DETECTION OF IMMATURE RICE WEEVILS, SITOPHILUS ORYZAE L. (CURCULIONIDAE, COLEOPTERA), BY AUDIO AMPLIFICATION

by

GEORGE ROBERT PESHO

B.S., Colorado Agricultural and Mechanical College, 1952

A THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Entomology

KANSAS STATE COLLEGE
OF AGRICULTURE AND APPLIED SCIENCE

1954

TABLE OF CONTENTS

INTRODUCTION

From 1911 to the present time reports concerning the use of audio amplification as a means of detecting the presence of insects in wood and in grain have appeared in the literature at irregular intervals. By audio amplification is meant the amplification, by means of electrical devices, of those sounds which are within the human auditory range. Sounds within a frequency range of about 20 to 20,000 cycles per second are perceptible to the human ear.

Snyder (1952) presented a brief history of work conducted in the United States of America and elsewhere utilizing audio amplification as a means of detecting the presence of termites in wood. He pointed out that the majority of these attempts has been unsuccessful except in the quiet surroundings of the laboratory, because of the inability of the equipment to screen out extraneous noises or "static".

Brain (1924) was the first worker to suggest that audio amplification might be a useful tool in detecting the presence of internal infesting species of insects in grain.

The work herein reported was designed to attempt to determine the usefulness of audio amplification as a tool of entomological research, particularly in those problems encountered in research concerning internal infesting species of insects in stored grain. These experiments were an attempt to define the limitation of audio amplification in such research, i.e., the nature of the sound caused by the insects, the age at which the experimental insects first could be detected in grain, and relationships between the number of insects present in a given sample of grain and the amount of sound caused by these insects.

The work herein reported was part of a cooperative project involving the Departments of Entomology, Electrical Engineering, and Flour and Feed Milling Industries, Kansas State College.

The electronic equipment used in this work was designed and constructed by Adams (1953) of the Department of Electrical Engineering. Because this work was part of a cooperative project, portions of it necessarily overlap the work of Adams (1953). The more technical aspects of equipment design and construction have been omitted because they have been reported by him, and because this work was not primarily concerned with equipment design and construction as such, but rather with the application of the equipment to entomological problems.

REVIEW OF LITERATURE

Escherich (1911), who termed his apparatus the "Termitensucher", made use of an adaptation of the telephone receiver to detect the presence of termites in the soil, in trees, and also in the walls of houses. His equipment consisted of a microphone inserted in a funnel at the end of a steel tube which was connected with a telephone receiver.

Brain (1924), who planned a series of investigations of insect sounds with an intensity outside the human audibility range, made use of the microphone, audio amplifier, and head phones or loudspeaker to detect and listen to such sounds. Preliminary studies by him indicated that the sounds created by the movements and gnawing of the larvae of the apple and quince borer, *Coryphodema tristis* Drury (Cossidae, Lepidoptera), within an apple stem approximately one inch in diameter, could readily be amplified and heard. He also reported that the presence of rice weevil larvae, *Sitophilus oryzae*

L. (Curculionidae, Coleoptera), in grain and in yeast cakes had also been detected by means of audio amplification.

The sound made by soldiers of a subterranean termite, Reticulitermes flavipes Kollar (Rhinotermitidae, Isoptera), while hammering their heads when disturbed against the wood which they occupied, was amplified and listened to by means of audio amplification by Emerson and Simpson (1929).

Field tests outdoors, utilizing audio amplification for the detection of termites in various types of wooden structures, as reported by Barton (1934), were not as successful as those made in the laboratory or elsewhere indoors. Field tests made in noisy districts were negative as the result of excessive interference caused by electrical equipment and vibrations of heavy industrial equipment, thus limiting the use of such a method of insect detection to the laboratory or to similar relatively quiet surroundings.

Schwarz, Kranz, and Sicke (1935) reported on a portable amplifier which they built to detect the presence of the old house borer, Hylotrupes bajulus (L.) (Cerambycidae, Coleoptera), in wooden beams of houses and industrial buildings. They too experienced difficulties in the field because of excessive interference of electrical circuits and suggested that this method of insect detection be scheduled for use in the field only during those hours of the day when electrical interference could be expected to be at a minimum. In addition, they experienced further difficulties in that the larvae of the old house borer remained inactive for long periods of time and were easily inactivated by strong knocking on the beams or other factors which caused the beams to vibrate, becoming active again only after a long rest period had passed. They used audio amplification in the laboratory as a means of evaluating the effectiveness of insecticides in the control of the old house borer.

The death watch beetle, Xestobium rufovillosum De Geer (Anobiidae, Coleoptera), one of the most common and most destructive species infesting cured hardwoods in furniture and in buildings in many parts of Europe and Great Britain, prompted Colebrook (1937) to use audio amplification as a means of detecting the presence of this insect in wood. Equipment used consisted of three main items: a microphone, sound proof box, and audio frequency amplifier with suitable reproducer (headphones or loud speaker). To test his equipment he placed two specimens of timber, one thought to be infested by the larvae of the death watch beetle and the other uninfested, in the sound proof container. A separate microphone was placed upon each of the two billets. It was found that the noise made by the larvae within the infested billet could readily and clearly be distinguished from the more uniform background noise of the amplifier. At full amplitude gain the noises made by the larvae were brought to an intensity great enough to be heard from a loudspeaker. At the level of sensitivity required for satisfactory detection of the larvae, it was necessary to close and securely fasten the lid of the sound proof box. This procedure was necessary to eliminate, as much as possible, the otherwise excessive stray noises picked up by the equipment in sufficient intensity to mask the noises made by the larvae being observed and, in addition, to eliminate acoustic interaction between the output and the input of the equipment with consequent generation of sustained audio frequency oscillation.

Adams (1953) who investigated possible methods of using electronic systems for the detection of the immature stages of internal infesting species of insects such as the rice weevil, in wheat, reported that the most promising method was that of sound or aural detection. The gross features of the equipment described by Adams (1953) were similar to those of the equipment used by Colebrook (1937). The main components of Adams' system were also a microphone placed in a sound proof box and a high gain audio amplification system with suitable reproducer. Adams (1953) carried his investigations one step further than previous workers, in that he investigated possible methods of correlating the degree of sound emitted by a given number of larvae of the rice weevil in a sample of infested wheat with the number of larvae present in that sample. Three general methods of correlation of sound to numbers of insects present, with several modifications of each general method, were tried. These methods were as follows: (a) taking photographs of the waveforms of the sound as they appeared on a cathode ray tube oscilloscope and analyzing the pictures; (b) the use of meters to measure the peak, minimum, and average value of the waveforms; and (3) the use of a Berkeley EPUT (events per unit time) meter to count the peaks of the waveforms. The only method which showed promise in obtaining the desired correlation was the method of using the Berkeley EPUT meter to count the peaks of the waveforms.

MATERIALS AND METHODS

Rearing Methods

Because of the short life cycle, ease of rearing, and prolificness of the rice weevil and because of its economic importance as a pest of stored grain, all experiments were conducted with the rice weevil as the test insect.

The test cultures of insects were maintained in a rearing cabinet approximately 18 inches by 24 inches by 30 inches in size. Preliminary attempts to control temperature and humidity utilized those methods reported by Brett (1944). When the electric fan recommended by Brett as a part of the humidity regulating mechanism was used, it was found that the fan motor generated excessive heat, resulting in temperatures within the rearing cabinet becoming too high for proper rearing of the test insects. By placing a shallow glass dish of water with a water surface area of approximately 0.7 square feet in the rearing cage, relative humidity could be maintained at an average reading of 79 per cent at an average temperature of 32° C. without the use of the electric fan. At the above temperature and relative humidity readings the infested grain was in equilibrium with atmospheric conditions within the rearing cabinet at approximately 13 to 14 per cent moisture content. Moisture content determinations were made with a Steinlite Type S moisture tester.

Uninfested wheat to be used for the rearing of experimental insects was placed in the rearing cabinet two to three weeks before adult insects were introduced to insure its being in equilibrium with atmospheric conditions within the rearing cabinet when needed for experimental purposes. At an average temperature of 32° C. and an average relative humidity of 79 per cent the rice weevil repeatedly completed its life cycle in an average interval of 28 days. These conditions were as near optimum as could be maintained with the equipment used, thus insuring maximum activity of the experimental insects at all times during the course of the experimental period.

The original stock from which the rice weevils were reared came from cultures of stored grain insects of the Department of Entomology, Kansas State College. All insects were reared in hard red winter wheat of varied sources.

Selection of Infested Kernels

Because no previous experimental methods of conducting the type of research herein reported were known, it was deemed advisable that all experiments should, in order to eliminate as many variables as possible, make use of previously established methods and tools of research in so far as possible. For these reasons the X-ray technique for detecting internal insect infestations of grain was used in all but a limited series of preliminary experiments.

Preliminary experiments, in which the acid fuchsin stain technique for detecting weevil infestation in grain (Frankenfeld, 1948) was used, led to undesirable results. The acid fuchsin stain technique presented an easy method of selecting those wheat kernels which were infested with the rice weevil; however, the dye solution appeared to act as an ovicide or larvicide or to prolong the life cycle of the surviving eggs or larvae. This prevented the use of infested kernels selected in this manner in experiments which required live insects.

The X-ray technique for detecting internal insect infestation in grain (Milner, Lee and Katz 1950) was used in all further experiments. The X-ray equipment was made available for this work by the Department of Physics, Kansas State College. The radiation source was a Machlett cobalt-target X-ray diffraction tube with a beryllium window. The tube was excited to a voltage of 15 k.v. at a current of eight to 10 m.a.. Exposure time ranged from seven to 10 seconds. Eastman Type A Industrial X-ray film was used.

Radiographic examination of the infested grain did not cause stimulating or inhibiting effects upon the insects examined.

Sound Proof Box

Barton (1934), who experimented with audio amplification as a means of detecting termites in wooden structures, found that this method of detection was almost necessarily limited to the laboratory because of excessive interference caused by electrical equipment and by the vibrations of heavy industrial machinery. Colebrook (1937) in similar experiments designed to detect the presence of the death watch beetle in wood, constructed a sound proof box which served as a housing and shield for the microphone. Infested billets were placed in this box in order to eliminate, as much as possible, the otherwise excessive extraneous noises which were picked up by the equipment and amplified with sufficient intensity to mask the noises made by the larvae being observed.

Adams (1953) experienced difficulties similar to those reported by previous workers and therefore designed and built the sound proof box used in the experiments reported in this work.

The sound proof box consisted, as a unit, of a series of four boxes, one placed within the other. The first and innermost box was 12 inches square and made of a fiber wallboard material called Celotex. The microphone rested on sponge rubber within the first box. A second box, constructed similar to the first, contained the first box mounted on sponge rubber. This combination of boxes, with lids, sufficed to a limited degree as a barrier to sound but was not capable of eliminating electrical interference. In order to eliminate electrical interference a third box made of 20 gauge copper and approximately 16 inches square with a tight fitting lid was constructed. The two Celotex boxes, each mounted on sponge rubber, were placed inside the copper box. Because of the light gauge of the copper box, its sides were not rigid and would vibrate when a loud sound was made within a few feet of the box, necessitating the construction of a fourth and final box. The fourth box, in which were placed the three previously described boxes, was built of concrete and was approximately two feet square with walls two inches thick and a form fitting concrete lid of the same thickness as the walls. Adams (1953) designed the outer box in this manner because it was his belief that a concrete box of sufficient mass would not permit sound to cause the walls of the box to vibrate.

The sound proof box, consisting as a unit of the four previously described boxes, was placed on an inflated automobile inner tube in order to prevent any sound conduction through the floor to the box.

The sound proof box was effective in eliminating all but those sounds of a lower frequency corresponding to the resonant frequency of the box itself.

Interior and exterior views of the sound proof box are shown in Plate I, Fig. 1 and Fig. 2.

The Microphone

Inasmuch as the application for which the microphone used in these experiments was different from the ordinary use of a microphone, several types of microphones were tested by Adams (1953) in order to find one that would prove adapted for the work. It was found that crystal microphones were the most sensitive. A Western Electric hearing aid microphone was used. The

EXPLANATION OF PLATE I

Photographs of Sound Proof Box

Fig. 1. Interior view of soundproof box, showing microphone, Celotex boxes, copper box, and outer concrete box.

Fig. 2. Exterior view of the concrete sound proof box, mounted on an automobile inner tube wrapped with burlap wrapping.

PLATE I

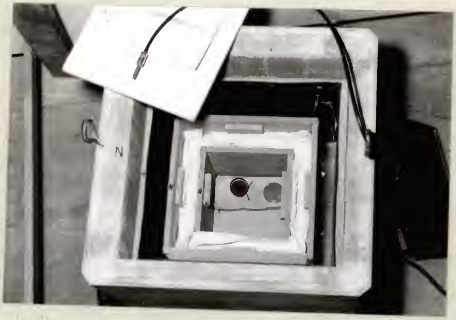


Fig. 1

Fig. 2

sound of the insects within the kernel of wheat was not sent through the air as a series of air waves but was conducted through the wheat and microphone parts as a series of mechanical vibrations, necessitating contact of the infested grain with the microphone dust cover. The infested wheat kernels were placed on the thin dust cover of the microphone which worked very well as a sound conductor.

The Amplifier

The amplifier consisted of a four tube high gain audio amplifier which utilized a low noise triode input stage. A laboratory power supply was used in addition to batteries for the filaments. The voltage gain of the final amplifier as measured across the speaker windings of the output transformer was 77,000, which, according to Adams (1953) represented a useful level; that is, the amplifier worked very well up to that point and then the noise level became excessive. However, when it is considered that the gain of the amplifier as actually used for the detection of insects was only between 5,000 and 6,000, the gain was sufficient.

The frequency response of the amplifier was checked by Adams (1953) and thought to be satisfactory. The amplifier was designed to have a high low-frequency cutoff to help prevent low frequency oscillations. It was thought that the insects would not emit low frequency sound because of their small size.

A circuit diagram of the amplifier is shown in Plate II.

Long Time Constant Average Reading Meter

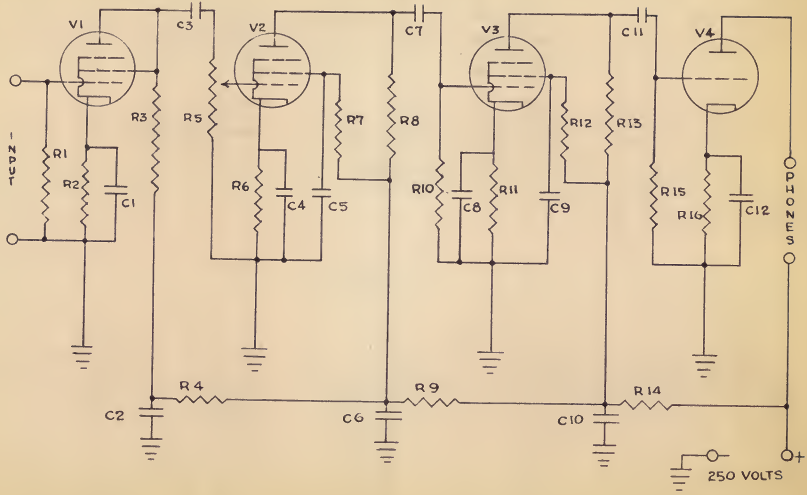
Preliminary experiments involving the use of a Tektronix 514D oscilloscope indicated that the pattern of sound made by a given number of

EXPLANATION OF PLATE II

Circuit Diagram of Audio Amplifier

R1 - 5.6 MEGOHM	C1 - 4 MFD.
R2 - 150 OHMS	C2 - 8 MFD.
R3 - 4,700 OHMS	C3 - 0.1 MFD.
R4 - 10,000 OHMS	C4 - 8 MFD.
R5 - 0.56 MEGOHMS	C5 - 0.05 MFD.
R6 - 1,500 OHMS	C6 - 0.5 MFD.
R7 - 1.2 MEGOHM	C7 - 0.01 MFD.
R8 - 0.25 MEGOHM	C8 - 8 MFD.
R9 - 47,000 OHMS	C9 - 0.05 MFD.
R10 - 0.5 MEGOHM	C10 - 0.5 MFD.
R11 - 1,500 OHMS	C11 - 0.01 MFD.
R12 - 1.2 MEGOHM	C12 - 8 MFD.
R13 - 0.25 MEGOHM	V1 - 6AC7
R14 - 47,000 OHMS	V2 - 6SJ7
R15 - 1 MEGOHM	V3 - 6SJ7
R16 - 1,000 OHMS	V4 - 6J5

PLATE II


V1
V2
V3
V4
C3
C7
C11
R1
R2
R3
R4
R5
R6
R7
R8
R9
R10
R11
R12
R13
R14
R15
R16
C1
C2
C4
C5
C6
C8
C9
C10
C12
INPUT
PHONES
+
250 VOLTS

insects of approximately the same age followed a recognizable and seemingly definite pattern. In order to record and interpret these sound patterns on a purely mechanical basis, the long time constant average reading meter was developed.

By means of the sound proof box, it was possible to eliminate all extraneous noises caused by mechanical vibrations and electrical systems. It was not possible to eliminate background noises, that is, those noises generated by the component parts of the amplifier and accompnaying circuits. In order to eliminate the background noise, a clipper circuit was designed and incorporated with the long time constant average reading meter.

In general and purely descriptive terms the combined clipper circuit and long time constant average reading meter worked in the following manner. When the microphone was disconnected, the signal generated by the component parts of the amplifier, if projected on a cathode ray oscilloscope, would present a waveform as represented in Plate III, Fig. 1.

When the microphone containing infested kernels was connected with the amplifier, the waveform of the signal constituting the combined noises of both the insects and the background noise would appear as represented in Plate III, Fig. 2.

Because the background noise was of a constant magnitude the clipper circuit was adjusted to a level which would clip or eliminate the background noise, thus resulting in a signal with a waveform as represented in Plate III, Fig. 3. Only those sounds with an amplitude larger than the amplitude of the background noise would be permitted to pass from the clipper circuit.

The clipped signal was then sent through an amplifier stage from which the signal emerged with a waveform as represented in Plate III, Fig. 4.

The amplified clipped signal was then sent through a bridge rectifier which rectified it from an alternating current to a full wave direct current value as represented in Plate III, Fig. 5.

The resulting full wave direct current signal was then sent through a long time constant filter to a voltmeter by means of which the signal strength could be read as numerical voltage values. Use of the long time constant filter resulted in a meter reading which represented the average value of the signal rather than the maximum or minimum values of the signal. A circuit diagram of the clipper-amplifier-long time constant average reading meter is shown in Plate IV. Photographs of the clipper circuit, audio amplifier and long time constant average reading meter appear in Plate V, Fig. 1. A photograph of the vacuum tube voltmeter used to obtain voltage readings appears in Plate V, Fig. 2.

EXPERIMENTAL DESIGN

Visual Interpretation of Sound Patterns

Experiments, designed to determine the practicality of visual interpretations of sound patterns caused by the immature stages of the rice weevil in wheat, were conducted for a period of four months. Equipment used in these experiments was the sound proof box containing the microphone, the audio amplifier, a speaker or headphones, and a Tektronix 514D cathode ray tube oscilloscope. These experiments used the rice weevil as the experimental animal. The primary objective was to determine whether or not reproduceable

EXPLANATION OF PLATE III

Changes in Waveforms Accomplished by Clipper Circuit

Fig. 1. Waveform of background noise.

Fig. 2. Waveform of background noise plus noises of insects.

Fig. 3. Waveform of clipped signal.

Fig. 4. Waveform of clipped, amplified signal.

Fig. 5. Waveform of full wave direct current value.

PLATE III

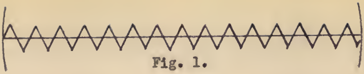


Fig. 1.

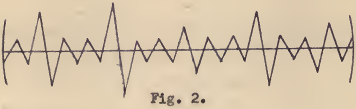


Fig. 2.

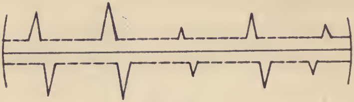


Fig. 3.

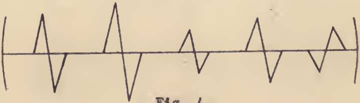


Fig. 4.

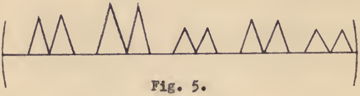


Fig. 5.

EXPLANATION OF PLATE IV

Circuit Diagram of the Clipper-Amplifier-
Long Time Constant Average Reading Meter.

R1 - 250,000 OHMS

R2 - 250,000 OHMS

R3 - 1 MEGOHM

R4 - 1 MEGOHM

R5 - 1 MEGOHM

C1 - 0.02 MFD.

C2 - 0.02 MFD.

C3 - 0.02 MFD.

C4 - 0.02 MFD.

C5 - 20 MFD. (C11)

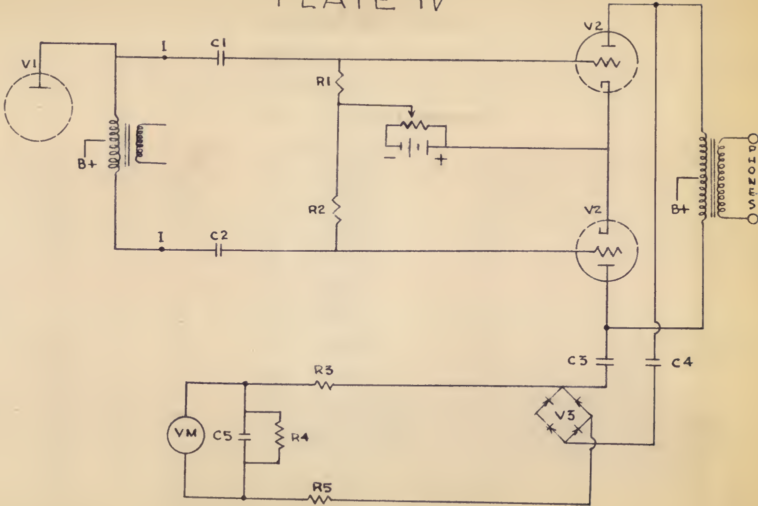
VI - 6C5 (In audio amplifier)

V2 - 6SL7-GT

V3 - 1N34'S

VM - Vacuum tube voltmeter.

PLATE IV



EXPLANATION OF PLATE V

Fig. 1. Photograph of the clipper circuit, audio amplifier and the long time constant average reading meter.

Fig. 2. Photograph of the vacuum tube voltmeter.

PLATE V

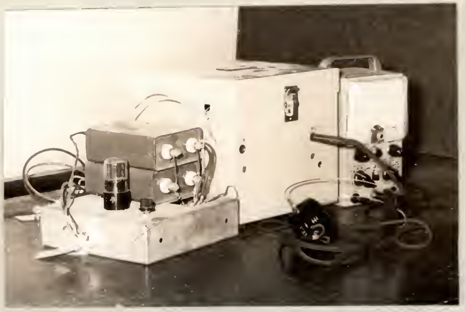


Fig. 1

Fig. 2.

and definite levels of sound, as determined by measurements of the maximum amplitude of the waveforms of the sounds caused by the insects, could be determined for a known degree of infestation of wheat by the rice weevil.

Various numbers of infested kernels, ranging from one to 20 in number, were placed in the microphone and the waveforms of the sound patterns caused by these insects were studied. Infested kernels were selected, by the X-ray method of detecting internal insect infestations of grain, from hard red winter wheat at 13 to 14 per cent moisture content which had been exposed to adults of the rice weevil for a period of 48 hours. All insects used were of the same age.

Studies of the maximum amplitude of the waveforms of the sounds caused by various numbers of the insects in a given sample were made on successive days as the insects matured. It was found that the maximum amplitude of waveforms increased with the ages of the insects to a certain and varying age and then leveled off or became erratic; in other words, a given number of larvae or a single larva created sound whose waveform amplitude progressively increased until the insect or insects had reached a certain age, after which the amplitude of the waveforms either leveled off or decreased but did not exceed previously recorded maximum amplitude measurements. It was observed that, as the number of infested kernels was increased, the number of impulses per unit of time increased correspondingly, even though the amplitude of the waveforms did not increase beyond a certain point. Because it was beyond the range of human capabilities to visually count the number of impulses per unit of time, the long time constant average reading meter method of determining the average value of the waveform peaks, in terms of volts for a given period of time was used.

Mechanical Interpretation of Sound Patterns

As a result of information gained from experiments designed to lend a visual interpretation of the sound patterns caused by the immature stages of the rice weevil, a mechanical method of interpreting these sound patterns was developed. Visual interpretations of sound patterns indicated that there was no pattern, as indicated by maximum wave amplitude measurements, to the sounds caused by the insects which would lend itself to further research. Visual interpretations did indicate, however, that a method of measuring the average value of the area described by the waveform peaks of the sound caused by the insects would lead to the establishment of definite relationships between the number of insects observed and the sound created by these insects.

It was observed in preliminary experiments utilizing the oscilloscope that, as the numbers of insects of approximately the same age was increased, the degree of sound emitted, as determined by the average value of the waveform peaks, increased proportionately. In experiments utilizing the oscilloscope it was also observed that the background noise was of a constant amplitude and prevented the recognition of insect sounds until the insects had become old enough to cause the emission of sounds with a volume greater than the volume of the background noise. It was impossible to distinguish the noises of very young larvae from the background noise. Because any attempt to measure the sound caused by the larvae, providing these sounds were detectable, would necessitate the development of a factor designed to compensate for the constant background noise it was decided that the best course to follow would be to eliminate the background noise. In order to eliminate the background noise the clipper circuit was used. As previously illustrated, that portion of the waveforms with an amplitude greater than the threshold level at which the clipper circuit was adjusted, was then amplified and rectified to a DC value; the average value of which was read as volts on the long time constant average reading meter.

Experiments using the long time constant average reading meter were designed to evaluate sounds caused by a varying number of insects of approximately the same age. Fifty to 60 adult insects, of mixed sexes, were placed in each of 70 eight dram shell vials filled approximately one-half full of hard red winter wheat at approximately 13.6 per cent moisture content. The vials were then placed in the rearing cabinet for a period of 48 hours after which the adults were removed. The contents of five vials, selected at random from the original 70 vials, were pooled to form a single sample. The pooled sample was then X-rayed and 50 infested kernels were selected for further use.

Readings were made from the first day that it was possible to detect the noises made by the larvae in a sample consisting of two infested kernels until the first adult emerged from the original sample of 50 infested kernels.

From the 50 infested kernels selected by means of X-ray photographs, two infested kernels were chosen at random and placed on the dust cover of the microphone. Readings of the average value of the sound caused by these two insects were made and recorded. The readings represented the voltage indicated on the voltmeter at each of 25 thirty-second intervals, or a total observational period of 12.5 minutes per sample. At the end of the 12.5 minute interval these two kernels were then removed from the microphone and replaced in the vial. After the vial and its contents had been inverted 10 times, five infested kernels were selected at random and placed on the dust cover of the microphone. Readings were made as previously described. The same procedure was repeated and replicated three times for each of the following number of infested kernels: 2, 5, 9, 13 and 18. Each of the 50 infested kernels contained only one larvae per kernel. The entire lot of 50 kernels was X-rayed at weekly intervals in order to be sure that the insects had remained alive.

RESULTS AND DISCUSSION

Sounds Caused by Insects

From force of habit and for want of better terms reference has been made to "insect noises" and "insect sounds" in this work. These terms are believed to be ambiguous because the sounds observed in these experiments were believed to be accidental sounds associated with normal insect behavior in feeding and moving. The sounds observed were not believed to be soundwaves created by the pulsating organ of the insect circulatory system, the gnashing of the mouthparts, or the normal movements and functions of other morphological structures.

The sound proof box was used in order to eliminate extraneous noises and to prevent acoustic interaction between the output and the input of the equipment. Because the infested kernels observed had to be placed on the dust cover of the microphone and because the microphone was contained within the innermost of the four boxes comprising the sound proof box, it was not possible to watch the insects feeding and moving. As a result it was not possible to definitely identify the sounds produced by these actions.

Three definite types of sound were observed. The first and most frequent type was a burst of noise comparable to the sound produced when a piece of peanut brittle or similar brittle materials are broken. The second type of sound, less frequently observed, was a scraping noise similar to the sound produced by rubbing a hard material over a hard surface. The third type of sound observed was a hollow, reverberating sound similar to that produced when the inner surface of an empty wooden barrel is repeatedly struck with a mallet. This type of sound was heard only when the insects observed were in the pupal stage.

None of the sounds observed were regular and rhythmical as could be expected of the sound produced by the pulsations of a pulsatory organ. None of the sounds observed were grinding sounds such as could be expected to be produced by the grinding or masticating of endosperm particles by the mandibles of the rice weevil. Available literature and the morphological features of the mandibles of larval stages of the rice weevil indicate that they are not capable of grinding or masticating their food.

The following speculative classification of the sounds observed is proposed: (a) those sounds resulting from the rupture of cells and tissues of the endosperm when the larva or adult within the kernel of wheat broke off a piece of endosperm; (b) those sounds created when the larva, while moving, rubbed its body against the walls of the larval tunnel; and (c) the sounds created by the pupa hitting the walls of the larval tunnel with the abdomen when moving or disturbed. It was believed that unless the insect was actively engaged in feeding or moving about no sound emanated from the infested kernel of wheat.

Age Factors in Relation to Sound

It was observed that until the larva had reached a certain age the sound created by the feeding and movements of the larva was not of sufficient volume to be distinguished from the background noise. The background noise was a hiss of a constant volume and was an inherent feature of the component parts of the amplifier and accompanying circuits. The background noise was present when the microphone was empty and also when the microphone contained infested kernels. In eliminating the background noise and accompanying sounds with a volume less than or equal to the volume of the background noise by use of the clipper circuit, no useful sounds were lost.

In order to determine at what stage in the growth of the insect the sounds created by the feeding and movements of the larva definitely could be identified, infested kernels were selected by means of X-ray equipment. The insects selected were listened to and observed for a period extending from the time the egg hatched until the adult emerged.

Infested kernels containing insects of the same age as the insects observed were dissected and measurements of the larval head capsules were made on successive days as the insects matured. Developmental stages were determined by the combined use of larval head capsule measurements and time lapse methods.

It was found that the noises created by the feeding and moving of the larvae were not of sufficient volume to be definitely identified until the larvae had begun the third larval instar. From the time the larva began the third larval instar, or 14 days from egg deposition, until it emerged from the kernel as an adult it was possible to definitely identify the noise created by the feeding and moving of the insect within the kernel of wheat.

In view of experimental results it was concluded that the inability of the equipment to amplify the sounds resulting from the movements and feeding of the insect within the kernel of wheat, before the third larval instar, was the result of one or a combination of the three following factors: (a) the larva was relatively inactive until it reached the third instar; (b) younger larvae were embedded in softer parts of the kernel which served to muffle sound; and (c) the larva was active during the first and second instar but the sound created by the feeding and movements of the larva was not of sufficient volume to be distinguished from the more uniform background noise created within the amplifier and accompanying circuits. Unverified experimental results indicated that the latter explanation was probably the most plausible explanation.

Correlation of Sound to Degree of Infestation

The volume of noise created by the movements and feeding of varying numbers of the rice weevil of the same age within kernels of wheat was studied for a total period of 14 days. This period included the third larval instar, fourth larval instar, pupal stage, and unemerged adult stage of the rice weevil.

The volume of noise, measured as volts, was studied by placing 2, 5, 9, 13, or 18 infested kernels of wheat on the dust cover of the microphone and recording the average number of volts every 30 seconds for a total period of 12.5 minutes. Three sets of readings were taken on each sample and there were 25 samples for each degree of infestation. This sampling was repeated daily for 12 days as the insects matured. The samples with increasing degrees of infestation were not derived from previous and lower degrees of infestation but were new and random samples.

The data analyzed (Tables 3 through 14) were the average volts for each infestation on each day. When these data were graphed in scatter diagrams it appeared that the degree of noise was approximately linearly related to the degree of infestation. This presumption was verified by computing the product moment coefficients of linear correlation for each day's five point scatter diagram (Table 1). Even with only three degrees of freedom all but one correlation was statistically significant at or beyond the five per cent level; seven were significant at or beyond the one per cent level; one reached the 0.1 per cent level. The results of the data analyzed indicate there must have been a close relationship between the degree of infestation of wheat by these insects of the same age and the degree of sound measured as average volts on a voltmeter.

Analysis of Variability

An analysis of variability between and within samples of the same age and the same degree of infestation was made. The samples analyzed were selected at random from the data for each degree of infestation on three different days within the observational period.

The variability from reading to reading within the same sample was invariably much greater than between different samples of the same age and same degree of infestation. This suggests that when future studies of this type are performed the number of samples should be reduced and the number of readings per sample should be increased. In other words, this would mean taking only eight samples for each age and degree of infestation instead of 25 samples as was done in this study, but at the same time replicate each sample five times instead of three times. Apparently these insects make the same volume of noise over a period of time for the same degree of infestation and with a given age level, but they do so sporadically and need to be observed more frequently. In practice, this would seem to indicate that relatively few samples would need to be taken, but that they should be observed over a longer period of time.

It was observed that the estimated variance within samples (2) increased with age for a given infestation. This would indicate that the insects became more active as they grew older.

The results of the analysis of variability between and within samples of the same age and same degree of infestation are tabulated in Table 2.

Statistical analysis was done by Dr. Holly C. Fryer, Kansas Agricultural Experiment Station Statistician.

CONCLUSIONS

From the observations made and the data collected under the conditions encountered during the course of this study, the following conclusions may be drawn:

1. It was not possible to identify the sound caused by the larvae of the rice weevil from the background noise until the insects observed had reached the third larval instar.

2. It is possible to detect the presence of immature stages of the rice weevil in wheat by means of audio amplification when the third larval instar is reached.

3. It is possible to detect the presence of a single immature rice weevil in a kernel of wheat by means of audio amplification when the third larval instar is reached.

Table 1. Product moment coefficients of linear correlation between average number of volts and degree of infestation.

Date	Stage	Correlation Coefficient (r)
7/ 9/53	Larval	.93*
7/10/53	Larval	.98**
7/11/53	Larval	.98**
7/13/53	Larval	.97**
7/14/53	Larval	.96**
7/15/53	Larval	.92*
7/16/53	Larval	.98**
7/17/53	Pupal	.96**
7/18/53	Pupal	.96**
7/20/53	Pupal	.90**
7/21/53	Pupal	.78ns
7/22/53	Adult	.99***

*5.0 per cent level
**1.0 per cent level
***0.1 per cent level

Table 2. Results of analysis of variability between and within samples of the same age and degree of infestation.

Degree of Infestation	Date	$\hat{\sigma}^2$	$\hat{\sigma}_s^2$
2	7/11/53	.0022	.0001
2	7/13/53	.1415	neg.
2	7/15/53	.0938	neg.
5	7/10/53	.0023	neg.
5	7/15/53	.0399	neg.
5	7/18/53	.0152	neg.
9	7/ 9/53	.0139	neg.
9	7/14/53	.0263	.0088
9	7/21/53	.1129	neg.
13	7/ 9/53	.0036	neg.
13	7/17/53	.0389	neg.
13	7/21/53	.1651	neg.
18	7/14/53	.0645	neg.
18	7/18/53	.0695	neg.
18	7/22/53	.1047	.0104

$\hat{\sigma}^2$ = estimated variance within samples.

$\hat{\sigma}_s^2$ = estimated variance between samples exclusive of that contributed by σ^2.

Table 3. Voltage readings at 30 second intervals of wheat kernels infested with 2, 5, 9, 13, and 18 immature rice weevils. Experiment performed July 9, 1953.

Interval of Readings	Number of Weevils: 2, Replicate # 1	2, Replicate # 2	2, Replicate # 3	5, Replicate # 1	9, Replicate # 1	9, Replicate # 2	13, Replicate # 1	13, Replicate # 2	13, Replicate # 3	18, Replicate # 1	18, Replicate # 2	18, Replicate # 3
30 sec.	0	0	0	.07	.02	.05	.07	.15	.10	.15	.40	.13
60 "	0	0	0	.07	.04	.06	.06	.18	.06	.12	.30	.12
90 "	0	0	0	.07	.06	.08	.10	.18	.04	.15	.25	.15
120 "	0	.02	0	.10	.06	.05	.09	.18	.06	.15	.35	.12
150 "	.02	.02	.01	.12	.15	.06	.09	.20	.02	.17	.35	.12
180 "	.02	.01	0	.08	.24	.04	.11	.25	.05	.17	.50	.13
210 "	.01	.01	.03	.12	.22	.05	.07	.24	.09	.18	.47	.13
240 "	0	0	0	.13	.25	.05	.07	.17	.06	.22	.45	.10
270 "	0	0	.01	.16	.25	.10	.07	.17	.07	.23	.40	.06
300 "	.02	0	0	.14	.17	.08	.07	.17	.06	.27	.42	.12
330 "	.04	.01	.01	.06	.22	.07	.10	.20	.08	.17	.38	.07
360 "	.03	.01	.02	.06	.25	.06	.12	.19	.07	.13	.48	.07
390 "	.04	.02	.04	.09	.28	.06	.12	.19	.08	.22	.46	.09
420 "	.04	0	0	.05	.29	.08	.10	.19	.10	.24	.45	.08
450 "	.05	0	0	.03	.28	.08	.15	.18	.10	.28	.45	.07
480 "	.04	0	0	.19	.24	.07	.21	.20	.12	.25	.44	.06
510 "	.05	0	0	.15	.32	.06	.13	.19	.13	.21	.42	.08
540 "	.05	.01	.01	.25	.28	.06	.13	.19	.10	.21	.34	.10
570 "	.06	.03	.03	.13	.23	.07	.12	.18	.08	.19	.44	.08
600 "	.07	.04	.04	.16	.25	.08	.15	.20	.20	.22	.44	.07
630 "	.06	.04	.04	.20	.28	.06	.13	.19	.21	.24	.37	.06
660 "	.06	.05	.05	.23	.24	.06	.12	.22	.28	.28	.40	.05
690 "	.07	.03	.06	.12	.23	.04	.15	.17	.24	.40	.47	.08
720 "	0	0	.06	.06	.20	.04	.10	.18	.15	.60	.45	.07
750 "	0	0	.03	.12	.19	.07	.15	.19	.18	.60	.50	.06
Average	.03	.01	.02	.12	.21	.06	.11	.19	.11	.24	.41	.09
Average of Replicates		.02		.12		.13		.14			.25	

Table 4. Voltage readings at 30 second intervals of wheat kernels infested with 2, 5, 9, 13, and 18 immature rice weevils. Experiment performed July 10, 1953.

Interval of Readings	Number of Weevils: 2, Replicate # 1	2	5, Replicate # 1	2	3	9, Replicate # 1	2	3	13, Replicate # 1	2	3	18, Replicate # 1	2	3
30 sec.	0	0	.03	.05	.06	.23	.31	.44	.27	.41	.14	.35	.09	.38
60 "	0	0	.04	.05	.06	.07	.52	.14	.25	.37	.13	.32	.07	.41
90 "	0	0	.02	.03	.07	.05	.42	.08	.30	.64	.13	.32	.17	.43
120 "	0	0	0	.04	.26	.10	.36	.09	.32	.59	.12	.31	.16	.36
150 "	0	.01	.01	.08	.13	.12	.30	.22	.29	.36	.11	.30	.30	.34
180 "	0	0	.02	.13	.09	.10	.20	.14	.22	.18	.16	.90	.15	.26
210 "	0	.03	.05	.11	.08	.12	.20	.10	.27	.14	.10	.85	.17	.31
240 "	0	.02	.08	.09	.09	.13	.22	.08	.17	.15	.12	1.30	.20	.32
270 "	0	.01	.05	.06	.10	.12	.19	.12	.23	.23	.10	1.45	.23	.25
300 "	0	.03	.05	.06	.08	.12	.27	.12	.24	.23	.15	1.05	.23	.38
330 "	0	.02	.04	.12	.09	.14	.24	.08	.22	.32	.16	1.30	.20	.38
360 "	0	0	.06	.03	.06	.14	.28	.12	.25	.33	.15	.80	.21	.35
390 "	0	0	.07	.03	.08	.12	.19	.08	.26	.23	.21	1.13	.22	.33
420 "	0	0	.05	.10	.11	.14	.22	.08	.37	.17	.25	1.20	.17	.55
450 "	0	.02	.03	.05	.07	.12	.23	.10	.31	.26	.14	.65	.24	.70
480 "	.02	0	.04	.02	.07	.13	.24	.30	.34	.14	.15	.38	.27	.45
510 "	0	0	.03	.05	.12	.13	.30	.35	.55	.34	.16	.24	.28	.50
540 "	0	0	.03	.03	.16	.12	.30	.27	.62	.29	.15	.25	.24	.45
570 "	.02	0	.01	0	.16	.12	.24	.23	.58	.35	.14	.23	.27	.59
600 "	.01	0	.05	.04	.12	.17	.31	.15	.45	.33	.14	.82	.23	.46
630 "	0	0	.07	.06	.16	.18	.31	.22	.47	.31	.17	1.20	.24	.52
660 "	.01	0	.06	.09	.10	.18	.31	.12	.37	.29	.21	1.50	.28	.42
690 "	.03	0	.07	.12	.08	.19	.24	.29	.34	.29	.23	1.58	.75	.65
720 "	0	0	.06	.13	.09	.18	.24	.29	.36	.29	.28	1.25	.78	.90
750 "	0	0	.07	.09	.12	.19	.29	.20	.28	.28	.16	1.20	.64	1.00
Average	.003	.006	.04	.07	.10	.14	.28	.18	.33	.30	.16	.83	.27	.47
Average of Replicates		.01		.07			.20			.26			.52	

Table 5. Voltage readings at 30 second intervals of wheat kernels infested with 2, 5, 9, 13, and 18 immature rice weevils. Experiment performed July 11, 1953.

Interval of Readings	Number of Weevils: 2 Replicate # 1	2	3	5 Replicate # 1	2	3	9 Replicate # 1	2	3	13 Replicate # 1	2	3	18 Replicate # 1	2	3
30 sec.	0	0	.10	0	.01	0	.04	.08	.10	.21	.09	.10	.17	.24	.12
60 "	0	0	.10	0	0	.02	.05	.15	.15	.13	.04	.25	.30	.23	.25
90 "	0	0	.02	.02	0	.05	.07	.14	.15	.15	.07	.33	.28	.28	.32
120 "	0	0	.06	0	.02	.03	.04	.08	.09	.13	.08	.32	.34	.28	.32
150 "	0	.02	.03	0	.01	0	.03	.12	.19	.12	.13	.23	.19	.29	.22
180 "	0	0	.04	0	0	.02	.04	.13	.14	.12	.09	.21	.14	.30	.18
210 "	0	0	.05	.02	.01	.05	.02	.13	.10	.12	.07	.24	.14	.24	.29
240 "	0	.03	.05	.04	0	.07	.01	.17	.07	.14	.07	.23	.27	.25	.26
270 "	0	.02	.06	.04	.03	.31	.03	.16	.16	.13	.06	.23	.25	.22	.28
300 "	.02	.03	.03	.04	.03	.28	.03	.23	.23	.12	.08	.27	.26	.22	.29
330 "	.02	0	.03	0	.04	.13	.05	.13	.36	.08	.09	.26	.24	.23	.27
360 "	.02	.01	.02	.02	.03	.08	.03	.14	.42	.08	.10	.15	.23	.22	.25
390 "	0	.02	.03	.03	.03	.08	.02	.12	.45	.14	.14	.13	.23	.23	.43
420 "	.04	.04	.07	.04	.02	.06	.02	.20	.54	.17	.13	.14	.37	.22	.36
450 "	.02	0	.10	.03	.01	.07	.02	.15	.51	.14	.24	.16	.43	.22	.40
480 "	.09	0	.07	.05	0	.06	.01	.17	.31	.12	.23	.17	.39	.24	.34
510 "	.11	.03	.08	.04	0	.04	.02	.14	.16	.13	.28	.15	.44	.19	.37
540 "	.06	.02	.09	.06	0	.04	0	.12	.20	.13	.36	.13	.23	.21	.32
570 "	.28	.02	.07	.08	.01	.03	.04	.24	.29	.12	.36	.18	.21	.17	.38
600 "	.18	0	.09	.07	.01	.02	.04	.16	.27	.14	.28	.19	.17	.28	.41
630 "	.12	0	.12	.06	.02	.06	.04	.13	.27	.12	.26	.18	.16	.22	.38
660 "	0	0	.09	.05	.02	.07	.12	.12	.40	.13	.36	.21	.15	.21	.38
690 "	0	.02	.04	.07	.01	.07	.06	.14	.44	.09	.28	.17	.13	.17	.40
720 "	0	.02	.03	.07	0	.04	.07	.13	.27	.14	.21	.16	.17	.24	.38
750 "	0	0	.02	.07	0	.02	.05	.09	.26	.11	.23	.17	.24	.28	.45
Average	.04	.01	.06	.04	.01	.07	.04	.14	.26	.13	.17	.20	.24	.23	.32
Average of Replicates		.04			.04			.15			.17			.26	

Table 6. Voltage readings at 30 second intervals of wheat kernels infested with 2, 5, 9, and 18 immature rice weevils. Experiment performed July 13, 1953.

Interval of Readings	Number of Weevils: 2, Replicate # 1	2	3	5, Replicate # 1	2	3	9, Replicate # 1	2	3	13, Replicate # 1	2	3	18, Replicate # 1	2	3
30 sec.	.02	.02	.06	.02	.01	.20	.40	.19	.38	.27	.72	1.42	.28	1.10	.45
60 "	.01	.02	.12	.03	.02	.44	.80	.56	.27	.33	.55	1.20	.30	.76	.82
90 "	0	.04	.60	.07	.13	.53	.90	.53	.73	.35	.84	.88	.28	1.60	.59
120 "	.02	.03	1.22	.12	.21	.43	.68	.43	.67	.27	.72	1.02	.25	1.31	1.05
150 "	.06	.05	.93	.09	.12	.39	.86	.42	.44	.28	.67	1.18	.25	1.21	.97
180 "	.01	.04	.87	.10	.29	.42	1.50	.39	.47	.31	.57	1.55	.20	1.42	.82
210 "	0	.03	1.02	.25	.13	.32	1.00	.44	.45	.52	.60	.97	.20	1.75	.78
240 "	0	.09	.70	.23	.23	.28	.93	.44	.47	.82	.78	.93	.18	1.55	.84
270 "	0	.06	1.02	.13	.39	.32	1.12	.42	.38	.90	.67	1.60	.26	1.43	.82
300 "	.02	.06	.42	.17	.52	.31	1.40	.52	.42	.75	.74	1.83	.34	1.36	.59
330 "	0	.04	.26	.07	.13	.46	1.30	.24	.47	.33	.76	1.87	.30	1.47	.73
360 "	.04	.07	.21	.05	.14	.38	1.34	.21	.34	.29	.73	1.81	.34	1.23	.75
390 "	.04	.05	.21	.12	.07	.46	.78	.42	.53	.73	.61	2.24	.40	1.52	.93
420 "	.04	.04	.72	.04	.23	.29	.69	.35	.82	.29	.63	1.60	.40	1.61	.79
450 "	.05	.07	1.02	.03	.16	.42	.62	.62	.63	.28	.89	2.05	.45	1.64	1.09
480 "	.02	.04	1.03	.06	.09	.53	.61	.36	.57	.26	.72	1.19	.53	1.66	1.28
510 "	.04	.05	.72	.06	.04	.46	.52	.42	.58	.30	.46	1.28	.51	1.33	.94
540 "	.02	.04	.24	.06	.02	.65	.58	.31	.40	.42	.52	.90	.42	1.73	.82
570 "	0	.03	.21	.07	.03	.32	.85	.24	.73	.40	.94	.72	.43	1.85	.92
600 "	.02	.03	.17	.09	.07	.54	1.40	.59	.47	.28	.73	.61	.42	1.60	1.02
630 "	.06	.02	.21	.10	.07	.73	1.24	.41	.72	.33	.69	.93	.33	2.02	1.17
660 "	.11	.02	.14	.23	.09	.62	.90	.46	.56	.15	.54	1.42	.49	1.78	1.23
690 "	.02	.04	.16	.35	.08	.63	.78	.39	.34	.29	.48	1.74	.33	1.93	1.33
720 "	.03	.04	.82	.33	.07	.36	.62	.62	.43	.51	.53	1.26	.32	2.23	.85
750 "	.02	.05	1.06	.14	.07	.42	.67	.35	.66	.41	.68	1.26	.35	1.88	.83
Average	.03	.04	.57	.12	.14	.44	.90	.41	.52	.40	.67	1.34	.34	1.56	.90
Average of Replicates		.21			.23			.61			.80			.93	

Table 7. Voltage readings at 30 second intervals of wheat kernels infested with 2, 5, 9, 13, and 18 immature rice weevils. Experiment performed July 14, 1953

Interval of Readings	Number of Weevils: 2		5		9		13		18	
	Replicate # 1	2	Replicate # 1	2	Replicate # 1	2	Replicate # 1	2	Replicate # 1	2
30 sec.	0	.03	.32	.12	.50	.37	.63	.50	.64	.78
60 "	.12	.03	.36	.18	.43	.22	.60	.63	.47	.84
90 "	.06	.09	.57	.27	.29	.23	.58	.64	.48	1.08
120 "	.06	.06	.34	.22	.32	.29	.72	.74	.73	.87
150 "	.03	.09	.17	.30	.27	.32	.54	.78	.71	1.14
180 "	.02	.06	.23	.27	.21	.24	.58	.53	.68	1.18
210 "	.02	.02	.36	.37	.42	.19	.62	.76	.58	1.12
240 "	.05	.04	.24	.27	.34	.26	.60	1.02	.59	1.02
270 "	.01	.04	.32	.26	.22	.24	.54	.84	.63	.87
300 "	.01	.03	.47	.23	.34	.28	.75	.63	.63	.87
330 "	.02	.04	.36	.14	.32	.34	1.02	.59	.59	.95
360 "	.03	.16	.33	.22	.30	.33	1.23	.66	.62	.84
390 "	.02	.06	.42	.20	.25	.73	1.12	.66	.64	1.07
420 "	.01	.04	.36	.23	.40	.78	.95	.49	.68	.97
450 "	.02	.09	.18	.24	.42	.72	.89	.52	.57	.92
480 "	.01	.07	.23	.29	.42	1.10	.72	.68	.58	.91
510 "	.02	.04	.32	.32	.29	.64	.92	.87	.59	.67
540 "	.14	.06	.26	.26	.62	.65	.76	.67	.58	.84
570 "	.07	.07	.22	.26	.73	.57	.87	.98	.52	.68
600 "	.07	.04	.21	.28	.58	.54	.89	.73	.57	.64
630 "	.04	.01	.26	.27	.54	.46	.73	.52	.54	.78
660 "	.05	.04	.22	.28	.28	.53	.80	.47	.53	.92
690 "	.07	.02	.34	.31	.49	.46	.87	.66	.52	.84
720 "	.04	.04	.33	.31	.54	.62	.87	.67	.64	1.22
750 "	.07	.12	.37	.26	.28	.44	.84	.78	.75	1.23
Average	.04	.06	.31	.25	.39	.46	.79	.68	.60	.93
Average of Replicates		.05		.28		.42		.73		.76

Table 8. Voltage readings at 30 second intervals of wheat kernels infested with 2, 5, 9, 13, and 18 immature rice weevils. Experiment performed July 15, 1953.

Interval of Readings	2 Replicate # 1	2 Replicate # 2	2 Replicate # 3	5 Replicate # 1	5 Replicate # 2	5 Replicate # 3	9 Replicate # 1	9 Replicate # 2	9 Replicate # 3	13 Replicate # 1	13 Replicate # 2	13 Replicate # 3	18 Replicate # 1	18 Replicate # 2	18 Replicate # 3
30 sec.	.03	.13	.66	.59	.28	.82	.24	.55	.58	1.28	.87	.36	2.45	1.83	1.18
60 "	0	.16	.41	.60	.58	.62	.25	.64	.44	1.68	1.23	.98	1.95	1.81	1.12
90 "	0	.04	.28	.59	.16	.86	.23	.57	.44	1.68	1.49	.74	1.93	1.58	1.52
120 "	.01	.06	.42	.64	.26	.72	.22	.82	.46	1.52	1.78	.63	2.94	1.54	1.10
150 "	.02	.02	1.02	.63	.28	.54	.23	.86	.76	1.33	1.81	.58	2.44	1.72	.97
180 "	.01	.03	.78	.58	.17	.47	.16	.58	.46	1.24	.98	.72	2.48	1.86	1.32
210 "	.02	.07	.78	.49	.17	.52	.23	.68	.44	1.02	.44	.74	2.12	1.96	1.46
240 "	.01	.06	.48	.55	.14	.63	.14	.67	.45	1.52	.46	.60	2.16	1.76	1.64
270 "	.02	.07	.67	.63	.17	.37	.24	1.07	.56	1.59	.32	.72	1.88	1.87	1.63
300 "	.01	.09	.61	.59	.47	.66	.17	1.12	.61	1.52	.31	.45	1.76	1.40	1.49
330 "	.03	.11	.96	.57	.48	.53	.08	1.34	.45	1.06	.19	.57	2.16	1.04	1.12
360 "	.02	.12	.59	.54	.37	.82	.09	1.11	.37	1.03	.17	.41	1.96	1.41	1.12
390 "	.01	.09	.58	.62	.29	.62	.19	.67	.49	1.26	.17	.34	1.67	1.67	1.32
420 "	0	.17	.57	.58	.36	.54	.16	.93	.64	1.36	.10	.62	1.96	1.58	1.62
450 "	0	.08	.77	.72	.28	.37	.14	.72	.53	1.03	.09	.48	1.93	1.57	1.46
480 "	.01	.14	.43	.73	.27	.36	.15	.55	.56	1.22	.12	.34	1.91	1.61	1.48
510 "	.02	.10	.47	.58	.42	.61	.16	.87	.49	1.36	.09	.36	2.14	1.60	1.28
540 "	.14	.08	.52	.62	.34	.73	.10	.88	.62	1.09	.09	.49	1.66	1.53	1.58
570 "	.15	.06	.42	.52	.36	.44	.24	.90	.33	1.26	.14	.59	2.22	1.63	1.43
600 "	.07	.04	.38	.50	.34	.59	.17	.77	.42	1.17	.14	.67	1.76	2.09	1.77
630 "	.04	.03	.37	.53	.47	.47	.23	.82	.29	1.52	.10	.88	1.37	2.09	1.18
660 "	.03	.04	.48	.58	.75	.67	.12	.93	.48	1.37	.22	1.12	1.56	2.06	1.92
690 "	.04	.03	.26	.63	.42	1.07	.09	.71	.96	1.36	.13	1.17	1.74	2.09	1.22
720 "	.12	.03	.16	.55	.47	.97	.09	.83	.72	1.26	.08	.97	1.48	1.92	1.18
750 "	.19	.02	.37	.57	.78	.71	.08	.47	.58	1.14	.09	.67	2.11	1.73	1.43
Average	.04	.07	.54	.59	.36	.63	.17	.80	.52	1.31	.46	.65	1.99	1.72	1.38
Average of Replicates		.22			.53			.50			.81			1.70	

Table 9. Voltage readings at 30 second intervals of wheat kernels infested with 2, 5, 9, 13, and 18 immature rice weevils. Experiment performed July 16, 1953.

Interval of Readings	Number of Weevils 2 Replicate # 1	2	3	5 Replicate # 1	2	3	9 Replicate # 1	2	3	13 Replicate # 1	2	3	18 Replicate # 1	2	3
30 sec.	0	.30	0	.13	.11	.92	.08	.36	.47	.72	.37	.48	.16	.56	.51
60 "	.04	.70	.02	.13	.13	.66	.38	.39	.62	.83	.58	.22	.31	.59	.52
90 "	0	.46	0	.20	.17	.32	.34	.48	.58	.52	.64	.38	.33	.49	.51
120 "	.02	.45	.01	.22	.13	.95	.52	.64	.67	.60	.50	.28	.36	.48	.61
150 "	0	.63	0	.09	.12	.58	.43	.53	.36	.34	.47	.38	1.52	.54	.60
180 "	0	.62	0	.10	.08	.48	.48	.92	.21	.30	.48	.42	.98	.67	.58
210 "	.01	.48	.06	.16	.06	.22	.62	.47	.22	.43	.42	.34	.69	.62	.68
240 "	.02	.34	.07	.04	.06	.26	.36	.39	.37	.51	.56	.27	.76	.81	.72
270 "	.01	.31	.03	.03	.06	.39	.54	.28	.42	.46	.60	.40	.47	1.02	.94
300 "	0	.29	.07	.13	.10	.72	.48	.42	.22	.53	.44	.49	.19	1.01	.92
330 "	0	.32	.04	.17	.14	.26	.27	.34	.43	.59	.47	.42	.24	1.23	.97
360 "	0	.24	.04	.07	.13	.26	.31	.67	.21	.61	.52	.48	.38	1.28	.62
390 "	.02	.36	.02	.01	.12	.14	.30	1.02	.32	.38	.77	.62	.29	1.06	.64
420 "	.03	.46	.03	.01	.08	.16	.36	.74	.43	.52	.87	.39	.44	1.08	.42
450 "	.06	.35	.02	.01	.08	.23	.60	.73	.36	.46	1.18	.46	.28	1.03	.44
480 "	.04	.32	.01	.07	.06	.72	.47	.46	.37	.42	1.04	.52	.52	.89	.43
510 "	.04	.30	.01	.06	.08	.46	.61	.62	.24	.38	.63	.53	.38	1.63	.60
540 "	.02	.38	.01	.04	.11	.28	.71	.43	.26	.53	.54	.54	.29	1.16	.58
570 "	.02	.34	.02	.03	.08	.25	.73	.44	.36	.43	.75	.58	.17	1.06	.74
600 "	.02	.46	.12	.02	.08	.49	.52	.42	.29	.26	.73	.43	.18	1.02	.62
630 "	.03	.38	.09	.02	.06	.36	.46	.44	.32	.18	.76	.38	.14	1.02	.62
660 "	.01	.34	.03	.02	.05	.52	.39	.73	.30	.42	.78	.38	.19	1.03	.54
690 "	.02	.44	.02	.02	.08	.18	.54	.54	.37	.29	.93	.39	.36	1.18	.64
720 "	.01	.61	.30	0	.08	.13	.43	.39	.45	.47	.76	.40	.37	1.16	.74
750 "	.01	.45	.06	.09	.08	.18	.57	.26	.49	.47	1.06	.42	.43	1.08	.68
Average	.02	.41	.04	.07	.09	.40	.46	.52	.37	.47	.67	.42	.42	.95	.63
Average of Replicates		.16			.19			.45			.52			.67	

Table 10. Voltage readings at 30 second intervals of wheat kernels infested with 2, 5, 9, 13, and 18 immature rice weevils. Experiment performed July 17, 1953.

Interval of Readings	Number of Weevils: 2, Replicate # 1	2	3	5, Replicate # 1	2	3	9, Replicate # 1	2	3	13, Replicate # 1	2	3	18, Replicate # 1	2	3
30 sec.	.14	.06	.22	.33	.34	.06	.34	.61	.27	.46	.55	.50	.34	2.12	.76
60 "	.11	.03	.15	.42	.20	.20	.30	.28	.30	.63	.75	.60	.22	1.61	.74
90 "	.15	.02	.30	.18	.30	.10	.13	.24	.30	.53	1.02	.78	.18	1.26	.58
120 "	.14	.04	.24	.14	.25	.08	.38	.25	.17	.50	.73	.92	.62	1.24	.53
150 "	.17	.05	.26	.21	.32	.08	.19	.17	.12	.65	.36	.56	.40	1.68	.59
180 "	.09	.04	.21	.15	.33	.01	.25	.13	.15	.73	.38	.58	.29	1.33	.52
210 "	.09	.02	.25	.07	.16	.08	.12	.35	.47	.42	.47	.68	.18	1.10	.69
240 "	.17	.02	.20	.12	.14	.05	.21	.23	.23	.29	.68	.60	.18	.98	.60
270 "	.18	.03	.22	.16	.64	.07	.28	.07	.17	.44	.81	.56	.12	.82	.62
300 "	.42	.02	.24	.13	.42	.27	.19	.07	.20	.34	.63	.61	.16	.84	.68
330 "	.48	.02	.17	.17	.34	.14	.17	.54	.15	.44	.81	.41	.22	.93	.56
360 "	.42	.02	.22	.12	.22	.04	.24	.82	.25	.28	.62	.37	.23	.68	.62
390 "	.33	.03	.20	.32	.44	.02	.34	.30	.15	.25	.92	.44	.14	.61	.54
420 "	.19	.02	.23	.28	.60	.06	.37	.60	.15	.25	.66	.41	.26	.72	.72
450 "	.06	.02	.29	.06	.52	.04	.16	.56	.18	.23	.67	.57	.14	1.07	.52
480 "	.14	.03	.24	.10	.43	.07	.19	.26	.13	.75	.60	.40	.15	1.21	.64
510 "	.17	.01	.19	.08	.30	.09	.13	.22	.13	.28	.59	.35	.16	.94	.57
540 "	.32	.02	.27	.06	.45	0	.14	.19	.15	.31	.48	.35	.23	1.16	.73
570 "	.12	.01	.24	.34	.26	.62	.09	.28	.06	.55	.40	.37	.22	1.07	.60
600 "	.13	.01	.24	.92	.14	.29	.98	.31	.07	.68	.62	.35	.16	1.02	.65
630 "	.17	.02	.25	1.03	.19	.06	.28	.28	.06	.67	.62	.44	.15	.86	.48
660 "	.13	.02	.12	.94	.24	.06	.11	.26	.06	.65	.53	.52	.14	1.05	.50
690 "	.24	.04	.11	.66	.20	.03	.06	1.18	.07	.64	.42	.31	.18	.72	.52
720 "	.20	.02	.20	.62	.36	.05	.07	.96	.14	.88	.45	.19	.07	.83	.48
750 "	.08	.06	.12	.66	.43	1.10	.05	.67	.12	.98	.62	.31	.06	1.03	.37
Average	.19	.03	.21	.33	.33	.15	.23	.39	.17	.51	.62	.49	.21	1.07	.59
Average of Replicates		.14			.27			.26			.54			.62	

Table 11. Voltage readings at 30 second intervals of wheat kernels infested with 2, 5, 9, 13, and 18 immature rice weevils. Experiment performed July 18, 1953.

Interval of Readings	2 Replicate # 1	2 Replicate # 2	5 Replicate # 1	5 Replicate # 2	9 Replicate # 1	9 Replicate # 2	13 Replicate # 1	13 Replicate # 2	18 Replicate # 1	18 Replicate # 2
30 sec.	.24	.06	.04	.16	.09	.24	1.20	.84	.47	.62
60 "	0	.90	.08	.12	.18	.31	.67	.55	.35	.82
90 "	0	.39	.04	.09	.85	.14	.43	.60	.39	.85
120 "	0	.10	.06	.05	1.06	.05	.34	.84	.42	.73
150 "	.13	.03	.07	.07	.42	.06	.56	.56	.48	.76
180 "	.02	.07	.02	.02	.22	.23	.48	.53	.52	.92
210 "	0	.06	.02	.01	.24	.20	.48	.25	.63	.63
240 "	.25	.03	.01	.02	.13	.10	.42	.30	.48	.46
270 "	.04	.02	0	.07	.12	1.06	.63	.42	.32	.64
300 "	0	.01	.01	.04	.23	.10	.52	.45	.44	.53
330 "	.24	.01	.07	.03	.19	.20	.42	.45	.32	.42
360 "	.02	.03	.02	.07	.14	.07	.98	.32	.43	.45
390 "	.02	0	.01	.06	.06	.12	.65	.27	.67	.47
420 "	.04	.01	0	.36	.08	.06	.74	.52	.67	.28
450 "	0	.02	0	.27	.26	.10	.87	.50	.42	.77
480 "	.24	.03	.04	.31	.32	.05	.56	.44	.51	.47
510 "	.02	.18	.03	.11	.26	.09	.52	.65	.58	.57
540 "	1.80	.19	.04	.05	.09	.13	.62	.39	.75	.52
570 "	.40	.05	.05	.02	.11	.20	.46	.54	1.80	.61
600 "	.08	0	.56	0	.28	.31	.82	.55	1.32	.64
630 "	.01	0	.28	.01	.23	.10	.62	.61	.75	.72
660 "	0	.04	.16	0	.08	.65	.55	.32	.56	1.04
690 "	0	.06	.19	.02	.46	.25	.44	.14	.62	.76
720 "	0	.03	.07	.02	.27	.31	.34	.24	.44	.70
750 "	0	.06	.02	.03	.33	.09	.39	.25	.82	.83
Average	.14	.09	.08	.08	.27	.17	.59	.46	.61	.65
Average of Replicates		.11		.08		.22		.52		.63

Table 12. Voltage readings at 30 second intervals of wheat kernels infested with 2, 5, 9, 13, and 18 immature rice weevils. Experiment performed July 20, 1953.

Interval of Readings	Number of Weevils: 2 Replicate # 1	2	3	5 Replicate # 1	2	3	9 Replicate # 1	2	3	13 Replicate # 1	2	3	18 Replicate # 1	2	3
30 sec.	.04	.06	0	.02	.60	.04	.06	.09	.30	.17	1.12	.07	.12	.37	.42
60 "	.04	.09	0	.03	1.05	.08	.04	.11	.29	.36	.66	.15	.35	.44	.66
90 "	.05	.14	0	0	.38	.05	.04	.13	.26	.12	.62	.17	.19	.24	.42
120 "	.04	.08	.09	0	.40	.02	.16	.11	.17	.16	.50	.23	.15	.57	.85
150 "	.03	.09	.03	.16	.45	.06	.12	.13	.15	.21	.39	.26	.09	.28	2.10
180 "	.02	.29	0	.13	.55	.02	.17	.09	.18	.12	.46	.32	.05	.94	.80
210 "	.04	.09	0	.14	.25	.02	.13	.06	.23	.27	.52	.33	.22	.57	.68
240 "	.03	.06	0	.10	.16	.05	.12	.04	.19	.34	.47	.45	.07	.67	.46
270 "	.02	.05	0	.08	.06	.02	.06	.05	.16	.14	.38	.35	.06	.53	.61
300 "	.02	.04	0	.09	.41	.01	.05	.03	.21	.23	.21	.95	.08	.60	.38
330 "	.09	.04	0	.10	.34	.15	.07	.02	.23	.15	.31	.55	.03	.62	.32
360 "	.13	.04	0	.09	.25	.07	.17	.12	.17	.07	.26	.25	.02	.85	.31
390 "	.15	.05	0	.07	.50	.04	.10	.15	.13	.17	.55	.34	.16	.72	.34
420 "	.09	.05	0	.15	.85	.02	.07	.09	.15	.14	.62	.25	.20	.76	.34
450 "	.05	.33	.01	.26	.40	.05	.04	.20	.13	.14	.40	.24	.16	.87	.41
480 "	.09	.05	0	.13	.47	.03	.08	.20	.15	.17	.51	.22	.23	.61	.36
510 "	.06	.03	0	.17	.48	.70	.11	.17	.13	.15	.58	.40	.06	.51	.26
540 "	.11	.06	0	.12	.27	.40	.36	.16	.14	.18	.95	.30	.08	.60	.27
570 "	.09	.03	0	.15	.18	.09	.15	.14	.27	.16	.92	.22	.42	.40	.32
600 "	.11	0	0	.22	.34	.06	.09	.08	.11	.18	.67	.19	.26	.43	.65
630 "	.06	.01	0	.27	.24	.06	.04	.05	.04	.58	.59	.13	.19	.45	.40
660 "	.16	.04	.01	.27	.28	.11	.04	.18	.09	.34	.37	.17	.17	.32	.42
690 "	.19	.04	0	.65	.22	.08	.04	.07	.12	.18	.68	.22	.27	.62	.73
720 "	.12	.06	0	.35	.34	.03	.05	.08	.09	.18	.97	.22	.29	.47	.52
750 "	.11	.01	0	.60	.22	.01	.15	.12	.11	.18	.81	.18	.23	.60	.42
Average	.08	.07	.01	.17	.39	.09	.10	.11	.17	.20	.58	.29	.17	.56	.54
Average of Replicates		.05			.22			.13			.36			.42	

Table 13. Voltage readings at 30 second intervals of wheat kernels infested with 2, 5, 9, 13, and 18 immature rice weevils. Experiment performed July 21, 1953.

Interval of Readings	Number of Weevils: 2			5			9			13			18		
	Replicate #			Replicate #			Replicate #			Replicate #			Replicate #		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
30 sec.	.01	.11	.16	.52	.28	.07	.10	.27	.58	.06	.04	2.02	.14	1.24	.42
60 "	0	.13	.05	.46	.42	.09	.18	.14	.45	.15	.02	1.28	.58	1.22	.41
90 "	0	.08	.09	.67	.31	.08	.68	.50	.44	.22	.02	1.05	.34	.88	.43
120 "	0	.06	.03	.65	.42	.06	1.05	.23	.73	.35	.14	.84	1.12	.54	.40
150 "	0	.09	.01	.64	.47	.08	.88	.37	.62	.50	.07	1.03	.89	.97	.62
180 "	.02	.14	.02	.36	1.00	.04	.58	.26	.45	.63	.02	.58	.45	.63	.48
210 "	0	.08	.09	.64	.72	.05	.38	.83	.52	.25	.01	.65	.87	.54	.46
240 "	0	.08	.08	1.22	.49	.02	.72	.43	.30	.28	0	.82	.44	.42	.44
270 "	0	.06	.03	.84	.37	.07	.60	.65	.30	.32	0	.59	.28	.52	.32
300 "	.03	.06	.02	.81	.65	.05	.53	.96	.22	.34	.02	.57	.48	.45	.72
330 "	.01	.08	.02	.65	.60	.12	.88	.72	.18	.33	.15	.68	1.34	.65	.65
360 "	0	.05	0	.55	.48	.10	.65	.57	.29	.29	.08	.55	.72	.83	.60
390 "	0	.04	0	.51	.57	.08	1.44	.53	.27	.29	.06	.86	.35	.76	.53
420 "	.01	.04	0	.59	.44	.04	1.82	.87	.38	.24	.04	.75	.44	1.13	.46
450 "	.01	.05	0	.60	.64	.04	1.33	1.31	.28	.16	.14	.26	.30	1.06	.41
480 "	0	.09	0	.36	.82	.07	.62	.78	.38	.15	.04	.14	.25	.77	.57
510 "	0	.09	0	.25	.78	.03	.58	.82	.32	.18	.02	.46	.75	1.03	.32
540 "	0	.28	.07	.45	.82	.04	.51	1.35	.17	.44	.28	.82	.95	.90	.35
570 "	.02	.13	.02	.30	.75	.02	.56	.89	.22	.32	.09	.67	.63	.52	.32
600 "	.02	.10	.01	.19	.82	.07	.62	.48	.38	.42	.07	.34	.97	.38	.47
630 "	.01	.07	.04	.25	.89	.03	.18	.52	.27	.98	1.02	.28	.82	.29	.41
660 "	0	.08	.01	.20	.86	.10	.21	.40	.26	.58	.95	.26	.74	.50	.42
690 "	0	.05	0	.23	.47	.12	.38	.23	.24	.28	.26	.21	.34	.37	.47
720 "	0	.08	.01	.36	.49	.04	.67	.24	.28	.50	.07	.62	.16	.27	.48
750 "	.01	.12	0	.30	.55	.04	.52	.66	.28	.32	.05	.60	1.10	.40	.23
Average	.01	.09	.03	.50	.60	.06	.67	.60	.35	.34	.15	.68	.62	.69	.46
Average of Replicates		.04			.39			.54			.39			.59	

Table 14. Voltage readings at 30 second intervals of wheat kernels infested with 2, 5, 9, 13, and 18 immature rice weevils. Experiment performed July 22, 1953.

Interval of Readings	Number of Weevils: 2, Replicate # 1	2, Rep. 2	2, Rep. 3	5, Rep. 1	5, Rep. 2	5, Rep. 3	9, Rep. 1	9, Rep. 2	9, Rep. 3	13, Rep. 1	13, Rep. 2	13, Rep. 3	18, Rep. 1	18, Rep. 2	18, Rep. 3
30 sec.	0	.02	0	.24	.03	.14	.54	.04	.17	.49	1.41	.55	1.91	.61	1.08
60 "	0	.02	0	.15	.01	.15	.50	.07	.27	.50	.90	.36	2.05	.64	.73
90 "	0	.02	0	.25	.01	.14	.60	.02	.24	.43	1.25	.37	1.03	.65	1.82
120 "	0	.01	0	.21	.01	.17	.53	.02	.18	.37	1.03	.26	.66	.53	.84
150 "	0	.01	0	.34	.02	.13	.22	.02	.17	.27	1.02	.68	.54	.38	.91
180 "	0	.01	0	.24	.02	.13	.15	.07	.17	.27	.97	.61	.34	.48	.52
210 "	0	.02	0	.11	.02	.17	.17	.02	.17	.24	.67	.44	.28	.47	.49
240 "	0	.03	0	.10	.01	.18	.14	.37	.27	.25	.70	.51	.50	.69	.47
270 "	.02	.02	.03	.08	.02	.24	.23	.14	.27	.23	.82	.34	.44	.62	.47
300 "	0	0	0	.12	.02	.19	.21	.06	.23	.19	.72	.25	.57	.50	.68
330 "	0	.01	0	.13	.02	.14	.20	.04	.26	.27	.86	.61	.54	.52	.50
360 "	0	.01	0	.16	0	.11	.23	.17	.24	.17	.98	.42	.34	.62	.67
390 "	0	0	0	.24	0	.15	.45	.05	.25	.14	.60	.25	.52	.62	1.24
420 "	0	0	0	.19	0	.18	.22	.04	.19	.37	.67	.14	.52	.46	.75
450 "	.02	0	0	.08	.01	.17	.14	.25	.19	.34	.67	.13	.62	.42	.86
480 "	0	0	0	.04	.01	.23	.48	.07	.16	.28	.87	.32	.64	.62	.57
510 "	0	.02	0	.02	.01	.17	.42	.06	.17	.32	.69	.19	.52	.72	.56
540 "	0	.01	0	.13	.01	.18	.25	.35	.17	.28	.74	.50	.66	.43	.53
570 "	0	.02	0	.05	.01	.14	.25	.24	.17	.23	1.01	.30	.72	.32	.48
600 "	0	0	0	.06	.02	.13	.75	.07	.20	.20	.58	.21	.94	.34	.85
630 "	0	.02	.01	.09	.02	.18	.65	.45	.26	.94	.76	.18	.75	.17	.74
660 "	0	.02	.02	.14	.02	.25	.33	.38	.19	.42	.54	.12	1.07	.17	.50
690 "	0	.03	0	.09	.02	.27	.57	.28	.20	.21	.74	.22	.82	.37	.42
720 "	0	.03	.03	.09	.02	.37	.29	.18	.15	.27	.64	.12	.80	.24	.45
750 "	0	.02	0	.12	.01	.32	.33	.25	.18	.13	.75	.27	1.07	.27	.52
Average	0	.01	0	.14	.01	.18	.35	.15	.20	.31	.82	.33	.75	.47	.71
Average of Replicates		0			.11			.23			.49			.64	

4. The volume of noise caused by varying numbers of immature rice weevils in wheat could be read as a definite number of volts on a voltmeter.

5. Analysis of the data collected indicated there must have been a close linear relationship between the degree of infestation of wheat by immature rice weevils of the same age and the volume of sound measured as average volts on a voltmeter.

6. An analysis of variability between and within samples of the same age and same degree of infestation suggests that the number of samples used in this study be reduced and the number of readings per sample used in this study be increased in any future studies of this nature.

7. Results of the analysis of variability indicated that apparently these insects made the same volume of noise over a period of time for the same degree of infestation and age level but that they did so sporadically.

8. It was observed that the estimated variance within samples increased with age for a given degree of infestation. This would indicate that the insects became more active as they grew older.

SUMMARY

Experiments were conducted in an attempt to define the limitations and usefulness of audio amplification in research concerning internal infesting species of insects in stored grain.

These experiments utilized a cathode ray oscilloscope, a sound proof box designed to exclude extraneous noises caused by electrical circuits and mechanical vibrations, a crystal microphone, a high gain audio amplifier, a clipper circuit, and a vacuum tube voltmeter.

Visual interpretations, utilizing the oscilloscope, of the waveforms of the sound patterns caused by various numbers of immature rice weevils in hard red winter wheat indicated that a mechanical method of interpreting these sounds would lead to positive results.

As a result of information gained from experiments utilizing the oscilloscope as a means of interpreting the sound patterns caused by immature stages of the rice weevil, the long time constant average reading meter method of determining the average value of the waveform peaks was utilized.

The sounds caused by the insects observed were not believed to be sounds resulting from the normal movements and functions of morphological structures of the rice weevil, but were thought to be accidental sounds associated with normal insect behavior while feeding and moving.

It was found that the noises created by the larvae were not of sufficient volume to be distinguished from the background noise until the larvae had begun the third larval instar.

Data collected indicated that the volume of noise created by varying numbers of larvae of the rice weevil, of the same age, was approximately linearly related to the degree of infestation, i.e., the number of insects per sample. This presumption was verified by computing the product moment coefficients of linear correlation for each day's data.

An analysis of variability between and within samples of wheat containing weevils of the same age and the same degree of infestation showed that the variability from reading to reading within the same sample was invariably much greater than between different samples of the same age and same degree of infestation. This would indicate that apparently these insects made about the same volume of noise over a period of time for the same degree of infestation and with a given age level, but they did so sporadically. This suggests that, when future studies of this type are performed, the number of samples (25) should be reduced and the number of readings per sample (3) should be increased.

ACKNOWLEDGMENTS

The writer wishes to express his appreciation to Prof. Donald A. Wilbur for his guidance and help during the course of this research and in the preparation of this manuscript.

Grateful acknowledgments are made to the administrators Dr. R. C. Smith, Dr. Herbert Knutson, R. G. Kloeffler and Dr. J. A. Shellenberger for their help, interest and for providing facilities.

Sincere appreciation is extended to Prof. J. E. Wolfe, Robert E. Adams, Dr. Max Milner and Dr. Paul A. Dahm for their invaluable advice, help, and encouragement during the course of this work.

Heartfelt appreciation is extended to the writer's wife, Grace, for her forbearance and constant encouragement during the continuation of this work.

BIBLIOGRAPHY

Adams, Robert E.
The aural detection of the larvae of wheat. Unpublished Master of Science Thesis, Kansas State College, Manhattan, Kansas, 1953.

Barton, R. C.
In Termites and termite control. Berkeley, California: University of California Press. 1934. p. 711-714.

Brain, Charles K.
Preliminary notes on the adaptation of certain radio principles to insect investigation work. Annals of the University of Stellenbosch. 2 Sec. A(2):45-47. July, 1924.

Brett, Charles
An electrically regulated humidity control. Jour. Econ. Ent. 37(4):552-553. August, 1944.

Colebrook, F. M.
The aural detection of the larvae of insects in timber. Jour. Scientific Instruments. 14:119-121. April, 1937.

Emerson, A. E. and R. C. Simpson
Apparatus for the detection of substratum communication among termites. Science n.s. 69(1799):648-649. 1929.

Escherich, K.
Hunting for ants with a telephone. In The Outlook. 97:853-855. April 22, 1911.

Frankenfeld, J. C.
Staining methods for detecting weevil infestation in grain. U. S. Dept. Agr. ET-256. July, 1948.

Milner, Max, Milford R. Lee and Robert Katz
Application of x-ray technique to the detection of internal insect infestation of grain. Jour. Econ. Ent. 43(6):933-935. December, 1950.

Schwarz, L., Kranz and Sicke
A sound amplifier for the detection of infestations by the house beetle (In German). Deutsche Bauzeitung. Heft 20:392-393. May 15, 1935.

Snyder, Thomas E.
Detection of termites by microphone. Pest Control. 20(7):33-34. July, 1952.

DETECTION OF IMMATURE RICE WEEVILS, <u>SITOPHILUS ORYZAE</u> L. (CURCULIONIDAE, COLEOPTERA), BY AUDIO AMPLIFICATION

by

GEORGE ROBERT PESHO

B.S., Colorado Agricultural and Mechanical College, 1952

AN ABSTRACT OF A THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Entomology

KANSAS STATE COLLEGE
OF AGRICULTURE AND APPLIED SCIENCE

1954

From 1911 to the present time reports concerning the use of audio amplification as a means of detecting the presence of insects in wood and in grain have appeared in the literature at irregular intervals. By audio amplification is meant the amplification, by means of electrical devices, of those sounds which are within the human auditory range.

The work herein reported was designed to attempt to determine the usefulness of audio amplification in those problems encountered in research concerning internal infesting species of insects in stored grain. These experiments were an attempt to define the limitation of audio amplification in such research, i.e., the nature of the sound caused by the insects, the age at which the experimental insects first could be detected in grain, and relationships between the number of insects present in a given sample of grain and the amount of sound caused by these insects.

All experiments utilized the rice weevil, Sitophilus oryzae L., as the test insect. The experimental insects were reared in hard red winter wheat. Infested kernels were selected by means of X-ray photographs. Radiographic examination of the infested grain caused no stimulating or inhibiting effects upon the insects so examined.

A sound proof box was used to eliminate extraneous noises caused by mechanical vibrations and electrical systems within the vicinity of the equipment used in these studies. The sound proof box contained the microphone and was effective in eliminating all but those sounds of lower frequency corresponding to the resonant frequency of the box itself. A Western Electric hearing aid microphone of the crystal type was used. The sound of the insects within the kernel of wheat was not sent through the air as a series of air waves but was conducted through the wheat and microphone parts as a series of mechanical vibrations, necessitating contact of the infested grain with the microphone. A four tube high gain audio amplifier which utilized a low noise triode input stage was used. The voltage gain and frequency response of the amplifier was checked and thought to be satisfactory.

Preliminary experiments utilizing an oscilloscope indicated that the pattern of sound made by a given number of immature rice weevils of the same age followed a recognizable and seemingly definite pattern. In order to record and interpret these sound patterns on a purely mechanical basis and to assign numerical values, in terms of volts, to them a long time constant average reading meter was used. This meter measured the average value in volts of the peaks of the waveforms of the sound produced by the insects.

Because the infested kernels had to be placed on the microphone which was housed in the sound proof box, it was not possible to observe the insects visually and thus identify the sounds produced by the insects.

Be means of the sound proof box, it was possible to eliminate extraneous noises. It was not possible to eliminate background noises by use of the sound proof box, that is, those noises generated by the component parts of the amplifier and accompanying circuits. In order to eliminate the background noise, a clipper circuit was incorporated with the long time constant average reading meter.

Fifty wheat kernels containing immature rice weevils of the same age were selected at random by means of X-ray photographs. Two of these kernels were chosen at random and placed on the dust cover of the microphone. Readings of the average value of the sound caused by these two insects were made and recorded. The readings represented the voltage indicated on the voltmeter at each of 25 thirty-second intervals, or a total observational period of 12.5 minutes per sample. At the end of the observational period these two kernels were removed from the microphone. The same procedure was repeated and replicated three times for each of the following number of infested kernels: 2, 5, 9, 13 and 18. Readings were repeated daily, as the insects matured, from the time it was possible to detect the noises made by the larvae in a sample consisting of two infested kernels until the first adult emerged from the original sample of 50 infested kernels. Each of the 50 infested kernels contained only one larva per kernel. The entire lot of 50 kernels was X-rayed at weekly intervals in order to be sure that the insects had remained alive.

The sounds caused by the insects observed were not believed to be sound resulting from the normal movements and functions of morphological structures of the rice weevil, but were thought to be accidental sounds associated with normal insect behavior while feeding and moving.

It was found that the noises created by the larvae were not of sufficient volume to be distinguished from the background noise until the larvae had begun the third larval instar.

Data collected indicated that the volume of noise created by varying numbers of larvae of the rice weevil, of the same age, was approximately linearly related to the degree of infestation, i.e., the number of insects per sample. This presumption was verified by computing the product moment coefficients of linear correlation for each day's data.

An analysis of variability between and within samples of wheat containing weevils of the same age and the same degree of infestation showed that the variability from reading to reading within the same sample was invariably much greater than between different samples of the same age and same degree of infestation. This would indicate that apparently these insects made about the same volume of noise over a period of time for the same degree of infestation and with a given age level, but they did so sporadically. This suggests that, when future studies of this type are performed, the number of samples (25) should be reduced and the number of readings per sample (3) should be increased.