had been used and found very effective in controlling grasshoppers under a variety of conditions. These insecticides had been applied in low volumes of water, 4 to 10 gallons per acre, and in the case of dieldrin only 1 1/2 ounces, active, per acre was required.

Before considering the changes in control measures that have become necessary through the change from baits to spray poisons a comparison of costs is interesting. In the control campaign of 1933, in all 18,615 farmers were supplied bait for an outlay for materials of $62,953 or an average of $3.38 each. In contrast in 1949 3,069 farmers were supplied chlordane for an outlay of $104,000, an average of $33.89 or just ten times the cost of the earlier campaign. In planning future control measures where poisons sprays are used to replace poisoned bait, consideration must be given to a number of points:

(a) Spray chemicals can be purchased, often locally, in handy container sizes, on short notice from the trade, in contrast to the more tedious and involved process of making available poisoned baits through governmental-municipal efforts.

(b) The aversion to spreading bait went far to serve as a deterrent to its unnecessary use. Chemical sprays, applied mechanically are in direct contrast.

(c) While a very cheap bait could be given to farmers free of cost, the same does not apply to expensive concentrated spray poisons. In the aggregate, unused amounts could conceivably run into thousands of dollars.

During the 1948-1952 campaign in Manitoba an attempt was made to meet changed conditions as follows:

(a) Where the chemical was to be applied by a municipal sprayer on road allowances it was supplied free by the Government and the Municipality assumed application costs.

(b) Where the chemical was to be applied on farm property such as along fence lines, lanes, margins of fields and pastures, or breeding grounds, the farmer paid a third of the cost of the material and two-thirds the cost of application. An alternate to dependence upon the municipal sprayer was the formation of groups of 10 to 20 farmers who undertook to apply the chemical supplied by the Government. In some cases only did the municipality assist such groups financially.

(c) Where grain fields were to be treated the chemical was purchased by the farmer through regular trade channels. The main weaknesses to this plan were that the Municipal sprayer proved inadequate to keep up with the demand. Farmer Units were found difficult to organize, service and control.

In closing this review the writer ventures the opinion that with the efficient spray poisons now available and with farmers equipped to apply these, that control would seem better left in the hands of farmers, rather than have municipalities and the government involved. Government authorities would keep abreast of the latest in control methods and inform and advise as control becomes necessary, but would not become involved financially.

Conclusions

1. Over the past 50 years or more the Manitoba Government in cooperation with municipalities, has aided financially and otherwise in control measures necessary to combat grasshopper outbreaks at recurring intervals.

2. Over this period there were marked changes in control campaign organization, particularly, poisons used, application procedures and methods of assistance. The two most outstanding developments were:

   (a) The steady improvement of poisoned bait while at the same time a lowering in cost. This was mainly due to an increase in percentage of sawdust used, and to less costly and more efficient poison materials.

   (b) The recent change from poisoned baits to sprays applied to the vegetation upon which grasshoppers feed.

3. Control measures over the period reviewed have improved in effectiveness and have resulted in very marked saving of grain and forage.

4. Future Government policy in regard to grasshopper control campaigns will necessarily take into consideration changes that have taken place in regard to spray chemicals.

THE GRASSHOPPER SURVEY IN MANITOBA

W. Romanow

Entomology Laboratory
Brandon, Manitoba

Grasshopper surveys have been conducted in Manitoba in various degrees of detail since 1931. They consisted at first of reconnaissance surveys of adult and/or egg abundance and were primarily made to forecast areas where control would be necessary. Since 1935 the survey has developed from a method of economic forecast of infestation into a scientific ecological study.

There are three main reasons why grasshopper surveys are carried out.

1. Economic importance. The primary purpose of surveys is to locate infestations, to rate them, and to forecast the probable outbreak for the following year.

2. Location of reservations. The second purpose is that of locating reservations, breeding centres or hot spots, if such exist, with the hope of suppressing incipient outbreaks.

3. Research. The third is to obtain data of a research nature.because a measure of population is basic to all our studies of the factors causing fluctuations in grasshopper populations.

The data required for the measurement of grasshopper populations are of two types:

1. General survey data. A general measure of adult and egg populations in the Province.

2. Permanent survey block data. A more detailed annual survey of nymphal, adult, and egg populations in restricted areas in the Province.

Mr. H. W. Moore developed the idea of Permanent Survey Blocks to obtain more uniform and detailed information on population fluctuations and to supplement the data secured from general surveys, particularly during periods of low populations. Two Permanent Survey Blocks were established in Manitoba in 1938, one in the Red River Valley and the other in the southwest corner of the Province. These blocks were selected on the basis of their grasshopper history. They are reasonably uniform in soil type, vegetation, and grasshopper fauna. They are about 45 to 50 townships in size.

Table I. Rating System Used in Manitoba 1935 to 1955

Category	Rating	Adult pop. / sq. yd. Roadside 1	Adult pop. / sq. yd. Roadside 3	Adult pop. / sq. yd. Field 1	Adult pop. / sq. yd. Field 2	Adult pop. / sq. yd. Field 3	Egg pods / sq. ft. Roadside 1	Egg pods / sq. ft. Roadside 1a	Egg pods / sq. ft. Roadside 3	Egg pods / sq. ft. Field 1	Egg pods / sq. ft. Field 3	Per cent crop involved
Normal	1-		4			2			2		5	0
		4		1	2		2	1		5		
	1		6			3			3		7	0
Light	2-	6	8	1.5	3	4	3	3	4	7	10	5
	2	8	12	2.0	4	6	4	5	6	10	15	10
Moderate	3-	12	16	3	6	8	12	10	10	15	20	25
	3	16	24	4	8	12	16	15	15	20	30	40
Heavy	4-	24	32	6	12	16	24	22	20	30	40	55
	4	32	48	8	16	24	32	30	30	40	60	70
Very heavy	5-	48	64	12	24	32	48	45	40	60	80	80 to
	5	49+	65+	16	32	33+	64	46+	41+	61+	81+	100

The columns "1" give the table of ratings as recommended by Canadian Committee on Grasshopper Research in 1935.

The column "1a " is the rating of roadside egg population adopted from King and used in Manitoba in 1936 and 1937.

The column "2" is adult field rating adopted from Shotwell's ratings for small fields and used in Manitoba in 1938.

The columns "3" are Shotwell's tables of ratings for large field areas except for the adult field ratings, for which his small field ratings were used. These were adopted by Manitoba in 1939 and have been used since.

According to Moore (1), the Canadian Committee on Grasshopper Research in 1935 adopted a rating system for grasshopper surveys prepared by Shotwell (See columns "1" in Table I). Moore reports that in 1936 and 1937 Manitoba used the rating system of King of Saskatoon. This was similar to the one recommended by the Committee except for the rating of the roadside egg populations (See column "1a" in Table I). In 1938 it was decided that the adult field ratings were not giving the egg populations expected from the rating system. This difference was one to one-and-a-half categories. In changing the rating for the adult field ratings Shotwell's ratings for small field areas were adopted (See column "2" in Table I). In 1939 a further change was made to try to approach conditions more closely than in the past. Shotwell's table of ratings for large field areas was adopted except for the adult field rating, for which his small field ratings were used (See columns "3" in Table I). The whole table was moved down one-half category due to misinterpretation of his original tables.

The Province has been divided into the following areas, according to the history of grasshopper outbreaks, for survey purposes:

1. Primary outbreak areas. Areas in which grasshoppers are practically a continuous threat.

2. Secondary outbreak areas. Areas in which grasshoppers occur periodically as an economic threat, but only after the primary areas have shown a build-up of population.

3. Tertiary outbreak areas. Areas that have only occasional outbreaks that are due mainly to migrations from other areas.

The primary outbreak areas and the Permanent Survey Blocks are covered each year during the adult survey. The secondary outbreak areas are surveyed every second year, preferably, part one year and part the next so as to keep the area surveyed more or less constant from year to year. Adult survey is carried out in the tertiary outbreak areas only during years of general outbreak.

Adult Survey

The main purpose of the adult survey is to secure a comparable measure of the adult population from year to year and to determine in what areas an egg survey will be necessary.

The adult survey is generally started as soon as grasshoppers have ceased migrating and are completed before they have started to die off in the fall.

The coverage during adult survey consists of lines of travel six miles apart with stops every four miles. At each stop a visual estimate of the grasshopper population is made in the field and along the roadside. The average number of grasshoppers per square yard is estimated for a distance of 100 yards into the crop. Along the roadsides the population is recorded as the average population for 100 yards on side of the road most favorable to grasshoppers. The population is estimated for centration areas and these are defined as to size and frequency.

The infestation at a stop is categorized with the assistance of the rating table. The economic species present are noted and are recorded as a percentage of the total population. The main economic species in Manitoba are M. bivittatus, C. pellucida, M. mexicanus, and M. packardii. The percentage of these species in the adult stage is recorded. Disease is noted and the species involved and percentage mortality are recorded. The crop present, its stage of development, and the side of the road on which the stop is made are recorded. The weeds present and the type and condition of the roadside vegetation are also noted. The location of the stop is plotted on the map.

Population maps for M. mexicanus, M. bivittatus, and C. pellucida adults are prepared from data collected during the adult survey. These maps show the abundance and distribution of each species from year to year and district to district.

Egg Survey

The main purpose of the egg survey is to forecast the probable economic infestation to be expected.

Egg survey is started when the majority of the eggs have been laid. This varies with the species and the season. The light soil and Camnula areas are generally surveyed first. A preliminary survey can be made in most years starting about mid September in M. mexicanus areas and somewhat earlier in Camnula and M. bivittatus areas.

All areas found to be economically infested during the adult survey are examined for eggs. One Permanent Survey Block, though not economically infested by adults, is surveyed for eggs. If one Permanent Survey Block has an economic adult population and one has a subeconomic adult population, then an egg survey is made in both.

The coverage during egg survey is very similar to that of the adult survey. The lines of travel are six miles apart with stops every six miles. In Permanent Survey Blocks and on the general survey where possible, the egg survey stops are made at the same location as the adult survey.

In the field, egg survey samples are taken at 3-, 10-, 15-, and 25-yard intervals into the crop; a fifth sample is taken anywhere beyond the fourth. Each sample consists of two sub-samples, 6 by 12 inches, taken along drill rows. The two parts are put through the sieve and recorded as one square foot sample.

Roadside sampling is restricted to probable oviposition sites but is not only confined to the most favorable spots. Samples are a half square foot in size and a minimum of four samples is examined whenever there is a favorable place of oviposition for the species recorded in the adult survey.

In purely M. mexicanus areas, roadsides are not sampled unless no eggs are found in the field. Then two samples are taken along the outside furrow of the field and two on the ditch. In areas where drift ridges or other typical egg-laying sites occur, five samples are taken and these are treated as concentration areas.

In areas where M. bivittatus was recorded as economically important in the adult survey, two samples are taken on the ditch crown, two on the sod area and/or two along the outside furrow, and two on the roadside slope.

Where C. pellucida was present during the adult survey, four 1/4-foot samples are taken on the egg bed.

Only viable pods are considered in the egg population data. The pods of M. bivittatus and C. pellucida are recorded to species while M. packardii and M. mexicanus are recorded under M. mexicanus. All other species are recorded under "others", and if they can be identified, a notation as to species is made.

The eggs in M. mexicanus and M. packardii pods found in field samples are counted and both the number of viable eggs and pods found recorded.

No count is made of the number of eggs in pods of C. pellucida and M. bivittatus found in fields, or of any species in roadside samples. A pod of M. bivittatus (45 eggs) in the field is considered equal to one M. mexicanus pod in outbreak. The field infestations are rated on the basis of eggs per square foot and the roadside infestation on the basis of pods per square foot.

Destroyed pods are recorded under the cause of destruction. Pods containing a predator are considered as destroyed except in the case of M. bivittatus pods, where they are recorded as one-half destroyed if only one predator is present.

Beefly and blister beetle larvae are recorded as egg predators found free in the sample, whether they are in an egg pod or not. When found loose in the soil they are considered to have already destroyed an egg pod. Wireworms, mites, and carabid larvae and adults are not recorded as egg predators unless they are found feeding on the eggs. When predators are found in egg pods the number and type of predator is recorded along with the species of pod in which it is found.

Pods destroyed by other causes, such as disease or desiccation, are recorded under "other causes".

The number of adults still present during egg survey, if significant, is recorded.

Nymphal Survey

A reconnaissance nymphal survey is carried out each spring to ascertain the date and duration of hatch and to appraise the forecast.

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FOOD PLANTS AND FEEDING OF GRASSHOPPERS

D. S. Smith
Field Crop Insect Section
Science Service Laboratory
Lethbridge, Alberta

Food Requirements and Food Selection of Phytophagous Insects

Our knowledge of the nutritional requirements of phytophagous insects is very limited. Our knowledge even of their food plants is quite sparse. There are long lists of supposed host plants for some species of insects in the literature but it must be realized that there may be considerable differences between plants that are "tasted" and those actually fed upon. Also in many cases there are differences between the food ingested and nutrients required. Dethier points out that "it is an all too common mistake to equate gross food intake and utilizable constituents".

Some 20 species of insects have been reared on synthetic diets and their nutritional requirements worked out. These insects are mostly those that feed on dried organic material (1), but they also include some mosquitoes (2) and Drosophila (3). The basic requirements of these insects are all essentially similar--a good quality protein or an adequate amino acid supply, at least eight of the B vitamins, a sterol, a readily available carbohydrate (which may differ with different species), and minerals. Fat is not generally required except by some species of Ephestia and possibly by Pyrausta.

Partial success has been obtained with four phytophagous species, the corn borer (4), oriental fruit moth (5), Mediterranean fruitfly (6), and the pink bollworm (7). The first two of these required powdered plant material in addition to the synthetic materials, the two fruit insect apparently needed organic acids and only a very low survival was obtained with the bollworm. On this very limited basis it is too soon to say that phytophagous insects require anything different from the others and all we can do at present is to assume that they have the same basic requirements. Fraenkel, on the basis of the few relatively complete analyses that are in the literature, considers that leaves of all plants contain these basic nutritional substances and hence that the selection of food plants is not made on a basis of nutritional needs (8). He suggests that "it is the presence or absence of odd chemical substances in which the plants differ such as glucosides, essential oils, alkaloids, saponins or tannins, which renders the plant a suitable or unsuitable food". Detheir (9) also believes that nutritionally unimportant stimuli are predominantly responsible for plant preferences.

Painter (10), however, considers that plants and different parts of the same plant may differ nutritionally, and states, "the absence of necessary vitamins, amino acids, or fatty acids in the part of the plant on which the insect feeds offers a possible explanation of the effects of some resistant plants on insects".

Kennedy (11) believes that there may be a definite causal relationship between preference and nutritional differences. Two sentences from his paper will serve to illustrate his views: "Attention has been concentrated, especially by those with a more academic approach, on selection by means of reactions to specific, non-nutritious properties of plants, to the point of erecting a general principle that this kind of selection is the only important one", and further, "Some of the insects responses are therefore to stimuli which are tokens of suitable food and may even be provided directly by the nutrients themselves".

Incidental to this Thorsteinson (12) has found that in some circumstances where an attractant is definitely involved, an enhanced feeding response can be obtained by adding nutrients to the attractant material.

It is an established fact that various biological measurements of an insect species such as mortality, rate of development, and fecundity may differ with different food plants. It may be argued that the differences are due to either differing consumption of the plants or that the insect in some cases may not be able to utilize some of the components as well. This is a point that has never really been settled and we are at present conducting some work that we hope may provide an answer. Parenthetically it might be observed that the grasshopper <u>Melanoplus mexicanus</u> feeds so readily on oats and alfalfa that it is hard to imagine that it is not consuming enough, if they are nutritionally adequate. Yet both plants are unsatisfactory so far as development and fecundity are concerned.

This has been a very hasty look at some of the questions concerning the feeding of phytophagous insects. We do not know their basic requirements though we can make assumptions based on what we know of other insects. We do not know why, in many cases, certain plants are preferred foods. With some, attractants or repellents are undoubtedly the answer, but nutritional needs may be partially or wholly responsible for others. And, of course, knowing neither the basic requirements of the insect nor the chemical make-up of the plant, we do not know why some plants are good foods and others are poor foods.

Food Preferences of Grasshoppers

For a long time it has been a popular conception that grasshoppers are almost omnivorous feeders. Until fairly recently, even scientific observers have subscribed to this idea. As will be seen later, this conception arose from their feeding habits. With the work of Criddle, Isely, and others it came to be realized that at most they were not truly polyphagous, but limited in their choice of food plants, many being oligophagous and a few strictly monophagous.

From field observations Criddle (13) was able to state that some species of grasshoppers were confined to a single plant species:

Melanoplus bowditchi canus to Artemesia cana and Hypochlora alba to Artemesia ludoviciana. Acrolophilus hertipes apparently fed only on members of the Boraginaceae.

Isely (14) carried out the first widespread investigation of food preferences among the Acrididae. Of 40 species, he found that 30 were essentially oligophagous, four approach monophagy and only two are typically polyphagous. Those species belonging to the subfamilies Acridinae and Oedipodinae showed a decided preference for grasses, while those belonging to the Cyrtacanthacrinae had a decided preference for forbs. He also established that the power of this preference was considerable, for example, nine of the eleven species subjected to this test starved to death in the presence of plants that served as preferred hosts for other species. Bermuda grass is a common introduced grass in the southern states and is a preferred food by many acridines and oedipodines but most cyrtacanthacrines will not feed on it.

Criddle (13) showed that within the grasses there was a considerable range of preference. Agropyron smithii was palatable to many species, even to some of the cyrtacanthacrines, while Agropyron tenerum seemed to be unpalatable to most 'hoppers. Setaria viridis is another grass that is hardly touched.

Criddle was of the opinion that some of the selection may have been due to water content. Sonchus and Lactuca, both with a copious milky exudate, are readily fed on by many species particularly after injury when the sap oozes out.. In semi-arid regions selection seems to be for the most drought-resistant plants. Trimerotropis feeds mostly on Astragalus and Schistocerca lineata on Glycyrrhiza.

Rubtzov (15) in a study of Siberian acridids has reached essentially similar conclusions in regard to their restricted feeding range. He studied chiefly two acridines, species of Gomphocerus and Chorthippus and found that they selected and fed on a small number of plants. In scanty vegetation the number of plants tasted increased considerably but the principal food plants changed hardly at all. The latter were mostly grasses, although two forbs, an iris and a plantain, were also highly preferred.

Recent work by Anderson and Wright (16) has extended these observations to a large number of species of range grasshoppers, with similar conclusions. Thus, we have a general picture of selected feeding and definite preferences. In some cases, a preferred plant of one species of grasshopper is spurned by another species but the reason for this is not known.

The grasshopper that most nearly approaches a true polyphagous condition is, as may be expected, our most widespread and serious pest species, Melanoplus mexicanus. Criddle (13) stated that it would eat almost any plant that grows, and while I think this is rather stretching it, it will certainly taste almost every plant and does not even confine itself to plants -- clothes, felt hats, even hoe handles have been attacked. We have been working with this species for some time now, so has Pfadt (17) in Wyoming and Barnes (18) in Arizona, and even here the same picture, of selection and food preferences, emerges. In range country the preference is for forbs over indigenous grasses and for certain forbs, dandelion, tansy mustard, hedge mustard, and alfalfa over others such as mallow, lambsquarters, and prickly lettuce.

We have been speaking so far of native food plants. When we come to consider crop plants the preferences of the pest grasshoppers can become much more striking. Brunson and Painter (19) report an extreme contrast between injury to corn and sorghum by Melanoplus bivittatus and M. differentialis, the latter crop being pratically untouched beside badly defoliated corn. Even individual sorghum plants standing in the midst of the corn were hardly fed on. Within 52 different corn hybrids defoliation ranged from 4 per cent to 60 per cent. Jacobson and Farstad (20) reported a differential injury by M. mexicanus to 41 maturing wheat varieties. The percentage of heads dropped varied from 0.3 per cent to 43 per cent.

Effect of Different Food Plants on Grasshoppers

Knowing now, that each grasshopper species has certain preferred food plants and that there are other plants that, in nature, it rarely touches, let us consider the effect on the insect of enforced feeding on only one plant. As already mentioned, Isely found that some species would literally starve in the presence of an abundant supply of a certain plant, that might be a preferred plant for some other species.

Except for Isely's paper most of the work of this type has been done on pest species, mainly, M. mexicanus and to a lesser extent M. differentialis, M. bivittatus, and a few species of locusts. These studies all show in common that, as measured by such criteria as survival, gain in weight, rate of development and fecundity, the different food plants can be arranged in a graded series from a good food presenting a maximum, often in all these criteria; to other foods so poor, that no insects survive on it to become adult. It might be profitable to consider some of this work in more detail. Pfadt (17), while studying the food plants of M. mexicanus in relation to its ecology, carried on some cage experiments in which he collected late-instar nymphs in the field and fed them on various plants to see how the adult longevity and egg-laying potential would be affected. He used a large series of plants and found that after four weeks, mortality varied all the way from 10 to 15 per cent on such plants as wheat, sunflower, corn, alfalfa, and dandelion, to over 90 per cent on various native grasses such as Stipa, Festuca, Bouteloua, and Calamovilfa. On only one grass was there a low mortality, 23 per cent on Bromus tectorum, an introduced grass. Of native grasses the best were Poa pratensis 43 per cent and Poa arida 48 per cent, the others were all over 50 per cent. Pfadt also found a highly significant positive correlation (0.9) between plants which were preferred and plants on which survival was high.

He later reared M. mexicanus through all the nymphal instars on a few of the same plants. These fell in much the same order with the notable exception of alfalfa, on which the 'hoppers suffered a mortality of 83 per cent. The weight of the adults produced followed the same pattern as survival on the different plants.

Smith et al (21) reared the same species on selected plants over three generations with similar results. Dandelion, barley, and wheat showed the lowest mortality and alfalfa the highest. Only two per cent of the third generation reared on alfalfa survived. The insects on alfalfa were the only ones having a significantly longer nymphal period. The fecundity showed a wide variation, that roughly paralleled survival; the average number of eggs per female varied from 117 on wheat to 12 on alfalfa and Russian thistle.

The work of Brett (22) and also of Barnes (18) further confirms the insufficiency of alfalfa as food when fed throughout the life cycle. The work of the latter again confirmed the fact that forbs were much superior to grasses. The best results on survival, adult size and longevity, and egg production were obtained with hedge mustard and goosefoot. Johnson grass, again an introduced species, was intermediate, alfalfa and Bermuda grass very poor; the latter gave no survival. It is interesting to note that a mixture of all species gave even better results than the best of the single plants. Pfadt found the same thing with the few mixtures he tried; better survival resulted from mixtures than with any one of the single plants alone. This would seem to refute the argument that grasshoppers do poorly on certain food because they consume less of them. But there needs to be more work done, using only the less favorable plants, to see how valid it might be.

Tauber, Drake and Decker (23) investigated the egg production of adult M. bivittatus fed on various plants and here again forbs were good, grasses poor. Their most interesting results came from feeding dried plants. Very few eggs were produced from 'hoppers fed on these although there was some increase when water was also supplied. But the survival time, on dried corn leaves, and on dried alfalfa with extra water supplied was as long as with the best succulent foods. Also the 'hoppers on this dry food showed a much increased activity and response to stimuli. The authors make the interesting suggestion that this may be what initiates flights and migrations in grasshoppers.

To sum up these two sections, we can say that generally food preferences and food suitability go hand in hand with the notable exception of alfalfa, a food highly preferred by several species, that is apparently adequate when fed to late instars and adults, but inadequate as the sole food for all stages. There is a definite pattern of preference related to taxonomic position, the acridines and oedipodines prefer grass, while cyrtacanthacrines prefer forbs. There is also some evidence that a mixture of two or more plants may form a better food than any one plant of the mixture alone. This fact may indicate that each plant is nutritionally inadequate in a different way but together they make a more adequate diet.

Amount of Food Eaten and Its Utilization

A popular pastime among grasshopper workers has been to estimate how much damage grasshoppers can do to native vegetation. Some estimates are based on cage studies and are open to obvious objections. For instance, Rubtzov (24), by feeding locusts in cages on *Bromus inermis*, calculated that 10 locusts per square meter would cause a gross loss of 682 kg. per hectare. Such calculations gloss over the fact that caged locusts might not require as much food due to decreased activity and moreover they apply only to feeding on a pure stand of *Bromus inermis*.

Anderson and Wright (16) avoided the cage technique and used poison to keep 'hoppers off selected areas, that could be compared to other normally infested areas. During the summer season they found that an average population of 7.7 range grasshoppers per square yard caused 52 per cent damage to a dense stand of *Agrophyron smithii*, while 3.5 per square yard caused 62 per cent damage in a sparse stand. Despite *M. mexicanus* being the dominant species it was not primarily responsible for this damage. By a comparison of the amount of damage and the different species making up the total population over a number of plots they were able to identify *Metator pardelinus* and *Drepanopterna femoratum* as the chief culprits.

Davey (25) has an interesting study on the amount of food eaten by the desert locust, *Schistocerca gregaria*, in relation to its growth. A mixture of *Poa* spp., *Phleum pratense* and *Agropyron repens* was fed to 'hoppers in cages starting as soon as the insects hatched. He found that similar amounts of food were eaten per unit body weight by both sexes. Growth rate was faster in the female and the absolute weight eaten was therefore greater. Average consumption of the nymphs was one gram (fresh weight) per gram body weight, while the adults ate approximately one-half gram per gram body weight. Total consumption from hatch to adult molt was 10 gm. for males and 13 gm. for females. He also calculated the percentage of food assimilated on a dry weight basis and found it to decrease from 78 per cent in first instar to 35 per cent in the final instar. This low percentage of utilization in the older insects is apparently common among phytophagous insects as evidenced by such values as 34 per cent for *Malacosoma*, 25 per cent for *Aglais*, and 36 per cent for Pieris obtained by Evans (26). Chauvin (27) calculated a value of about 33 per cent for adult *S. gregaria*. Brenniere *et al* (28), although they do not calculate it as such, give figures for fourth-instar *S. gregaria* which show a percentage utilization of around 55, rather higher than would be expected.

In the course of our experiments in Lethbridge on *M. mexicanus* we have obtained tentative percentages of utilization for both oats and wheat. Over a 40-day period following hatch these percentages are both approximately 33. But when broken down into five-day periods, they decrease from 55 in the first period to 21 in the last for oats, and from 70 in the first period to 30 in the last for wheat. The difference between the percentages on the two food is chiefly in the first instar, from second instar on they lie quite close together. Such low utilizations are only to be expected from phytophagous animals where such a large part of the diet is composed of indigestible materials such as cellulose and lignins. What is surprising is the high utilization in the early stages. Perhaps this may only be an artifact due to retention of the faeces within the gut. We hope to be able to get more information on this by chemical analysis of food and faeces, and to obtain utilization values for the different food categories, protein; carbohydrates and fats.

Adaptations to Different Diets

Brues throughout his work (see 29) has called attention to the biological significances of food adaptations. The mandibles are remarkably plastic in this connection, so much so, that they can be quite misleading in taxonomic studies. Isely, as a result of his findings that grasshoppers can be grouped into grass, forb and mixed feeders, undertook an extensive study of the relation of the mandible pattern to these diets (30). He was able to distinguish two extremes, one for grass feeders and one for forb feeders, with intermediates leaning to one extreme or the other dependent on whether the mixed feeder was predominantly a forb or grass feeder. These extremes are based on incisor and molar patterns. The forbivorous type has sharp and prominently pointed incisors and molars. The graminivorous type shows a tendency to reduction of the sharp points of the incisors with a fusion towards a continuous cutting edge, while the molar area is modified into a grooved and ridged grinding area. These two types are based on Brachystola magna a definite forb feeder which will die if supplied only with grasses and on Mermeria maculipennis a grass feeder.

Most of our worst pest 'hoppers among the Melanopli, are mixed feeders, predominantly feeding on forbs. M. differentialis has an intergrade pattern corresponding to this diet. The incisors are typically forbivorous with definite individually pointed dentes, while the molar area, although still having peaks is arranged in a pattern of ridges and furrows, intermediate between the two types.

Isely has examined 89 species of Acrididae as well as other Orthoptera and has fully confirmed this close correspondence of mandible pattern to diet. He compares the pattern to those of mammalian teeth where similar adaptations to food have occurred; he considers this a striking example of convergent evolution. Williams (31) studied the mandibles of several species of British acridids and also some locusts to give further confirmation to the work of Isely.

It is quite possible that the armature of the proventriculus will be found to have differences correlated with diet. The work of Judd (32) and Williams (31) gives some suggestion of this, but an insufficient number of species has been examined to reveal whether this is actually so.

Feeding Behaviour of Grasshoppers

The way in which a grasshopper eats has been described by several workers, and since it has a bearing on food selection a short description taken from a paper by Williams (31) will not be out of place. Usually the food is first touched with the antennae and then the head is lowered until the labrum is in contact with the food. The tips of the palpi then stroke the leaf several times and finally the mandibles are closed over the edge of the leaf and a small bite taken. This is then thoroughly chewed and, apparently depending on the results of this or perhaps a second exploratory bite, the insect decides either to continue feeding or to move on. When it feeds, the head is moved from a raised to a lowered position removing crescentic areas from the edge of the leaf. The habit of taking exploratory bites before actively feeding means that caution must be used in describing certain plants as food plants simply because a bite is made in them.

Furthermore, Williams (31) has undertaken to study the factors influencing the finding and selecting of food by grasshoppers from a behavioural standpoint. He measured the toughness of various grasses by their resistance to penetration. It varied from four units on Holcus to 25 on bamboo, but showed no correlation with food acceptance, except in very young 'hoppers. An effect of toughness was found. There were smaller sized particles in the faeces of those feeding on the tougher grasses, suggesting that these had to be bit off in smaller particles. Surface texture seemed noneffective. A biting response was elicited with equal frequency on a large variety of plants with different surfaces, and with no discrimination between grasses and forbs. Leaf shape also caused no discrimination. Moisture content did affect feeding. The frequency and amount decreased on both sow thistle and Holcus when dried as compared with fresh plants, or even compared to dried and then re-wetted Holcus. Biting responses were more frequent on wet paper than dry.

Color was noneffective as no differences in biting response could be seen with white and various shades of green paper. Phalaris leaves were separated into yellow and green portions but showed no differential feeding.

Moisture then, of all these physical factors, was the only one that affected food selection.

The role of the different sense organs was then examined. Covering the eyes reduced feeding, as did darkness, but this may simply be due to decreased activity. Cages were arranged so that different patterns could be placed on one side. The insects showed a definite preference for stripes lying between 45° and 90° to the horizontal. They tended to settle down on these stripes and climb along them, and some even attempted to feed on the edges of the stripes. There was much more feeding on vertical than horizontal blades of grass. Since the species he tested were all grass feeders, the relation of the behavioural pattern to feeding is obvious. Unfortunately no forb feeders, or even mixed feeders, were used in these tests.

The removal of antennae made little, if any, difference to the amount of food eaten. Olfactometer tests gave no evidence that an olfactory sense was instrumental in locating food.

Organs of taste lie on the maxillary and labial palps and on the hypopharnyx. Grasshoppers with palps intact would not bite untreated paper in preference to paper smeared with Holcus or with digitalis, that is, they seem to be able to detect vegetable matter without biting. Those with the palps removed were much slower in biting response on Holcus and on Holcus-smeared paper, and green paper also elicited a biting response. So taste does appear to be a factor governing food selection. Other evidence already cited points to a more discriminatory taste sense, possibly on the hypopharynx, since an exploratory bite is necessary with some plants before rejection or acceptance.

In conclusion, it is obvious that there is still a lot of knowledge to be accumulated before we can say why and through what agencies certain plants are selected as foods by grasshoppers.

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SOME OBSERVATIONS ON THE LOCUST PROBLEM IN AFRICA

by

L. G. Putnam

Organization of Locust Control in Relation to Species

Locust control and research can be considered in relation to the principal species and their outbreak centres, where such exist. The following are the main species, approximately in order of general importance:

The desert locust (Schistocerca gregaria)
The African migratory locust (Locusta migratoria migratorioides)
The red locust (Nomadacris septemfasciata)
The brown locust (Locustana paradalina)
The Moroccan locust (Dociostaurus maroccanus)

The desert locust has no known outbreak centres, at least in the conventional sense of the word; this locust occurs, "wherever you find it". The African migratory and red locust do have recognizable and reasonably well-defined outbreak centres, although the distribution of these species, even in the solitary phase, and during non-outbreak periods, is by no means restricted to those centres. The brown and Moroccan locusts apparently have general areas in which they multiply and become gregarious, but with less ensuing international threat. The brown locust as a problem belongs almost exclusively to the Union of South Africa. The Moroccan locust is distributed around the Mediterranean coastal areas, e.g. in Cyprus and Syria, as well as Morocco. It is being investigated ecologically on the island of Cyprus by a small scientific team staffed from the Anti-Locust Research Centre. The Ministry of Agriculture of the government of Syria at Damascus has an anti-locust service, aimed principally against the Moroccan locust. Also, the French at Maison Carrée, Algiers (Office National Anti-Acridien) are active against this locust. Dr. Bodenheimer in Israel makes frequent reference to the Moroccan locust, and has a scientific interest in it, presumably because of his country's susceptibility to outbreaks.

I should now like to refer to the organizations that are concerned with the two major species that have "conventional" outbreak centres. The outbreak centre of the African migratory locust is the flood plains of the Middle Niger in the French Sudan, somewhat upstream from Timbuktu-the epitome, perhaps, of remoteness. I did not visit this place, but did visit its administrative headquarters in Nogent-sur-Marne, a suburb of Paris. The organization is called the Comité International Provisoire de Prévention Acridienne au Soudan Francais, "CIPPAS". No research work is done in the headquarters, and only a small staff is maintained, but I did meet a research worker, Mr. J. T. Davey, normally resident in the field on the Middle Niger, who happened to be at his headquarters while "writing up" several years' data. He later appeared at informal discussions held at the Anti-Locust Research Centre in London, along with Dr. B. N. Zolotarevsky, the secretary-general of CIPPAS. CIPPAS is supported by the British, French and Belgian on the basis of 40, 40, and 20 per cent, respectively. The other organization is the International Red Locust Control Service. It has its headquarters at Abercorn, at the northern tip of Northern Rhodesia, and is supported by the Union of South Africa, the Rhodesian Confederacy, and the adjacent Portuguese colonies. The main outbreak centre of the red locust are shores and flood plains of Lake Rukwa, which is across the border in Tanganyika. Lesser potential outbreak centres of this locust exist in the Malagarasi Basin, slightly north of Rukwa, and in the Meru wa Ntipa, somewhat west of Abercorn in Northern Rhodesia. All these outbreak centres have in common the fact, that they are subject to at least shallow flooding either as alluvial or lacustrine flood-plains. I met a number of the staff member of the I.R.L.C.S. at the informal discussions in London, including the Director, Dr. D. L. Gunn, and Mr. Vesey-Fizgerald. Others I met during a visit to Avercorn and the Rukwa Valley. I.R.L.C.S. has scouting, control, and research personnel at Abercorn and in the various outbreak centres, especially in the northern part of the Rukwa Valley. I shall refer later to the manner in which these people exercise their functions.

The desert locust has caused the most widespread alarm in recent years. Swarms have recently swept from the countries bordering the Persian Gulf through Saudi Arabia into Eritrea and British Somaliland, Ethiopia and down to Kenya, as well as across the Sahara Desert into Morocco. Administrative headquarters for the Desert Locust Survey and Control is in Nairobi, Kenya, but most of the actual work takes place at a distance from Nairobi. Much of the field activity is based on Asmara in Eritrea and Hargeisa in British Somaliland. As these countries face Saudi Arabia, they are as it were on the "operational front" of Desert Locust Control. Because these coastal countries are rather narrow, swarms are controlled before they penetrate into neighboring Ethiopia, and finally into northern Kenya. Desert Locust Survey and Control are responsible to the Anti-Locust Research Centre in London. Field operations on this insect are carried on from tented camps when outbreaks are remote from headquarters; whereas, field operations, whether for research or control, against the African migratory and red locusts are carried on from permanent camps in the breeding-centres. This organization reflects the basic differences in the nature of the problems.

It is evident that the separate research and control organizations, supported financially by the countries threatened by potential outbreaks and under independent directors, are in a position to carry on research on their own initiative. But over and above all this, these independent organizations accept research personnel from the Anti-Locust Research Centre. This personnel, in addition to making excursions into the field to do research on the desert locust, may also be sent into the theatres of the red or the African migratory locusts for varying periods, to undertake the investigation of special problems. I am unable to state whether or not this relationship is formalized.

Recently, Hambleton and Fracker (1) presented a chart showing the general organization of locust control. In this, the Anti-Locust Research

Centre was shown as deriving its authority from FAO. No doubt there is liaison, if not co-ordination, between FAO and ALRC, but I doubt if the impression of subordination, as given by the chart, is correct. At any rate, the funds for the support of ALRC come directly from the British Government.

Some General Biology of Locusts in Relation to Control

The African migratory locust.--The seasonal life-history of this insect involves a cycle of movements which are related to the rise and recession of the flood-waters of the Middle Niger. These movements have recently been studied using a large number of marked locusts, and something like the following pattern is now believed to occur. The waters in the river system rise during the rainy season and flood the plains, forcing the adult population of locusts out of this part of the habitat. They move out as solitary locusts in a northwesterly direction into the upland shrub desert, known as the Ferimake, where green vegetation permits breeding. A new generation is produced in this area. With the onset of the dry season, this new generation moves southeastward, behind the receding flood waters, gradually advancing to reoccupy the flood plains. Oviposition occurs as this movement goes on. There is a tendency for the eggs to be concentrated on the small islands that first appear above water as the floods recede. It is suspected that these concentrations result in the formation of nymphal bands, which may be dense enough to become gregarious and result in swarm formation. I understood that most control operations are carried on against these bands. Unless the locust hoppers display the colour and morphological characteristics of the gregarious phase, no action is taken, because it is assumed that solitary hoppers (that is in the morphological sense and irrespective of their numbers) have no swarming potential, and therefore represent no threat. Neveretheless, I got the impression that control operations are necessary every year, to at least some extent, with emphasis on alternate years. This two-year cycle is thought by Mr. Davey to be an effect of control operations depressing the population to a point, such that two years are required for the population to rebuild to a level that requires major control operations. Thus far, since the control operations of CIPPAS have been functioning with reasonably full effect, no swarms have erupted from the outbreak centre of the African migratory locust. However, personnel of CIPPAS have at least a minor reservation about future prospects. They suspect that this locust may not have exerted its full pressure against the control organization; but the conditions under which this pressure might develop are not yet known with certainty.

On the other hand, it is reasonably certain that the red locust of the Rukwa valley most nearly realizes its full reproductive potential during years in which the precipitation during the rainy season (approximately October to March) is below normal. The reasons for this are rather simple. During a dry cycle of years, Lake Rukwa gradually recedes, leaving a larger area of the lake bed exposed, or to state the case another way, the plains surrounding the lake are less likely to be flooded for a lengthy period; thus the habitat is improved from the point of view of the red locust because a larger area is made favourable for its breeding. The extreme possibilities in the fluctuations of water level were emphasized to me by pointing out that an African village, now miles from the water-line, had within living memory been a fishing village. Because the plains are subject to annual flooding by waters that pour down on the plains from the highlands, the vegetative cover consists of grass, with no trees except around the periphery of the plains, at the foot of the escarpment. With its grass cover, flat topography and heavy lacustrine soil, the general aspect of the Rukwa valley is suggestive of the lacustrine soil areas of the Prairie Provinces of Canada. The critical elements in the Rukwa Valley ecology that favour the red locust are thought to be the mosaic established by the mixed patches of tall grass species (about 6 feet in height) and the short grasses and sedges (about 1½ feet in height); or, in some cases, the mosaic effect obtained by burning. Because islands of incompletely burned grasses are left behind with the Africans habitually burn off the country-side during the dry season. It should also be mentioned that the Rukwa plains are not exploited agriculturally in any way, not even for grazing by domestic animals, although several species of ungulate game animals make their home there at least part of the year. In the outbreak centres, the red locust has one life cycle per year. Egg laying takes place during the rainy season; there is no diapause in the egg stage, and hatching takes place after about a month. Nymphal development is completed and the adult stage reached while the rainy season is still in progress. Because of the danger of locusts becoming too numerous to handle in the adult stage, control operations begin in the nymphal stage. Since conditions at this time are too dificult for heavy equipment, puffer dusters, borne by labourers, are used to apply BHC dust wherever hoppers are numerous enough to justify the effort, and of course wherever they can be reached.

The locusts do not reach sexual maturity until the onset of the next rainy season. They spend the months of the dry season in the valley, without breeding. The basic situation is one of rather wide dispersal of the population, although this is of course not uniform. Swarms may form up from the dispersed population, and this process may continue through most of the dry season if the basic population is large enough to supply many swarms. During the summer of 1955 the cycle of locust abundance was near a peak and swarms were aggregating almost daily during my visit to the Rukwa. These swarms may mill about the valley for a few days, and then leave. Once out of the valley, they are very difficult to track and control; it is therefore the purpose of the control service to prevent the eruption of swarms, by applying control measures, as soon after swarm formation as possible. Almost complete success has been reported in this aim in recent years. Scouts are able to detect the formation of swarms by observing flights and usually to find the roosting place of a swarm during that evening. The locusts roost on the upper stems of the tall, dense grasses, and spraying must be carried out before the insects descend or become mobile the following morning. Before dawn, European control officers and African scouts drive out, sometimes pushing through a blank wall of grass and uncannily finding their way across a singularly featureless landscape. Scouts with tracking markers are placed out on the boundaries of the spray path to guide the aircraft; they move over one swath-width, after each successive emission run. I saw one operation of this kind; in some respects it was not very dissimilar to aircraft control operations witnessed in Canada. The I.R.L.C.S. has abandoned, for the time being, ground-to-ground spray operations against the red locust, and was attempting during the summer of 1955 to prevent the escape of swarms by using aircraft only. I believe one light aircraft was all that had been found necessary, but even the use of this, on a contract basis, was expensive.

Ground-to-ground sprayers were still to be seen, and I saw one in operation for a special purpose. The problem with ground sprayers is to get the spray up high enough so that it can drift out over a wide swath and fall on the roosting locusts, much as though it was applied from an aircraft. A wide swath is necessary to avoid knocking a large number of locusts off their roosts by the passage of machinery, and a high trajectory is of course needed to cover the swath and prevent impaction of an excessive amount of spray on the tall vegetation. The principle involved was essentially similar to that used in the Buffalo Turbine sprayer. The nozzle was directed upward and directly to the rear, but a more powerful air blast was used. The unit I saw in operation was driven by a powerful and heavy engine, mounted on a substantial four-wheeled trailer, making a heavy and rather cumbersome unit. Development work was in progress on lighter units, presumably for use when population levels would not justify the employment of an aircraft.

It was noticeable that the early stage of swarm formation was regarded as the vulnerable point in the locust's life during the adult stage, because of concentration of large numbers within a limited area. Although the outbreak area is comparatively small (the North Rukwa covers roughly 550 sq. mi.; a Saskatchewan rural municipality covers 324 sq. mi.) no one suggested 'blitzing' the whole area with the locusts in dispersed condition, more or less in one fell swoop. Such an operation could only be completed at fantastic expense. Control, even in a small outbreak area, is not a simple straightforward matter.

Surveys of abundance are basic to the control scheme, because the data obtained through these constitute intelligence on the swarm-forming potential of the population. Basically, quantitative surveys, or scouting as it is referred to by personnel of the I.R.L.C.S., is on the basis of line transects through the infested area. This has been done on foot, using African labour. Serious attempts are now being made to replace this method by the use of vehicles, wherever the terrain permits, in order to speed up operations and reduce the need for African scouts, whose reports are sometimes not reliable.

Research is conducted on the problems of control. Two such projects are set up to investigate; the objective accuracy of quantitative surveys and the effects of protecting the plains from the customary annual burning. The latter project is based on the hypothesis that such protection could alter the vegetative species complex or prevent a drastic change in the physical structure of the vegetation. It is presumed that such changes favour locust breeding. Other ecological approaches to control are being actively considered, but have not yet been tried. One is some form of agricultural utilization of the Rukwa plains. This occurs at once to a Western Canadian, familiar as he is with the high productivity of lacustrine soils in the Prairie Provinces. There are of course local factors in the situation that disturb the first impression of similarity.

A number of papers have been published dealing with the general ecology of the Rukwa Valley as well as various aspects of the biology of the red locust.

Locust Control in Africa and Grasshopper Control in Canada

By this time, it will be obvious that locust control in Africa, whether it concerns the widespread and nomadic desert locust or one of the species having outbreak centres, differs from grasshopper control in most of Canada. In the Prairie Provinces, most pest species of grasshoppers are associated with arable agriculture through all stages of development, and are thus accessible by virtue of human settlement and a road system. The outbreak centres in Africa present ecological characteristics suited to multiplication of locusts, but in their present state, not to agriculture. Therefore, they support no human population with an immediate interest in control. Agriculture might in fact disturb the ecology from the point of view of the locust. There is no good road system and I.R.L.C.S. has had to build its own roads and bridges to connect the few existing country roads with its theatres of operation. These roads are as simple as they can be; they are rough in the dry season and muddy in the rainy season. The indigenous human population of adjacent rural areas is far below a stage of development in which it could be entrusted with control without detailed supervision and direction by Europeans. Most Canadian farmers, can be persuaded that grasshoppers should be controlled, and can learn the simple procedures necessary. Finally, although we in Canada once entertained the "breeding centre" or "outbreak centre" concept, nothing we have seen in nearly 25 years of observation and survey has lead us to think that these exist under our conditions. Rather, we think that our outbreak species are distributed constantly throughout the potential area of economic infestation, awaiting favourable environmental conditions wherever they may develop. This writer thinks now that the more we can succeed in persuading farmers themselves to assume responsibility for grasshopper control, the more efficiently it will be done. This is because of the inherent nature of the problem in the Prairie Provinces: its close association with arable agriculture, its widespread distribution, and the shifting locale of affected areas from one outbreak to the next.

The Present Status of the Phase Theory of Locust Transformation

In some instances, it is particularly difficult to get a clear-cut impression of what locust phases mean to people involved in locust control. What relationship does phase have to outbreak? Of what, if any, significance is phase solitaria? Is it always present in the outbreak centres of those species that have outbreak centres and is this phase capable of producing phase gregaria? This question returns us to a consideration of Key's Critique on the Phase Theory of Locusts (2). In this work, Key took the closest and hardest look at the phase theory since perhaps 1921, when Dr. Uvarov (and Dr. Faure indepentently) first proposed it. He decided that the phase theory had never really been succinctly formulated, but that one could infer from it the following: ".......different degrees of mutual stimulation.... lead to the appearance of distinct physical types -- the 'phases' -- which typically differ also in their physiology and behaviour. The phases may, within one or several generations, be transferred one into the other by an alternation in the degree of mutual stimulation". According to Key, the phase theory also apparently implied that, "... the transformation of the phases is responsible for the periodicity of locust invasions, because of the gregarious phase is capable of more rapid multiplication than the solitary phase, and is migratory, whereas the solitary phase is sedentary". One might say that according to this, phase transformation is a cause and outbreak an effect. However, after his exhaustive consideration of the evidence, Key denies this in his statement:

> "Phase transformation must be regarded as a secondary concomitant in the development of locust outbreaks, or at most a minor contributing factor in which only certain aspects of the transformation are significant. The development of outbreaks and their periodicity are not, strictly speaking, the concern of the Phase Theory at all."

In other words the phase theory was concerned primarily with a morphological change and not migrations for animals may band together normally for migration without exhibiting major morphological changes. Furthermore:

> "......The classical physical phase differences arise as secondary consequences of the outbreak process and play no important part in promoting either further phase transformation or further development of the outbreak process. They are.....pointers to the stage that has been reached in the outbreak process, and somewhat unreliable pointers at that.",

because:

> "The funamental cause of outbreaks is multiplication, and the 'irregular periodicity' of outbreaks is due to changes in the population level of the outbreak areas, whose ecological characteristics are particularly well adapted to permit survival under favourable conditions".

Is the experience of field workers, who have the responsibility of controlling two species of locust in their respective outbreak centres, in line with these statements? If it is, it should mean that they would disregard phase entirely and be guided in their activities only by abundance. This is not altogether the case, but it is partly so. According to the remarks of Mr. J. T. Davey, of CIPPAS, the African migratory locust is a 'text-book locust'; it does what a locust is supposed to do, and it is considered that this species presents no hazard unless and until its nymphs exhibit the striking coloration associated with phase gregaria. When they do this, control operations are under-taken. It should now be recalled however that control operations are reported to be necessary every year, or at any rate every second year. So actually even on the Middle Niger the clue to impending danger, i.e. phase transformation, would appear to be a manifestation of multiplication, as claimed by Key.

In the Rukwa Valley, the main outbreak centre of the red locust, Nomadacris septemfasciata, the locusts seem to be morphologically and colorimetrically somewhere in an intermediate or transiens stage all the time. Phase solitaria of this species is said to exist. I have seen some in museums and it was reported to me that phase solitaria can be found in areas not known to produce swarms. I never saw any in the Rukwa, and no one pays any attention to phase there; in a behaviouristic sense its conduct is peculiar to itself. As young adults at the beginning of the dry season, the locusts may be widely scattered through the Valley, at low density, so that in travelling a tenth of a mile through the tall grass in a vehicle (standard method of quantitative survey) one might flush out only a few. Nevertheless, populations of this low density situated in vegetation of such height and density that "mutual stimulation" would seem to be of small probability, are capable of forming swarms. If the population in its non-swarming stage is much denser than "a few per tenth of a mile" the only difference seems to be that more swarms may form. During 1955 dry season, it seemed that swarms were forming almost daily throughout the season. Whatever the level of abundance, swarm formation has to be watched for every year. It follows therefore that the only concern of the I.R.L.C.S. is for total numbers; the denser the population, the more potential swarms.

The act of swarm formation has some subtleties about it. From a dispersed population, a swarm can form up in a few hours. The process is difficult to describe without resorting to anthropomorphic terms. I have observed a flight of locusts proceeding as though toward a known rendezvous, with the wind tending to blow them off course. When the wind speed became too high for them to stay on course, they settled as though determined not allow themselves to drift. Migrations such as this resulted in concentrations of locusts of the order of perhaps 30 per square yard; such concentrations seemed to possess enough coherence to remain together and thus be regarded as a swarm, and in this condition, unless controlled by chemicals, there was frequently a danger that they might escape from the Valley. So finally, the position is that in the Rukwa Valley and its subsidiary outbreak centres, i.e. the Meru wa Ntipa and the Malagarasi basin, density of population is of interest from the point of view of the number of swarms likely to form, and phase variation, if indeed it enters the picture at all, is for practical purposes disregarded.

We have seen what appears to be a difference in some respects between Locusta and Nomadacris; what about the desert locust, Schistocerca? This locust currently is trying the resources of Desert Locust Survey and Control, in parts of Africa along and inland from the Red Sea coast (Eritrea, British Somaliland, Ethiopia). One has to start with the assumption that S. gregaria has no "breeding centre" at least not in the sense of those of the previously mentioned species. The desert locust, like other desert fauna, and indeed the human inhabitants of deserts, apparently survives by moving about, following favourable conditions. If this is true, then mobility, facilitated by swarming, is an essential attribute of the species. If this is true, what does phase solitaria mean to the desert locust? Workers who have carried on investigations refer to solitary, non-swarming populations of the desert locust, so these undoubtedly exist. However it is difficult to get anyone to state what they mean, potentially, in terms of outbreak. Therefore, I am not prepared to say whether solitary living desert locusts are merely left-overs from previous swarms, or whether they in themselves ever, under certain favourable conditions, produce swarms independently of re-inforcement.

It would seem that in those species that manifest more extreme forms of phase variation (in respect of morphology and colour) than the red locust, a swarm can be pretty heterogeneous; in other words, although all the individuals in it behave gregariously, they don't necessarily conform morphometrically. This disturbed Key, and caused him to ask what was the meaning of phase if behaviouristic and morphometric attributes of phase were not necessarily correlated. Nor is that all: in a series of individuals, the various measurements used or proposed as indicators of phase are not always well correlated. This has led to an attack on the problem by statisticians, who by a mathematical approach seem about to develop a morphometric index of phase much more discriminating than any of the simple measurements or ratios yet used. This is perhaps an indication of the return, on the part of a number of workers, to an investigation of the meaning of phase; which has in fact been somewhat in disrepute since Key's paper appeared.

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HIBERNATION OF SCOLIOPTERYX LIBATRIX L.

(LEPIDOPTERA: PHALAENIDAE)

by Walter Krivda
Riverton, Man.

In Manitoba we have little knowledge of the hibernation habits of many of our common species of moths. Scoliopteryx libatrix L. is found throughout Manitoba and I have observed adults of this species dormant in late fall.

At The Pas, Manitoba, in 1953, I found a dormant specimen beneath a slab in a wood pile, and in 1954 another specimen was found dormant in an old tin can buried in a patch of knee-deep grass. In 1955 I captured a female moth on May 28, at Gillam, Manitoba. It was fluttering about the light in a dugout basement and apparently it had overwintered there.

Records concerning hibernating moths of S. libatrix are found in the European literature. An interesting record from France by V.M. Muspratt (1954) reports that 30 moths were found hibernating in a tunnel (150 meters long) connecting a chateau and house. Some of the moths had been frozen in icicles hanging from the ceiling of the tunnel; the moths were living the following spring.

Reference: Muspratt, V.M. (1954) Hibernation of Scoliopteryx libatrix Linn. Entomologist's Record and Journal of Variation 66:203.

APPENDIX I

INDICES TO PROCEEDINGS OF THE ENTOMOLOGICAL SOCIETY OF MANITOBA VOLUMES 1 TO 10

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Subject Index

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APPENDIX II

ADDITIONS TO THE LIBRARY OF THE ENTOMOLOGICAL SOCIETY OF MANITOBA

The following list contains the names of publications received in exchange for the Proceedings since the list published as Appendix I to Volume 10 of the Proceedings for 1954.

Proceedings of Entomological Society of British Columbia. Vol. 51. Issued Nov. 30, 1954.

Bollettino dell' Instituto Li Entomologia Della Universita Degli Studi Di Bologna. Vols. XVIII, XIX, and XX.

Proceedings of the Second Annual Meeting of The Entomological Society of Alberta, Lethbridge, Alberta. October 1, 1954.

Kelsey, L.P. 1954. The skeleto-motor mechanism of the dobsonfly, Corydalus cornutus. Part I. Head and prothorax. Cornell University. Memoir 334.

Redia. Giornale di Entomologia, published by Dalla Stazione di Entomologia Agraria, Firenze. Vol. XXXIX.

Zastita bilja. (Plant Protection). Vols. 27, 28, 29. Published by the Institute for Plant Protection. Beograd-Topcider. Narodna Republika Srbija. (Jugoslavija)

A series of publications and reprints received in exchange from Professor Florkin, University of Liege:

Duchateau, Gh. et Marcel Florkin. 1954. Constitution quantitative de la composante protidique non proteique du Muscle de Carpe. Comptes rendus des seances de la Societie de Biologie - Tome CXLVIII.

Duchateau, Gh. et Marcel Florkin. 1954. Types de composition du pool des acides amines non proteiques des muscles. Arch. internat. Physiol. LXII.

Duchateau, Gh. et Marcel Florkin. 1954. Sur la composition de l'arthropodine et de la scleroproteine cuticulaires de deux crustaces decapodes (Homarus vulgaris Edwards, Callinectes sapidus Rathbun). Physiologia Comparata et Oecologia. Vol. III, No. 4.

Duchateau, Gh., M. Florkin et H. Sarlet. 1954. Types de composition des proteines globales et du pool d'acides amines non proteiques des muscles. Arch. internat. Physiol. LXII.

Duchateau, Gh. et Marcel Florkin. 1955. Acides amines non proteiques du plasma d'hemolymphe et du tissu musculo-cutane, chez les chenilles de deux Lepidopteres (Bombyx mori, Sphinx ligustri). Arch. internat. Physiol. Bioch. LXIII.

Florkin, Marcel. 1954. Aspects Zoologiques des pools d'acides amines non proteiques. Bulletin de la Societie Zoologique de France. Tome LXXIX.

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Gregoire, Ch., Gh. Duchateau et M. Florkin. 1955. La Trame Protidique des Nacres et des Perles. Annales de L'Institut Oceanographique. Tome XXXI, Fasc. 1.

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Jeuniaux, Ch. et M. Amanieu. 1955. Mise en evidence d'une chitinase dans le liquide exuvial de Bombyx mori L. Arch. internat. Physiol. Bioch. LXIII.

Leclercq, Jean. 1954. Phytophagy among Necrophorus vespillo (L.) (Col., Silphidae). Reprint from the Entomologists' Monthly Magazine. Vol. XC.

Leclercq, Jean. 1954. Sur la voracite d'une Tettigonia viridissima L. (Orth. Tettigoniidae). Bull. et Ann. Soc. Entom. de Belgique, 90, XI - XII.

Leclercq, Jean. 1954. Pullulation et moeurs stercophages de Bibio hortulanus L. (Dipt. Bibionidae). Bull. et Ann. Soc. Entom. de Belgique, 90, XI - XII.

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Leclercq, Jean. 1954. Notes detachees sur les Hymenopteres Aculeates de Belgique. Bull. et Ann. Soc. Entom. de Belgique, 90, IX - X.

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