RESPONSE OF HORNWORM MOTHS TO MONOCHROMATIC RADIATION IN THE VISIBLE AND NEAR ULTRAVIOLET SPECTRUM

BY

Jesse J. Lam, Jr.

Thesis Submitted to the Graduate Faculty of the

Virginia Polytechnic Institute

in Candidacy for the Degree of

MASTER OF SCIENCE

in

Agricultural Engineering

June 1964

Blacksburg, Virginia

TABLE OF CONTENTS

List of Figures

List of Tables

INTRODUCTION

Damage to tobacco, caused by the tobacco hornworm (*Protoparce sexta* (Johan.)) and the tomato hornworm (*P. quinquemaculata* (Haw.)), has been costly to tobacco growers. The estimated annual loss for the year of 1944, due to the tobacco hornworm alone, was placed at 84,073,000 dollars (10).*

The objectionable stage in the life cycle of the insect is the leaf-eating larva which often seriously damages several leaves (7). In addition to tobacco, these insects attack tomatoes, eggplants, peppers, and potatoes. The damages to these crops add materially to the total losses caused by these pests (18, 13).

Both species are nocturnal and abundant throughout the tobacco growing areas of the United States. The tobacco hornworm occurs over the greater part of the United States, West Indies, Mexico, Central America, and parts of South America (13). The tomato hornworms are found from Florida to Canada (18).

Both species are similar in appearance and habits. The female deposits spherical greenish-yellow eggs, one in a place, on the lower side of the leaves. Larvae hatch in about a week, and feed for three or four weeks. Full-grown larvae, three to four inches long, dig into the soil three or more inches and change to pupae (13,18). In warm climates the pupal stage may last only about three weeks. In the South three generations of hornworms develop during the summer. In Virginia the third generation is usually insignificant. Late summer or early

---

*Numbers in parenthesis refer to Bibliography fall pupae go through the following winter before they transform into moths. Winter conditions ordinarily kill approximately 75 percent of the over-wintering pupae (7).

Early attempts to control hornworm moths with light traps were largely unsuccessful. One limitation is thought to be the lack of a suitable radiant energy source, although trap design may be an important factor. Recent studies (12), on an area coverage, indicate that light traps significantly reduced hornworm damage to tobacco. This fact gives increased impetus to the importance of a study of energy sources in an effort to make them more effective as attractants in light traps. Numerous lamps covering a spectral range from the ultraviolet into the infrared region are available. However, it is not known which energy bands, if any, are most attractive to the hornworm moth.

Studies have shown that the hornworm moth apparently is more responsive to the near ultraviolet than to the visible spectrum (2, 11, 16, 22, 23). However, much of the work was exploratory in nature and the number of moths tested under a single set of conditions was too small to produce meaningful results.

Motivated by the apparent successful use of light traps on an area basis, with more refined techniques and instruments available, with a somewhat better insight into the problem statistically, and with an appreciation of the acuteness of the chemical residue problem, this study of the influence of narrow bands of radiant energy on hornworm moths was undertaken.

LITERATURE REVIEW

Numerous investigators have studied the effects of environmental factors on the behavior of insects. These factors include radiant energy (wavelength and intensity), temperature, relative humidity, air currents or wind velocity, barometric pressure, and others. Of these, the effect of radiant energy on insects has probably been studied most.

According to Frost (6), reports concerning observations of insects about light traps were published as early as 1835. He indicated that many attempts have been made to control injurious insects with lights in Europe, China, Japan, Trinidad, and elsewhere, but the results were not successful due largely to ineffective light sources.

Investigators (9, 26, 27, 28) have found, by field or laboratory studies, that many insects are attracted more by radiant energy in the near-ultraviolet and violet (3200 - 4300 Angstroms) than to other regions of the spectrum. Marshall and Hienton (14) reported in 1938 that light traps using sources emitting larger amounts of ultraviolet energy were more attractive to the codling moth. Weiss, et al, (31) found, in 1942, that the largest numbers of most of the species tested reacted positively to 3650 - 3663 A. Pfrimmer (20) reported in 1955 that a BLB (blacklight blue) fluorescent lamp attracted twice as many insects as a trap using a BL (blacklight) fluorescent lamp and twelve and one-half times as many as a trap using Argon lamps.

Laboratory studies (2, 11, 23, 25) indicate that the hornworm moth responds best to energy in the near ultraviolet (3200 - 4000 A.)

region. However, it is not known exactly which part of the near ultraviolet is most attractive.

Merkl and Pfrimmer (17) reported in 1955 that in a field study 59 percent of the tobacco hornworm moths caught in traps preferred a blacklight fluorescent lamp compared to a mercury-vapor lamp, while 71 percent of the tomato hornworm moths preferred the mercury-vapor lamp.

Work has been done in an attempt to find a band of radiant energy which would be most attractive to the tobacco and tomato hornworm moth. Kent (11) found no difference in response to energy bands 100 A. wide centered at 3200, 3300, 3400, 3500, 3600, 3700, 3800, and 3900 A. Raju (23) found the response of hornworm moths to 100 A. wide energy bands in the 3100 to 3800 A. range to be erratic. He was unable to establish significant differences in responses to any of the energy bands. Pruitt (22) exposed hornworm moths to energy bands 100 A. wide centered at 3050, 3150, 3250, 3350, 3450, 3550, 3650, and 3750 A. and found no significant difference in responses to the treatments. Menear (16) irradiated hornworm moths with energy bands 100 A. wide centered at 2550, 3150, 3350, 3550, 3750, 3950, 4150, 4350, and 4550 A. He concluded that reaction was greatest at 3150 A. and least at 4350 A. Raju (23) also found what appeared to be good response to irradiations in the vicinity of 3150 A. None of these studies had the refinement necessary to qualify them to be statistically meaningful.

The effects of the intensity of radiant energy on insect response is not generally agreed upon. In 1938, Marshall and Hienton (14) concluded that three things influence the attractiveness of light to codling moth; namely, intrinsic brilliance, the size of the luminous area, and the color. Weiss, et al, (29) reported in 1945 that unattractive wavelengths may be made attractive by increasing their intensity. That is, it was possible to vary the behavior pattern of the insect by varying intensity of radiation, Weiss (30) later concluded in 1946 that brilliance or intensity is probably more important than wavelength in initiating responses. Taylor, Deay, and Orem (28) reported that the corn borer moth was slightly more attracted to increased light intensity.

In 1954, Frost (5) reported that more moths were attracted to blacklight than to white* light regardless of intensity or position of the trap. Miller (19) reported in 1957 that two 15-watt BL, one 15-watt BL, and a combination of a 15-watt BL and 15-watt green were equally attractive from the viewpoint of the number of species collected. Raju (23) found little response of the hornworm moth to irradiation at intensity levels below 10 units. Kent (11), in 1958, observed little difference in response of hornworm moths when using intensities within a range of 1.25 to 80 measuring units.

The effects of temperature and relative humidity on insect response are not clear. Weiss, et al, (30, 31), Merkl and Pfrimmer (17), and Byer (3) reported that insect catches in light traps were influenced by temperature and relative humidity. Mazokhin (15) observed mass flights of insects on quiet, warm, and cloudy nights. Glick and Hollingsworth (8) found fewer pink bollworm moths collected in field traps when the

*Terminology used by Frost

temperature was below 60°F. Carruth and Kerr (4) found light trap catches of the corn earworm moth to be appreciably reduced by a mean night temperature of 60°F. or below. During laboratory studies, Bell (2), Kent (11), and Raju (23) detected no significant effect of temperature in the range of 75° to 89°F., or relative humidity within 40 to 75 percent, on hornworm responses to wavebands of radiant energy. Menear (16) also found no effect on response of hornworm moths due to temperature in the range of 60° to 80°F.

Stirrett (27) placed the optimum temperature for European corn borer response to radiant energy at 70°F. Menear (16) concluded that some studies indicate an optimum temperature for maximum response of the hornworm moth to be between 65° and 80°F. In view of these reports, it appeared advisable to control the temperature at 75°F. in this study.

Although sexes of the tobacco hornworm moth occur approximately equal in nature (13), field studies (1, 24) show a female catch of only 20 to 25 percent of the total catch in light traps.

Stanley and Dominick (25) found in a three year study, that only 17.9 percent of the tobacco hornworm moths caught in light traps were females while an overall average of 45.8 percent of the tomato hornworm moths caught were females. Bell (2), Kent (11), Pruitt (22), and Menear (16) were unable to establish differences in the response of the two sexes of hornworm moths to various wavelengths of light in laboratory tests.

OBJECTIVE

The objective of this investigation was to study the response of tobacco and tomato hornworm moths to selected narrow bands of radiant energy in the visible and near-ultraviolet spectrum.

FACILITIES

The following major items of equipment were used in the investigation:

1. Grating Monochromator: Bausch and Lomb 33-86-40, 250 mm focal length, 50 mm x 50 mm grating area with 600 grooves per mm., range of 2,000-14,000 A. (first order).
2. Mercury-vapor lamp: General Electric, H4GS, Par-38, 100-watt.
3. Photometer: Photovolt model 520-A, with a 1P28 photomultiplier tube as a transducer.
4. Infrared scope and power supply: U. S. Army surplus model MI.
5. Hygrothermograph: Friez Instrument, model 594.
6. Precision Potentiometer: Rubicon Company.
7. Fan: Redmond Company, model 8704, type L.
8. Transformer: Constant-voltage output, No. 892961.
9. Psychrometer: Friez Instrument, Catalog No. 573.
10. Air Conditioner: one-ton capacity.
11. Humidifying Unit: Standard Engineering Works, model 42-L, with humidistat, model 32-W.
12. Testing chamber: 4 ft. x 4 ft. x 7 ft. high, constructed of Masonite-fiberboard.

A sketch showing the relative positions of the equipment during the tests is shown in Figure 1.

Equipment for this investigation was available and only minor adjustment and calibration were required. The study was conducted in an air conditioned room as described by Menear (16).

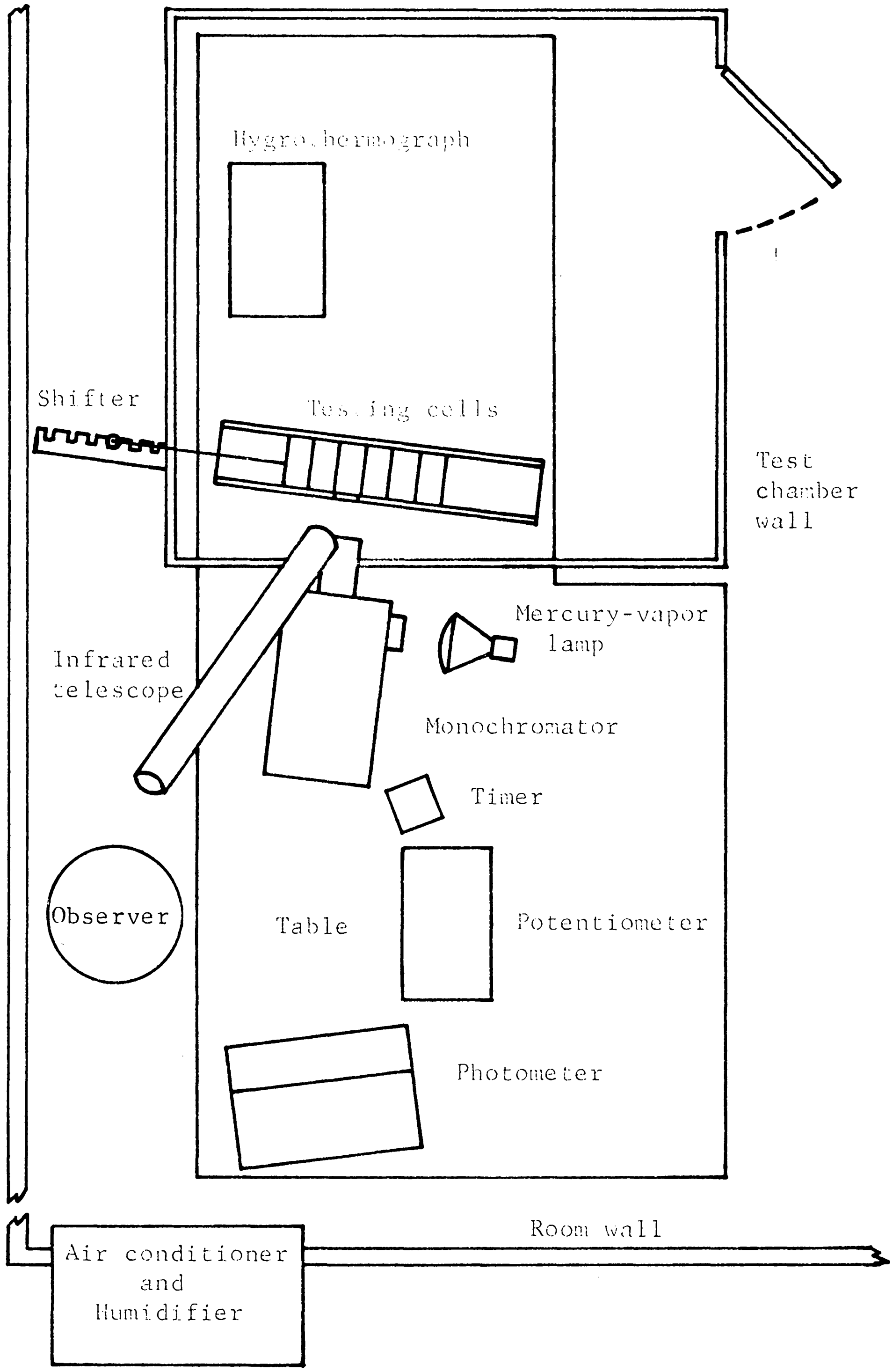

Figure 1 - Position of equipment used in the investigation.

The temperature and relative humidity within the light-tight, test chamber were controlled at 75°F. (± 2°) and 80% (± 15%) respectively. Temperature and relative humidity were continuously recorded with a hygrothermograph which was calibrated daily with a motor driven psychrometer. A thermocouple mounted near the test cell block was used to verify chamber temperature during tests.

A block of six testing cells (Figure 2) as described by Menear (16) was used to hold the moths during tests.

A General Electric, H4GS, PAR-38, 100-watt mercury-vapor lamp, was used as an input energy source to a Bausch and Lomb 33-86-40 grating monochromator. The lamp was energized at least 20 minutes before a test began. Voltage input to the lamp was measured with a vacuum-tube voltmeter. A small fan directed cooling air over the bulb during operation. Through a cylindrical tube embedded in the chamber wall, the monochromator output was beamed toward the quartz window (Figure 3) in the cell block.

The input and output slit openings of the monochromator were adjusted to 0.5 millimeters wide and 25 millimeters high for all tests. The linear dispersion of the monochromator was 6.6 millimicrons per millimeter, thus, each of the irradiating wavebands had a nominal width of 33 A.

Eight wavebands, centered at 3129, 3341, 3654, 4047, 4358, 4916, 5461, and 5780 A. were selected by rotating a selection drum on the side of the monochromator. The known line spectral output of the lamp was used to calibrate the drum position for each waveband.

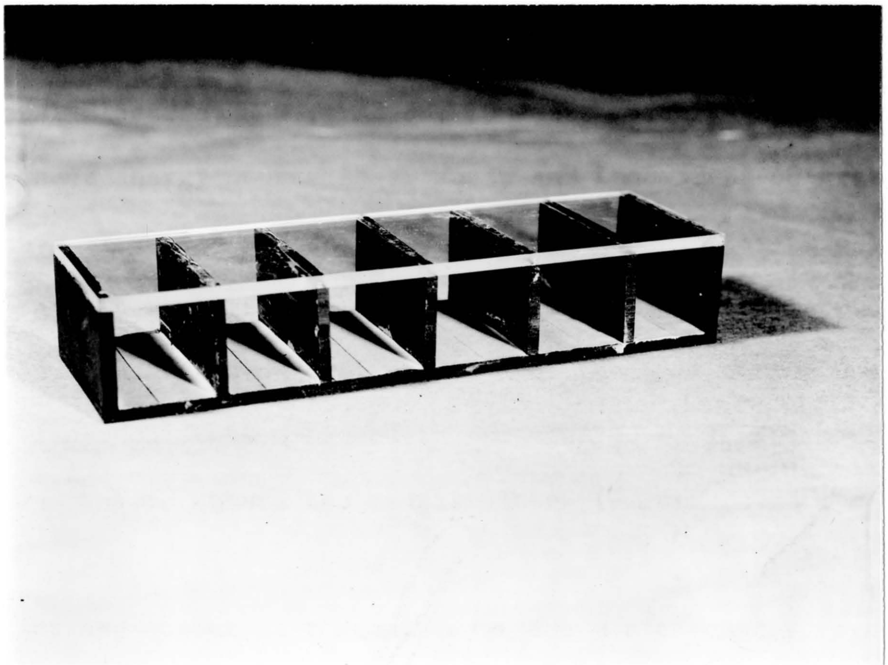

Figure 2 - Block of six testing cells used to hold moths during tests.

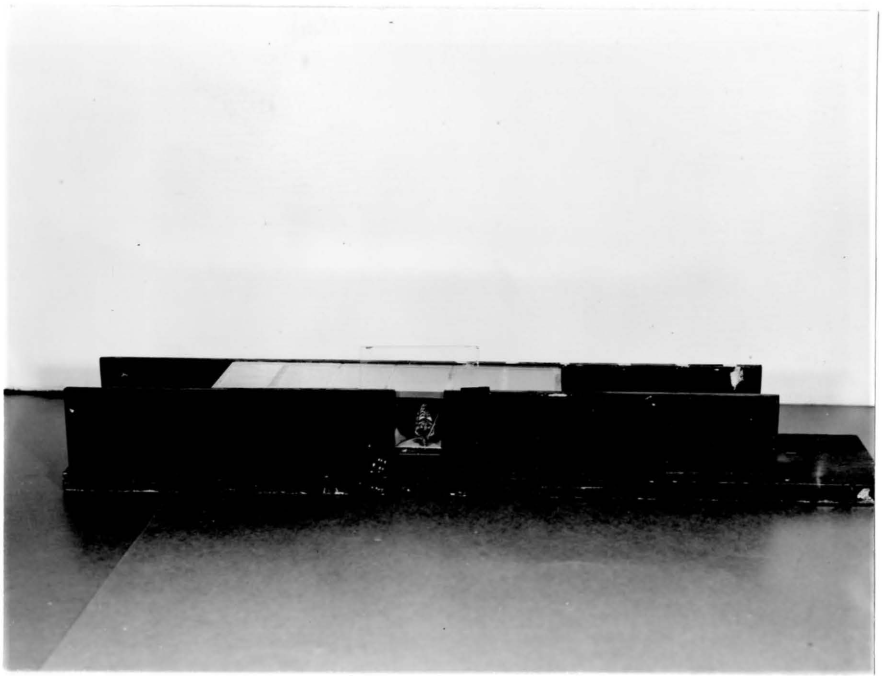

Figure 3 - Test cells located in a wooden trough with one cell, containing a moth, positioned behind the quartz window.

The relative intensity of each waveband was measured with a Photovolt Corporation Model 520-A photometer which used a 1P28 photomultiplier tube as a transducer. The photometer was allowed to warm up at least one hour before it was used and the zero scale was used for all measurements. Due to the lamp's spectral output characteristics, the average relative intensity ranged from approximately 1.8 to 128 units, depending on the waveband measured. Table 1 gives the range of photometer readings and the corrected relative intensity range for each waveband.

The cycle of irradiation was controlled manually. A one r.p.m. timer which produced a slightly audible sound every 10 and 20 seconds alternately was used to measure the exposure time interval.

Visual observation of each moth response was accomplished with an infrared telescope as described by Pruitt (22). He found the hornworm moths not responsive to infrared radiation and the heating effect due to the infrared lamp negligible.

The trapped moths used in this study were caught in light traps (Figure 4) which used a General Electric 15-watt BL fluorescent lamp as an attractant.

Figure 4 - Typical trap used to catch moths from field population.

PROCEDURE

Three hundred and nineteen hornworm moths, mostly tobacco, were caught in light traps at Blacksburg, Virginia. Collections were made daily from seven traps within five miles of Blacksburg. These moths were tested the same day. They were confined in a small screened cage during transfer from the field to the laboratory where they were released into larger cages (Figure 5).

Early morning automobile trips to Chatham, Virginia, were made at various intervals during the summer to obtain 297 hornworm moths, mostly tomato, trapped in that area. During transport the moths were confined in a small screen cage (Figure 6) which was covered with wet burlap to keep them cool and retard loss of moisture from the moths. Upon arrival in Blacksburg, usually around noon, the moths were transferred to larger cages and allowed to rest for a minimum of two hours before testing. All were tested within 36 hours after arrival in Blacksburg.

Four hundred and twenty seven tobacco hornworm pupae were brought from Oxford, North Carolina. They were placed on screens positioned about three inches above moist sawdust and kept in a dark area within the air-conditioned room. When the first moth emerged, the pupae were transferred to a large screened cage where the remainder emerged during the next several days. No pattern of emergence could be detected. Two hundred and thirty-two, or 54.3 percent, of the moths emerged and were tested during the day following emergence. Several had deformed wings and were not tested.

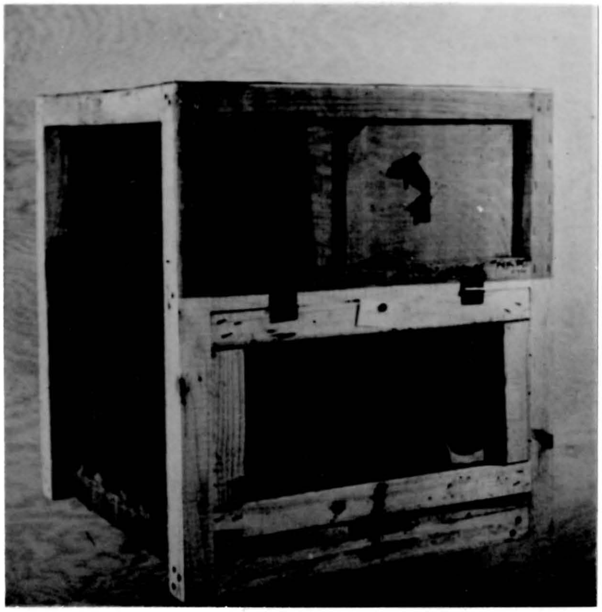

Figure 5 - Screened cage used to hold moths awaiting tests.

Figure 6 - Screened cage used to hold moths during transport.

A small vial of 10 percent (by weight) sugar water was maintained in the cages at all times, as a source of food. A few drops of isoamyl salicylate, as an olfactory attractant, were placed on paper which extended out from the top of the vial. Although no moths were observed to feed, the solution level usually dropped slightly overnight.

Moths were randomly selected, placed in individual cells, and the sex, species, source, and cell number were recorded. The cell block was then placed in the test chamber (Figure 7). The moths were allowed to become dark-adapted for at least 20 minutes before testing. This also gave the moths time to become settled after being handled and confined to the small cell.

A preliminary investigation indicated that moths in the test cells often became active when the cell block was moved. Therefore, after each moth was positioned, irradiation was delayed for at least one minute. The moth was subjected to irradiation at all eight wavelengths before being moved.

The first waveband given each moth was selected so that each of eight consecutive moths of the same group would receive a different first waveband exposure. These eight consecutive moths constituted a unit. Each group consisted of moths of the same species, sex, and source. The sequence of waveband exposures after the first was randomly selected.

The irradiation cycle consisted of 10-seconds exposure followed by 20-seconds darkness, and lastly, another 10-seconds exposure. A one

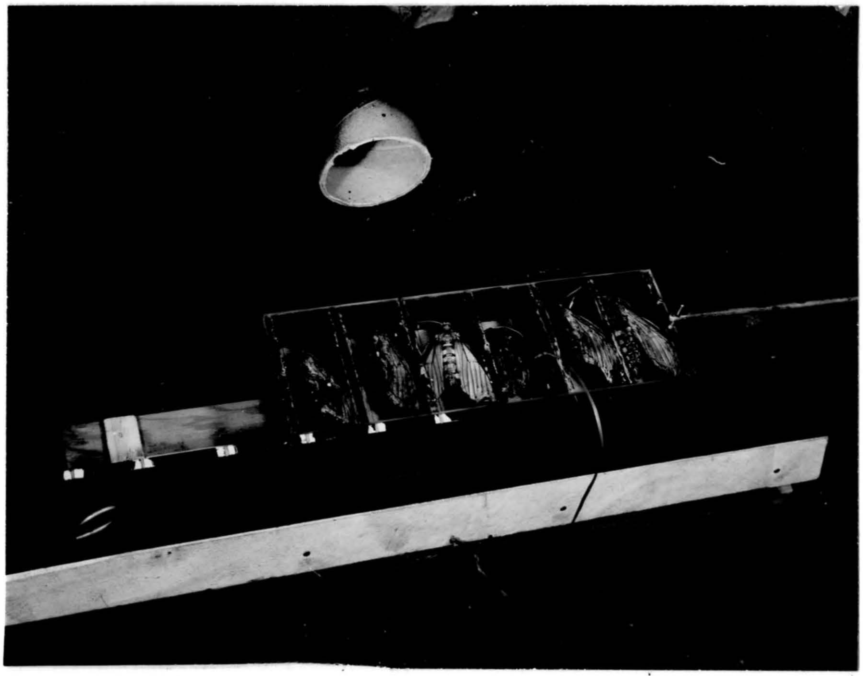

Figure 7 - Positions of moths in test chamber during tests.

minute rest period was given a moth between waveband exposures. One or more movements of the moth during irradiation was considered a response. Therefore, it was possible to have only one response per irradiation.

After the moths were tested, the temperature and relative humidity of the test chamber were recorded and the relative intensity of each waveband was measured and recorded.

The groups, with the number of moths and units in each, are shown in the following table.

MOTH GROUP	NUMBER	UNITS
Reared male tobacco	104	13
Reared female tobacco	128	16
Trapped male tobacco	200	25
Trapped female tobacco	96	12
Trapped male tomato	176	22
Trapped female tomato	144	18

The statistical study consisted of an analysis of variance, plus a Duncan's Multiple Range Test on all wavelength factors found significant. The data were studied to determine if there were significant differences in the responses (a) to the waveband treatments in each of the moth groups, (b) to the waveband treatments in various combinations of moth groups, (c) of reared versus trapped moths, (d) of the two species, and (e) of the sexes.

Examples of the statistical calculations are given in Appendix IV and the data used in the analytical procedures are found in Appendix V.

R E S U L T S

Analysis of All Units Tested in Each Group

A one-factorial analysis of variance of the data from each moth group was made on all units in each group (Appendix II). Each unit was considered a repetition and the number of responses to each of the eight wavebands in a repetition was considered a sample.

There was a significant difference in response to waveband treatments at the one percent level in all groups except the reared male tobacco group. In this latter group there was a significant difference at the five percent level.

As shown in Table 2, responses were highest for the four shorter wavelength treatments. The data summarized suggest that the reared male tobacco moths were less selective in their responses to radiant energy bands than any other group.

Analysis of the First 12 Units Tested in Each Group

To determine whether the additional moths in some groups materially influenced the results, the analysis was repeated using only the first 12 units of each group (Appendix III and Table 3).

A significant difference was found in response to waveband treatments at the one percent level for all trapped groups but not for the reared groups. For the reared female group the difference was significant at the five percent level. Differences at the one percent level were found for the trapped groups in both 12 units and all units.

The results indicate that on the order of 12 repetitions of tests for each moth group are required to detect differences in response to the energy bands. This relatively large number of observations needed to obtain meaningful results confirms the findings of other researchers that the behavior of hornworm moths exposed to radiant energy is erratic.

Analysis of the First 12 Units Tested in All Groups of Moths

Responses to the treatments centered at 3129 and 3341 A. were significantly greater than to other waveband treatments (Table 4). Responses to wavebands centered at 3654 and 4047 A. were significantly greater than to the four longer wavelength treatments centered at 4358, 4916, 5461, and 5780 A. This agrees with previous reports that hornworm moths respond better to the near-ultraviolet spectrum than to the visible.

Reports of significant differences in hornworm moth response to waveband treatments within the near-ultraviolet spectrum were not found. Previous studies were exploratory in nature and fewer moths were tested under each set of conditions. In this study, possibly for the first time, the number of moths treated with narrow bands of energy has been adequate for a meaningful statistical treatment. Interaction between waveband treatments and moth groups was not significant at the one percent level for the first 12 units of all moths.

Analysis of Major Group Combinations

Four separate analysis of variance tests, including contrast comparisons, were conducted for (a) all groups combined, (b) all reared groups combined, and (c) all trapped groups combined. These four tests considered data from (a) the first exposures in the first 12 units,

(b) all exposures in the first 12 units, (c) the first exposures in all units of each group, and (d) all exposures in all units of each group.

Very little differences in responses were found (Tables 5 and 6) between 12 units and those from all units. Responses (Table 6) of moths and trapped moths, to all of the exposures, were greatest to wavebands centered at 3129 and 3341 A. Responses to wavebands centered at 3654 and 4047 A. were greater than to the remaining four longer wavelengths. Reared moths responses were significantly greater to the four shorter wavelength treatments than to the four longer wavelengths.

Trapped tobacco and trapped tomato hornworm moths responded better to the four shorter wavelengths than to the four longer ones (Table 7). Males and females responded likewise. Highest responses were to the two shortest wavebands which were centered at 3129 and 3341 A. These results suggest that sources radiating primarily in the range of 3000 to 3400 A. may be more efficient in eliciting response of hornworm moths.

The responses of several groups of moths to the first waveband exposures are given in Table 8. A comparison with Table 7 reveals that the moths were much more responsive, but less selective, to first waveband exposures than to exposures occurring later in the test. This suggests that the moths may be somewhat startled by the first irradiation and that they may have become somewhat accustomed to the irradiation treatment, as the test progressed. No other reason suggests itself as to why they responded more to the first exposures.

The contrast comparisons for 12 units revealed significant interaction between trapped moth species and trapped moth sexes (Table 9). Therefore, the significance of sex and species for trapped moths could not be evaluated for 12 units.

Based on all exposures there was a significant difference at the one percent level between the responses of reared versus trapped moths (Table 10). Reared ones responded more. Reared tobacco males responded significantly more than reared tobacco females. Trapped tobacco hornworm moths responded significantly better than the trapped tomato hornworm moths.

There was a significant difference in the response of the trapped hornworm species based on first responses (Table 11). The tobacco hornworm moth responded more than the tomato species. Reared moths responded better than those caught in traps. No differences were detected between responses of sexes within reared or trapped groups. Interaction between trapped moth sexes and trapped moth species was not significant.

Moths Responding to First Wavebands

Slightly less than one-half of the moths responded, at least once, to the first waveband exposure (Table 12). The reared male tobacco group was highest with approximately fifty-six percent. The trapped male tomato was lowest with only about forty percent of the moths responding to the first waveband treatments.

Approximately eighteen percent of the moths tested did not respond to any treatment (Table 13). The percentage of tomato hornworm moths not responding to any waveband was much higher than the percentage of tobacco hornworm moths not responding. Male moths not responding to any waveband were consistently higher than females.

Roughly seven and one-half percent of the moths tested responded to all wavelength treatments. The percentage of reared moths was more than double the percentage of trapped moths responding to all wavebands.

Re-Exposure of Moths After Regular Tests

It was noted early in the investigation that the wavebands occurring in the latter part of the exposure sequence appeared to be less effective in eliciting response than those occurring early. To determine if moths would respond to the same wavebands at a later time, a "re-exposure" to those wavebands to which a moth had responded previously, was given at the end of the regular test procedure. The results (Table 14) revealed that a relatively small percentage (8.6 to 28.4 percent) of the moths responded to the same wavebands to which they had just responded during test. This lends support to the idea that moths are less responsive to wavebands which occur late in a sequence of exposures. It also supports the claim that the responses of hornworm moths are erratic.

Responses to "re-exposure" for the two shortest wavelengths (3129 and 3341 A.) were well above those for wavebands centered at longer wavelengths. These observations tend to confirm those previously presented that responses to the wavebands centered at 3129 and 3341 A. were higher than response to wavebands centered at the longer wavelengths.

CONCLUSIONS

The following conclusions are based on data obtained in this investigation:

1. Within each moth group, there was a significant difference in response to eight waveband treatments. Responses to the four treatments centered at 3129, 3341, 3654, and 4047 A. were the highest numerically.
2. When considering all moths or all trapped moths, responses were greatest to wavebands centered at 3129 and 3341 A. and second greatest to 3654 and 4047 A.
3. When considering all reared moths, responses were greatest to the wavebands centered at 3129, 3341, 3654, and 4047 A.
4. Reared moths responsed significantly more than trapped moths.
5. Reared male tobacco moths responded significantly greater than any other group.
6. Reared male and female groups responded significantly different but no difference in the responses of the trapped male and female groups could be detected.
7. The responses of the trapped tobacco hornworm moths were significantly greater than the trapped tomato hornworm moths.
8. First waveband exposures elicited, numerically, a higher percent response than exposures occurring later in the tests.

RECOMMENDATIONS

1. Further studies should be conducted to determine the response characteristics of hornworm moths to the middle-ultraviolet spectrum as compared with responses to the near-ultraviolet.
2. Close confinement of moths undergoing tests should be eliminated. Free flight would be desirable, possibly in tunnels, to determine whether activity is caused by attractive or repelling forces.
3. Improved techniques to measure the amplitude, duration, and direction of moth response are desirable.
4. Relative intensities of the irradiating wavebands should be more nearly uniform than those used in this study.
5. The effects of various intensities of irradiation should be investigated.
6. Tests should be conducted to determine if intermittent irradiation would elicit greater response than constant irradiation.
7. Provisions should be made to eliminate, during tests, relative motion between moth and surfaces in contact with the moth.
8. An energy source of known absolute intensity should be used as a reference to calibrate intensity measuring instruments.

S U M M A R Y

The purpose of this study was to determine hornworm moth response to narrow wavebands of radiant energy. Eight hundred and forty-eight hornworm moths were irradiated individually with eight narrow bands of electromagnetic energy. Six hundred and sixteen tobacco and tomato hornworm moths were caught in blacklight traps and 232 tobacco hornworm moths were laboratory reared. All moths were tested in a light-tight chamber in which the temperature and relative humidity were controlled at 75°F. (± 2°) and 80% (± 15%) respectively.

A block of six testing cells was used to hold the moths during tests. The cell block could slide in a channel so that any individual cell could be positioned behind a quartz window, permitting irradiation of only one moth at a time.

A 100-watt mercury-vapor lamp was used as an energy source for the input to a grating monochromator. Wavebands having a nominal width of 33 A. and centered at 3129, 3341, 3654, 4047, 4358, 4916, 5461, and 5780 were obtained from the monochromator. A moth was given two 10-second exposures to each of the eight wavebands before the test cell was moved to place the next moth into the test position.

Visual observation of moth response was accomplished with an infrared telescope. One or more movements of the moth while under irradiation was considered a response.

A significant difference in responses to waveband treatments was found within each group. Generally, responses to the four shorter

wavelengths were greater than to the four longer. When considering all moths or all trapped moths, best responses were to 3129 and 3341 A. and second best were 3654 and 4047 A. When considering all reared moths, the response was better to the four shorter wavebands than to the four longer. Reared moths were more responsive but less selective to treatments than trapped moths. Greatest response was obtained from the reared male tobacco hornworm moths.

Trapped tomato hornworm moths were less responsive to treatments than trapped tobacco hornworm moths. The female tomato moths were, numerically, least responsive but appeared to be most selective of any group.

All moths tended to respond more to the first waveband exposures they received than to later exposures.

A C K N O W L E D G E M E N T S

The author wishes to express sincere appreciation to Professor U. F. Earp of the Agricultural Engineering Department for his invaluable encouragement, assistance, and advice throughout this study.

of the Farm Electrification Research Branch, Agricultural Research Service, U.S.D.A., for his cooperation, aid, and helpful suggestions, is gratefully acknowledged. Appreciation is also expressed to other members of the Agricultural Engineering Department who offered assistance and suggestions during the investigation.

Special appreciation is due Dr. C. Y. Kramer of the Statistics Department who gave numerous helpful suggestions and guidance for the statistical analysis of the data.

Sincere thanks go to of the Oxford Tobacco Research Station, Oxford, North Carolina, for providing the hornworm pupae used in the study and to of the Chatham Research Station, Chatham, Virginia, for furnishing most of the tomato hornworm moths tested.

Recognition is also due the Farm Electrification Branch of the Agricultural Research Service, the Virginia Agricultural Experiment Station, and the Agricultural Engineering Department for providing funds, equipment, and laboratory space for conducting this investigation.

B I B L I O G R A P H Y

Literature Cited

1. Allen, Norman and C. R. Hodge, "Mating Habits of the Hornworm," Journal of Economic Entomology, Vol. 48, pp. 526-528, October 1955.

2. Bell, Jr., E. S., "The Relative Attraction of Certain Commercially Available Electric Lamps for Hornworm Moths," Unpublished M.S. Thesis, Library, Virginia Polytechnic Institute, Blacksburg, May 1955.

3. Byer, G. F., Ten Years Experience with Codling Moth Bait Traps, Light Traps, and Trap Bands, New Mexico Agricultural Experiment Station Bulletin 253, February 1950.

4. Carruth, L. A. and F. W. Kerr, Jr., "Reaction of Corn Ear Worm and Other Insects to Light Traps," Journal of Economic Entomology, Vol. 30, pp. 297-305, April 1937.

5. Frost, S. W., "Response of Insects to Black and White Light," Journal of Economic Entomology, Vol. 47, pp. 275-278, April 1954.

6. ____________ Light Traps for Insect Collection, Survey, and Control, Pennsylvania State College, Agricultural Experiment Station Bulletin 550, April 1952.

7. Gilmore, J. U., "Observations on the Hornworms Attacking Tobacco in Tennessee and Kentucky," Journal of Economic Entomology, Vol. 31 (6), pp. 706-712, December 1938.

8. Glick, P. A. and J. P. Hollingsworth, "Response of Pink Bollworm Moth to Certain U.V. and Visible Radiation," Journal of Economic Entomology, Vol. 47 (1), pp. 81-86, October 1954.

9. ____________ and ____________________, "Further Studies in the Attraction of Pink Bollworm Moths to Ultraviolet and Visible Radiation," Journal of Economic Entomology, Vol. 49, pp. 158-161, April 1956.

10. Haeussler, G. J., "Losses Caused by Insects," Insects, Yearbook of Agriculture, U.S.D.A., pp. 141-143, 1952.

11. Kent, T. E., "A Laboratory Study of the Response of the Tobacco Hornworm Moth to Ultraviolet Radiation," Unpublished M. S. Thesis, Library, Virginia Polytechnic Institute, Blacksburg, October 1958.

12. Lawson, F. R., Cecil R. Gentry, and James M. Stanley, Effect of Light Traps on Hornworm Populations in Large Areas, Agricultural Research Service, U.S.D.A., Publication 33-91, November 1963.

13. Madden, A. H. and F. S. Chamberlin, Biology of the Tobacco Hornworm Moth in the Southern Cigar Tobacco District, U. S. Department of Agriculture Technical Bulletin, p. 896, 1945.

14. Marshall, G. E. and T. E. Hienton, "The Kind of Radiation Most Attractive to the Codling Moth," Journal of the New York Entomology Society, Vol. 31, No. 3, pp. 360-366, June 1938.

15. Mazohkin, G. A., "Nocturnal Catch of Insects by Light of a Mercury Lamp and the Outlook for its Utilization in Applied Entomology," Zoological Journal, Vol. 35 (U.S.S.R.), September 1956.

16. Menear, J. R., "Response of Tobacco and Tomato Hornworm Moths to Monochromatic Radiation in the Near Ultraviolet," Unpublished M.S. Thesis, Library, Virginia Polytechnic Institute, Blacksburg, August,1961.

17. Merkl, M. E. and T. R. Pfrimmer, "Light Trap Investigations at Stoneville, Mississippi, and Tallulah, Louisiana During 1954," Journal of Economic Entomology, Vol. 48 (6), pp. 740-741, December 1955.

18. Metcalf, C. L. and W. P. Flint, Destructive and Useful Insects, New York, McGraw Hill Book Company, Fourth Edition, 1962.

19. Miller, R. L., "The Attractiveness of Various Wavelengths of Radiant Energy to Vegetable Garden Insects," B. S. Thesis, Purdue University, West Lafayette, Indiana, June 1957.

20. Pfrimmer, T. R., "Response of Insects to Three Sources of Black Light," Journal of Economic Entomology, Vol. 48, No. 5, p. 619, October 1955.

21. _______________, J. J. Lukefahr, and J. P. Hollingsworth, Experiments with Light Traps for Control of the Pink Bollworm, U.S.D.A. A.R.S. Publication 33-6, March 1955.

22. Pruitt, D. W., "Response of Tobacco Hornworm Moths to Ultraviolet Radiation," Unpublished M. S. Thesis, Library, Virginia Polytechnic Institute, June 1960.

23. Raju, S. R., "Response of Tobacco Hornworm Moths to Selected Narrow Waveband Ultraviolet Energy," Unpublished M. S. Thesis, Library, Virginia Polytechnic Institute, Blacksburg, May 1959.

24. Stahl, C. R., "Trapping Hornworm Moths," Journal of Economic Entomology, Vol. 47, pp. 879-882, October 1954.

25. Stanley, J. M. and C. B. Dominick, "Response of Tobacco and Tomato Hornworm Moths to Black Light Traps," Journal of Economic Entomology, Vol. 51, No. 1, pp. 78-80, February 1958.

26. Stermer, R. A., "Instrumentation for Measuring the Spectral Response of Insects," Paper presented at annual meeting of the American Society of Agricultural Engineers, Santa Barbara, California, June 23, 1958.

27. Stirrett, G. M., "The Flight of the European Corn Borer - The Influence of the Physical Factors Upon Flight," Scientific Agriculture, Vol. 18, pp. 536-557.

28. Taylor, J. G., H. O. Deay, and M. T. Orem, "Some Engineering Aspects of Electric Traps for Insects," Agricultural Engineering, Vol. 32, pp. 496-498, September 1951.

29. Weiss, H. B., "Insect Response to Colors," The Scientific Monthly, Vol. 59, pp. 51-56, July 1945.

30. ____________, "Insects and the Spectrum," Journal of the New York Entomology Society, Vol. 54, pp. 17-30, March 1946.

31. ____________, F. A. Soraci, and E. E. McCoy, Jr., "The Behavior of Certain Insects to Various Wave-Lengths of Light," Journal of the New York Entomological Society, Vol. 50, No. 1, pp. 1-35, March 1942.

32. ______________________________, "Insect Behavior to Various Wave Lengths of Light," Journal of the New York Entomological Society, Vol. 51, pp. 117-131, June 1943.

Literature Examined

1. Deay, H. O. and J. B. Taylor, "Preliminary Report on the Relative Attractiveness of Different Heights of Light Traps to Moths," Proceedings of the Indiana Academy of Science for 1953, Vol. 63 pp. 180-184, 1954.

2. Edwards, D. K., "Laboratory Determinations of the Daily Flight Times of Separate Sexes of Some Moths in Naturally Changing Light," Canadian Journal of Zoology, Vol. 40, pp. 511-530, July 1962.

3. Frost, S. W., "Traps and Lights to Catch Night Flying Insects," Interval Cong. Emt. Proc. 10 (August 17-25, 1956), Vol. 2, pp. 583-587, 1958.

4. ___________, "Insects Captured in Light Traps With and Without Baffles," Canadian Ent., Vol. 90 (9), pp. 566-567, September 1958.

5. Gilmore, J. U., "Notes on Apanteless Congregatus (Say) as a Parasite of Tobacco Hornworms," Journal of Economic Entomology, Vol. 31, pp. 712-715, December 1938.

6. Girardeau, Martha F., J. M. Stanley, and D. W. LaHue, Preliminary Report on Light Traps for Catching Night Flying Insects, 1951, Georgia Coastal Plain Experiment Station, Technical Mimeograph Paper No. 5, July 1952.

7. Gui, H. L., L. C. Porter, and C. F. Prideaux, "Response of Insects to Color Intensity and Distribution of Light," American Society of Agricultural Engineering Journal, Vol. 23, pp. 51-58, February 1942.

8. Hollingsworth, J. P. and others, "Some Factors Influencing Light Trap Collections," Journal of Economic Entomology, Vol. 54, pp. 305-308, April 1961.

9. King, W. E. and A. T. Kind, "Activity and Abundance in Insect Light Trap Sampling," Annals of the Entomological Society of America, Vol. 53, No. 4, pp. 524-529, July 1960.

10. Madden, A. H. and F. S. Chamberlin, "Biological Studies of the Tomato Worm on Tobacco in Florida, 1936 and 1937," Journal of Economic Entomology, Vol. 31, pp. 703-706, December 1938.

11. Treat, A. E., "Comparative Moth Catches by an Ultrasonic and a Silent Light Trap," Annals of the Entomological Society of America, Vol. 55, pp. 716-720, November 1962.

12. Weiss, H. B., Frank A. Soraci, and E. E. McCoy, Jr., "Additional Notes on the Behavior of Certain Insects to Different Wave-lengths of Light," Journal New York Entomological Society, Vol. 49, pp. 149-159, June 1941.

13. ___________, E. E. McCoy, Jr., and W. M. Boyd, "Group Motor Responses of Adult and Larval Forms of Insects to Different Wave-lengths of Light," Journal of the New York Entomological Society, Vol. 52, p. 37, March 1944.

14. William, C. B., "A Second Experiment on Testing the Relative Efficiency of Insect Traps," Bul. Ent. Res., Vol. 46 (1), pp. 193-204, April 1955.

The vita has been removed from the scanned document

APPENDIX I

Table 1 - Relative Intensities of Each Waveband

Waveband Centered at (Angstroms)	Range of Photometer "0" Scale Reading	Relative Transducer Sensitivity	Range of Corrected* Relative Intensities
3129	0.9 to 2.5	.934	.96 to 2.68
3341	2.8 to 6.0	.993	2.82 to 6.04
3654	74.0 to 110.0	.955	77.50 to 115.00
4047	31.0 to 57.0	.835	37.10 to 68.20
4358	60.0 to 90.0	.720	83.40 to 125.00
4916	0.6 to 1.5	.540	1.11 to 2.78
5461	34.0 to 52.0	.330	103.00 to 157.00
5780	9.8 to 15.0	.170	57.60 to 88.20

*Corrected values obtained by dividing the photometer reading by the relative sensitivity of the transducer.

Table 2 - Average Responses per Unit When Considering all Units of Moths in Each Group
(16 Responses Possible)

Waveband Center (Angstroms)	Reared Tobacco		Trapped Tobacco		Trapped Tomato	
	Male	Female	Male	Female	Male	Female
3129	8.07[a]	6.56[ef]	7.24[i]	6.75[m]	5.45[q]	5.83[u]
3341	8.38[a]	7.25[e]	5.72[j]	6.58[m]	5.31[q]	4.94[uv]
3654	8.23[a]	6.43[ef]	4.64[jk]	4.83[n]	4.68[qr]	4.50[uv]
4047	7.30[ab]	6.25[efg]	5.32[j]	4.58[no]	3.68[rs]	4.05[vw]
4358	6.84[b]	5.12[fgh]	3.32[kl]	4.08[no]	3.27[s]	1.83[x]
4916	5.92[ab]	4.81[fgh]	3.56[kl]	3.17[no]	2.77[s]	1.66[x]
5461	6.07[ab]	4.50[fg]	2.44[l]	2.83[o]	3.50[rs]	2.66[wx]
5780	5.46[b]	4.18[g]	3.20[kl]	2.92[no]	2.90[s]	1.94[x]
Units	13	16	25	12	22	18

Values in each vertical column followed by the same letters are not significantly different at the 5 percent level.

Table 3 - Average Responses per Unit When Considering the First 12 Units in Each Group (16 Responses Possible)

Waveband Center (Angstroms)	Reared Tobacco Male	Reared Tobacco Female	Trapped Tobacco Male	Trapped Tobacco Female	Trapped Tomato Male	Trapped Tomato Female
3129	8.16[a]	6.08[ef]	6.75[i]	6.75[m]	5.08[qr]	5.67[u]
3341	8.41[a]	6.41[e]	5.75[i]	6.58[m]	5.33[q]	4.50[uv]
3654	7.91[a]	5.66[ef]	4.67[ij]	4.83[n]	3.92[qrs]	3.83[v]
4047	7.16[a]	6.33[e]	4.75[ij]	4.58[n]	3.17[s]	3.17[vw]
4358	5.75[a]	5.00[ef]	2.92[jk]	4.08[no]	2.92[s]	1.17[x]
4916	5.83[a]	4.41[ef]	3.08[jk]	3.17[no]	2.58[s]	1.08[x]
5461	6.00[a]	4.50[ef]	2.42[k]	2.83[o]	3.42[rs]	2.00[wx]
5780	5.91[a]	3.58[f]	2.75[jk]	2.92[no]	3.08[s]	1.50[x]
Units	12	12	12	12	12	12

Values in each vertical column followed by the same letters are not significantly different at the 5 percent level.

Table 4 - Average Response per Unit When Considering the First 12 Units of All Moths

Wavebands Centered at (Angstroms)							
5780	5461	4916	4358	4047	3654	3341	3129
3.29	3.52[c]	3.38[c]	3.62[c]	4.86[b]	5.13[b]	6.16[a]	6.41[a]

Values followed by the same letters are not significantly different at the 5 percent level.

Table 5 - Percent Response* to the First Exposures in (a) 12 Units and (b) All Units

Waveband Center (Angstroms)	12 Units			All Units		
	All Moths	All Reared Moths	All Trapped Moths	All Moths	All Reared Moths	All Trapped Moths
3129	65.9^{a}	72.9^{e}	62.5^{i}	68.3^{m}	74.4^{q}	65.2^{u}
3341	55.5^{abcd}	64.5^{e}	51.0^{ijk}	60.5^{mn}	64.1^{q}	58.7^{uv}
3654	62.5^{ab}	70.8^{e}	58.3^{ij}	66.4^{m}	76.3^{q}	61.4^{u}
4047	59.7^{abc}	81.2^{e}	48.9^{ijk}	62.6^{m}	85.3^{q}	51.3^{uvw}
4358	35.4^{d}	56.2^{e}	25.0^{l}	43.1^{o}	60.8^{q}	34.3^{w}
4916	38.1^{d}	47.9^{e}	33.3^{kl}	39.1^{o}	50.5^{q}	33.5^{w}
5461	48.6^{bcd}	62.4^{e}	41.6^{jkl}	47.0^{no}	63.9^{q}	38.6^{w}
5780	43.0^{cd}	47.9^{e}	40.6^{jkl}	42.0^{o}	44.5^{q}	40.8^{vw}

Values in each vertical column followed by the same letters are not significantly different at the 5 percent level.

$$\text{*Percent Response} = \frac{\text{responses obtained}}{\text{responses possible}}$$

Table 6 - Percent Response* to All Exposures in (a) 12 Units and (b) All Units

Waveband Center (Angstroms)	12 Units			All Units		
	All Moths	All Reared Moths	All Trapped Moths	All Moths	All Reared Moths	All Trapped Moths
3129	40.1[a]	44.5[e]	37.8[i]	41.7[m]	46.2[qr]	39.5[u]
3341	38.5[a]	46.3[e]	34.6[i]	39.5[m]	48.0[q]	35.2[u]
3654	32.1[b]	42.4[e]	27.0[j]	34.7[n]	45.8[qr]	29.1[v]
4047	30.3[b]	42.1[e]	24.4[j]	32.5[n]	42.6[r]	27.5[v]
4358	22.6[c]	33.3[f]	17.3[k]	24.3[o]	34.0[s]	19.5[w]
4916	21.1[c]	32.5[f]	15.5[k]	22.9[o]	33.8[s]	17.4[w]
5461	22.0[c]	32.8[f]	16.6[k]	22.8[o]	32.8[s]	17.8[w]
5780	20.5[c]	29.6[f]	16.0[k]	21.4[o]	30.1[s]	17.1[w]

Values in each vertical column followed by the same letters are not significantly different at the 5 percent level.

$$\text{*Percent Response} = \frac{\text{responses obtained}}{\text{responses possible}}$$

Table 7 - Percent Response* of Major Group Combinations to All Exposures in the First 12 Units

Waveband Center (Angstroms)	All Moths	All Reared Tobacco	All Trapped Tobacco	All Trapped Tomato	All Male	All Female
3129	40.1[a]	44.5[e]	42.1[i]	33.5[m]	41.6[q]	38.5[u]
3341	38.5[a]	46.3[e]	38.5[i]	30.7[m]	40.6[q]	36.4[u]
3654	32.1[b]	42.4[e]	29.6[j]	24.2[mn]	34.3[r]	29.8[v]
4047	30.3[b]	42.1[e]	29.1[j]	19.7[no]	31.4[r]	29.3[v]
4358	22.6[c]	33.3[f]	21.8[k]	12.7[o]	23.9[s]	21.3[w]
4916	21.1[c]	32.5[f]	19.5[kl]	11.4[o]	24.3[s]	19.0[x]
5461	22.0[c]	32.8[f]	16.4[l]	16.9[no]	24.6[s]	19.4[w]
5780	20.5[c]	29.6[f]	17.7[kl]	14.3[o]	24.4[s]	16.6[x]

Values in each vertical column followed by the same letters are not significantly different at the 5 percent level.

*Percent Response = $\frac{\text{responses obtained}}{\text{responses possible}}$

Table 8 - Percent Response* of Major Group Combinations to the First Exposures in the First 12 Units

Waveband Center (Angstroms)	All Moths	All Reared Tobacco	All Trapped Tobacco	All Trapped Tobacco	All Male	All Female
3129	65.9[a]	72.9[e]	66.6[i]	58.3[m]	66.6[q]	65.2[u]
3341	55.5[abcd]	64.5[e]	62.5[i]	39.5 [no]	63.8[q]	47.2[u]
3654	62.5[ab]	70.8[e]	64.5[i]	52.0[mn]	65.2[q]	59.7[u]
4047	59.7[abc]	81.2[e]	62.5[i]	35.4 [no]	56.9[q]	62.5[u]
4358	35.4 [d]	56.2[e]	43.7[i]	6.2 [p]	36.1[q]	34.7[u]
4916	38.1 [d]	47.9[e]	41.6[i]	25.0 [o]	38.8[q]	37.5[u]
5461	48.6 [bcd]	62.4[e]	47.9[i]	35.4 [no]	50.0[q]	47.2[u]
5780	43.0 [cd]	47.9[e]	43.7[i]	37.5 [no]	43.0[q]	43.0[u]

Values in each vertical column followed by the same letters are not significantly different at the 5 percent level.

$$\text{*Percent Response} = \frac{\text{responses obtained}}{\text{responses possible}}$$

Table 9 - Summary of Analysis for All Responses in 12 Units

SOURCE	D.F.	S.S.	M.S.	F.
Moth Group	5	11,295.25	2,259.05	54.12**
Sex within Reared	1	1,580.06	1,580.06	54.90**
Species within Trapped	1	1,212.78	1,212.78	31.68**
Sex within Trapped	1	69.03	69.03	1.80
Sex X Species within Tr.	1	385.04	385.04	10.06**
Reared Vs. Trapped	1	8,048.34	8.048.34	123.61**
Wavelength	7	9,826.96	1,403.85	33.63**
Wavelength within Reared	7	2,191.44	313.06	10.88**
Wavelength within Trapped	7	8,091.22	1,155.89	30.20**
Error	35	1,461.04	41.74	
Reared error	7	201.44	28.78	
Trapped error	21	803.90	38.28	
Reared Vs. Trapped error	7	455.78	65.11	
Total	47			

Table 10 - Summary of Analysis for All Responses in All Units

SOURCE	D.F.	S.S.	M.S.	F.
Moth Group	5	2,515.88	503.18	41.75**
Sex within Reared	1	273.07	273.07	94.82**
Species within Trapped	1	180.50	180.50	17.36**
Sex within Trapped	1	18.60	18.60	1.79
Sex X Species within Tr.	1	25.21	25.21	2.42
Reared Vs. Trapped	1	2,018.50	2,018.50	150.19**
Wavelength	7	2,779.55	397.08	52.91**
Wavelength within Reared	7	721.29	103.04	35.78**
Wavelength within Trapped	7	2,152.38	307.48	29.56**
Error	35	332.71	9.51	
Reared error	7	20.18	2.88	
Trapped error	21	218.41	10.40	
Reared Vs. Trapped error	7	94.07	13.44	
Total	47	5,628.14		

Table 11 - Summary of Analysis for First Responses in All Units

SOURCE	D.F.	S.S.	M.S.	F.
Moth Group	5	5,538.06	1,107.61	5.80**
Sex within Reared	1	439.95	439.95	2.49
Species within Trapped	1	1,990.81	1,990.81	14.67**
Sex within Trapped	1	11.29	11.29	-----
Sex Species within Tr.	1	20.15	20.15	-----
Reared Vs. Trapped	1	3,075.86	3,075.86	19.62**
Wavelength	7	6,011.91	858.84	7.48**
Wavelength within Reared	7	2,558.48	369.78	2.10
Wavelength within Trapped	7	4,550.69	650.10	4.79**
Error	35	5,181.24	148.04	
Reared error	7	1,235.20	176.46	
Trapped error	21	2,848.78	135.66	
Reared Vs. Trapped error	7	1,097.22	156.74	
Total	47	16,731.21		

Table 12 - Moths Responding to the First Waveband Exposures

Moth Group	Number of Moths in		12 Units				All Units			
			Responded to First Exposure		No. Response to First Exposure		Responded to First Exposure		No Response to First Exposure	
	12 Units	All Units	Number	Percent	Number	Percent	Number	Percent	Number	Percent
Reared Male Tobacco	96	104	54	56.2	42	43.7	59	56.7	45	43.2
Reared Female Tobacco	96	128	44	45.8	52	54.1	62	48.4	66	51.5
Trapped Male Tobacco	96	200	42	43.7	54	56.2	102	51.0	98	49.0
Trapped Female Tobacco	96	96	51	53.1	45	46.8	51	53.1	45	46.8
Trapped Male Tomato	96	176	37	38.5	59	61.4	74	42.0	102	57.9
Trapped Female Tomato	96	144	45	46.8	51	53.1	67	46.5	77	53.4
Totals	576	848	273		303		415		433	
Averages				47.3		52.6		48.9		51.0

Table 13 - Moths Responding to All Waveband Exposures

Moth Group	Number of Moths in 12 Units	Number of Moths in All Units	12 Units: Responded to All Wavebands		12 Units: Responded to No Waveband		All Units: Responded to All Wavebands		All Units: Responded to No Waveband	
			Number	Percent	Number	Percent	Number	Percent	Number	Percent
Reared Male Tobacco	96	104	20	20.8	14	14.5	20	19.2	14	13.4
Reared Female Tobacco	96	128	11	11.4	13	13.5	17	13.2	15	11.7
Trapped Male Tobacco	96	200	2	2.0	16	16.6	6	3.0	33	16.5
Trapped Female Tobacco	96	96	4	4.1	7	7.2	4	4.1	7	7.2
Trapped Male Tomato	96	176	6	6.2	35	36.4	11	6.2	54	30.6
Trapped Female Tomato	96	144	2	2.0	26	27.0	4	2.7	31	21.5
Totals	576	848	45		111		62		154	
Averages				7.8		19.2		7.3		18.1

Table 14 - Responses to Re-Exposure of Moths

	Waveband Centered at (Angstroms)							
	3129	3341	3654	4047	4358	4916	5461	5780
Number of Re-Exposures	190	188	148	115	93	69	95	92
Response to Re-Exposures	54	46	21	20	8	7	12	10
Non-Response to Re-Exposure	136	142	127	95	85	62	83	82
Percent Response to Re-Exposures	28.4	24.4	14.1	17.3	08.6	10.1	12.6	10.8

APPENDIX II

Summary of Analysis for All Units of Each Group

Reared Male Tobacco (13 Units)

Source	S.S.	D.F.	M.S.	F.
Wavelength	134.62	7	19.20	2.62*
Error	683.71	96	7.11	
Total	818.33	103		

Reared Female Tobacco (16 Units)

Source	S.S.	D.F.	M.S.	F.
Wavelength	140.97	7	20.14	3.42**
Error	706.50	120	5.88	
Total	847.47	127		

Trapped Male Tobacco (25 Units)

Source	S.S.	D.F.	M.S.	F.
Wavelength	446.46	7	63.78	10.15**
Error	1206.56	192	6.28	
Total	1653.02	199		

Trapped Female Tobacco (12 Units)

Source	S.S.	D.F.	M.S.	F.
Wavelength	211.46	7	30.20	6.65**
Error	400.17	88	4.54	
Total	611.63	95		

Trapped Male Tomato (22 Units)

Source	S.S.	D.F.	M.S.	F.
Wavelength	173.22	7	24.74	6.47**
Error	642.32	168	3.82	
Total	815.54	175		

Summary of Analysis for All Units of Each Group (Continued)

Trapped Female Tomato (18 Units)

Source	S.S.	D.F.	M.S.	F.
Wavelength	324.97	7	46.42	9.26**
Error	682.28	136	5.01	
Total	1007.25	143		

APPENDIX III

Summary of Analysis for 12 Units of Each Group

Reared Male Tobacco

Source	S.S.	D.F.	M.S.	F.
Wavelength	109.41	7	15.63	1.98
Error	694.75	88	7.89	
Total	804.16	95		

Reared Female Tobacco

Source	S.S.	D.F.	M.S.	F.
Wavelength	90.45	7	12.85	2.26*
Error	500.38	88	5.68	
Total	590.83	95		

Trapped Male Tobacco

Source	S.S.	D.F.	M.S.	F.
Wavelength	210.82	7	30.11	5.40**
Error	490.42	88	5.57	
Total	701.24	95		

Trapped Female Tobacco

Source	S.S.	D.F.	M.S.	F.
Wavelength	211.46	7	30.20	6.65**
Error	400.17	88	4.54	
Total	611.63	95		

Trapped Male Tomato

Source	S.S.	D.F.	M.S.	F.
Wavelength	86.79	7	12.39	3.06**
Error	355.84	88	4.04	
Total	442.63	95		

Summary of Analysis for 12 Units of Each Group (Continued)

Trapped Female Tomato

Source	S.S.	D.F.	M.S.	F.
Wavelength	242.65	7	34.66	9.21**
Error	331.59	88	3.76	
Total	574.24	95		

APPENDIX IV

Example of the Statistical Analysis of an Individual Group
(Responses per Unit per Waveband Considered a Sample)

Analysis of variance for 12 units of the trapped male tobacco group (data found in Table 17)

Grand total, $G = (33+29+ \cdot \cdot \cdot +81) = 397$

Correction factor, $G^2/N = C = (397)^2/96 = 1641.76$

S.S. total $= (\Sigma\Sigma X^2_{ij}) - C = 4^2+3^2+ \cdot \cdot \cdot +4^2+6^2) - C = 701.24$

S.S. wavelength $= (\Sigma T^2_j/n - C = (33^2+29^2+ \cdot \cdot \cdot +81^2)/12 - C$

$= 210.82$

S.S. error = S.S. total - S.S. wavelength = 490.42

Summary of Analysis

Source	S.S.	D.F.	M.S.	F.
Wavelength	210.82	7	30.11	5.40**
Error	490.42	88	5.57	
Total	701.24	95		

Standard error of mean, $S_m = \sqrt{5.57/12} = .681$

Significant studentized ranges for 88 degrees of freedom at 5% level

5% level		(2) 2.81	(3) 2.96	(4) 3.06	(5) 3.13	(6) 3.19	(7) 3.23	(8) 3.27
Least significant ranges:		1.91	2.02	2.08	2.13	2.17	2.20	2.23

Results:

Wavelength: 5461	5780	4358	4916	3654	4047	3341	3129
Avg. means: 2.42	2.75	2.92	3.08	4.67	4.75	5.75	6.75

Example of the Statistical Analysis of a Group Combination
(Responses per Waveband Considered a Sample)

Analysis of variance for the first 12 units of reared moths (data found in Table 21)

Grand total, G = (71+72+ · · · +77+73) = 1167

Correction factor, $G^2/N = C = (1167)^2/8 = 85118.06$

S.S. total = $(\Sigma\Sigma X^2_{ij}) - C = (71^2+72^2+ \cdots +73^2) - C = 3972.94$

S.S. group = $(\Sigma R^2_i/t) - C = (663^2+504^2)/8 - C = 1580.06$

S.S. wavelength = $(\Sigma T^2_j/r) - C = (171^2+178^2+ \cdots +114^2)/2 - C$

$= 2191.44$

S.S. residual = S.S. total - (S.S. group + S.S. wavelength) = 201.44

Summary of Analysis

Source	S.S.	D.F.	M.S.	F.
Wavelength	2191.44	7	313.06	10.88**
Moth group	1580.06	1	1580.06	54.90**
Residual	201.44	7	28.78	
Total	3972.94	15		

Standard error of mean, $S_m = \sqrt{28.78/2} = 3.793$

Significant studentized ranges for 7 degrees of freedom at 5% level

	(2)	(3)	(4)	(5)	(6)	(7)	(8)
5% level	3.36	3.49	3.56	3.60	3.61	3.62	3.62
Least significant ranges:	12.67	13.20	13.47	13.62	13.69	13.73	13.77

Results:

Wavelength:	5780	4916	5461	4358	4047	3654	3129	3341
Avg. means:	52.00	62.50	63.00	64.00	81.00	81.50	85.50	89.00

Example of the Statistical Analysis of all Groups
(Responses per Unit per Treatment Considered a Sample)

Analysis of variance for the first 12 units of all moth groups combined (data found in Tables 15 through 20)

Grand total, $G = (71+72+70+ \cdots +54+68) = 2622$

Correction factor, $G^2/N = C = (2622)^2/576 = 11935.56$

S.S. total $= \sum\sum\sum X^2_{ijk} - C = (5^2+4^2+3^2+ \cdots +6^2+9^2) - C = 4639.08$

S.S. group $= (\sum R^2_i/nt) - C = (663^2+ \cdots +275^2)/96 - C = 941.27$

S.S. wavelength $= (\sum T^2_j/nr) - C = (462^2+ \cdots + 237^2)/72 - C$

$= 818.91$

S.S. exp. total $= (\sum\sum W^2_{ij}/n) - C = (98^2+73^2+ \cdots +18^2)/12 - C$

$= 1881.94$

S.S. interaction = S.S. exp. total - (S.S. group + S.S. wavelength)

$= 121.76$

S.S. sampling error = S.S. total - S.S. exp. total = 2757

Summary of Analysis

Source	S.S.	D.F.	M.S.	F.
Wavelength	818.91	7	116.98	22.40**
Groups	941.27	5	188.25	36.06**
Interaction	121.76	35	3.47	.66
Error	2757.00	528	5.22	
Total	4638.94	575		

Standard error of mean, $S_m = \sqrt{5.22/72} = .269$

Significant studentized ranges for 528 degrees of freedom at 5% level

	(2)	(3)	(4)	(5)	(6)	(7)	(8)
5% level	2.79	2.94	3.04	3.11	3.17	3.21	3.25
Least significant ranges:	.75	.79	.82	.84	.85	.86	.87

Results:

Wavelength:	5780	4916	5461	4358	4047	3654	3341	3129
Avg. means:	3.29	3.38	3.52	3.62	4.86	5.13	6.16	6.41

APPENDIX V

Table 15 - Responses per Unit of Reared Male Tobacco Moths (16 Responses Possible)

Unit Number	Waveband Centered at (Angstroms) 5780	5461	4916	4358	4047	3654	3341	3129
1	5	4	3	2	6	9	11	8
2	4	3	3	5	5	5	8	5
3	6	6	5	7	5	12	8	9
4	6	6	4	7	8	6	8	5
5	4	7	4	4	4	6	7	8
6	7	6	7	6	8	6	7	7
7	6	6	6	6	6	6	8	5
8	2	2	6	3	6	3	6	7
9	3	5	6	2	3	5	4	4
10	9	9	9	8	12	13	11	9
11	12	10	10	10	14	15	14	16
12	7	8	7	9	9	9	9	13
12 Unit Sub-total	71	72	70	69	86	95	101	98
12 Unit Average	5.91	6.00	5.83	5.75	7.16	7.91	8.41	8.16
13	0	7	7	7	9	12	8	9
13 Unit Total	71	79	77	76	95	107	109	107
13 Unit Average	5.46	6.07	5.92	5.84	7.30	8.23	8.38	8.07

Table 16 - Responses per Unit of Reared Female Tobacco Moths
(16 Responses Possible)

Unit Number	Waveband Centered at (Angstroms) 5780	5461	4916	4358	4047	3654	3341	3129
1	0	3	6	4	8	3	7	7
2	3	3	5	6	8	4	3	4
3	3	3	5	3	3	4	5	5
4	2	8	5	2	2	6	10	5
5	6	10	8	9	10	10	9	9
6	3	4	1	2	8	7	3	5
7	4	3	2	6	4	3	4	4
8	0	1	4	2	5	3	9	6
9	6	5	3	6	8	8	4	6
10	4	4	5	8	8	3	7	8
11	4	4	4	5	5	5	7	6
12	8	5	5	7	8	12	9	8
12 Unit Sub-total	43	54	53	60	76	68	77	73
12 Unit Average	3.58	4.50	4.41	5.00	6.33	5.66	6.41	6.08
13	4	4	8	4	4	12	11	9
14	11	5	5	5	8	8	9	7
15	1	4	4	8	6	7	9	7
16	8	5	7	5	6	8	10	9
16 Unit Total	67	72	77	82	100	103	116	105
16 Unit Average	4.18	4.50	4.81	5.12	6.25	6.43	7.25	6.56

Table 17 - Responses per Unit of Trapped Male Tobacco Moths
(16 Responses Possible)

Unit Number	Waveband Centered at (Angstroms) 5780	5461	4916	4358	4047	3654	3341	3129
1	0	4	3	3	4	6	5	7
2	8	6	9	5	10	7	11	13
3	2	1	3	4	5	8	11	6
4	2	1	1	2	5	7	5	4
5	4	2	4	3	3	3	2	7
6	3	2	2	3	7	8	10	7
7	3	1	3	2	2	2	3	3
8	0	2	1	3	4	6	5	7
9	2	2	3	6	3	6	3	5
10	3	0	1	2	5	1	5	8
11	0	4	3	2	5	0	5	8
12	6	4	4	0	4	2	4	6
12 Unit Sub-total	33	29	37	35	57	56	69	81
12 Unit Average	2.75	2.42	3.08	2.92	4.75	4.67	5.75	6.75
13	7	5	8	6	11	10	11	13
14	1	0	3	2	6	6	3	7
15	2	1	3	2	2	5	3	6
16	2	4	4	0	7	4	3	6
17	7	2	5	5	9	3	8	8
18	2	2	7	4	3	3	10	7
19	3	3	3	6	8	4	1	3
20	5	3	3	7	7	7	8	9
21	3	0	1	1	2	2	4	7
22	9	6	7	4	8	9	8	12
23	1	5	5	4	9	3	8	11
24	3	2	2	5	3	3	5	6
25	1	0	1	2	1	1	2	5
25 Unit Total	80	61	89	83	133	116	143	181
25 Unit Average	3.20	2.44	3.56	3.32	5.32	4.64	5.72	7.24

Table 18 - Responses per Unit of Trapped Female Tobacco Moths
(16 Responses Possible)

Unit Number	Waveband Centered at (Angstroms) 5780	5461	4916	4358	4047	3654	3341	3129
1	3	3	1	2	6	3	5	5
2	1	0	2	2	3	5	4	9
3	1	0	1	0	3	3	3	4
4	4	4	5	6	5	5	7	8
5	2	1	2	5	4	2	5	5
6	3	5	2	5	6	5	9	7
7	2	2	2	1	3	5	9	4
8	3	2	2	8	3	5	3	7
9	5	5	8	6	6	5	9	9
10	6	4	4	4	3	6	9	6
11	5	6	5	7	8	12	9	9
12	0	2	4	3	5	2	7	8
12 Unit Sub-total	35	34	38	49	55	58	79	81
12 Unit Average	2.91	2.83	3.16	4.08	4.58	4.83	6.58	6.75

Table 19 - Responses per Unit of Trapped Male Tomato Moths
(16 Responses Possible)

Unit Number	Waveband Centered at (Angstroms) 5780	5461	4916	4358	4047	3654	3341	3129
1	0	0	3	0	3	3	3	4
2	2	6	4	4	4	4	5	4
3	4	2	0	4	2	4	8	9
4	3	4	0	0	0	1	2	2
5	5	4	1	6	3	8	8	5
6	1	0	0	0	2	3	4	4
7	2	2	4	6	4	2	6	3
8	4	6	4	4	4	4	4	4
9	6	3	5	3	4	7	6	7
10	2	5	0	2	3	2	6	3
11	1	2	4	2	4	5	5	8
12	6	7	6	4	4	4	7	8
12 Unit Sub-total	37	41	31	35	38	47	64	61
12 Unit Average	3.08	3.42	2.58	2.92	3.17	3.92	5.33	5.08
13	1	3	1	7	3	3	3	3
14	3	4	6	3	7	3	4	6
15	3	4	3	2	4	6	8	5
16	1	4	1	2	1	4	2	2
17	3	4	3	4	6	5	8	7
18	4	4	5	5	8	10	8	9
19	3	5	2	3	3	6	5	9
20	4	2	1	2	4	8	6	5
21	2	2	3	5	2	5	5	7
22	4	4	5	4	5	6	4	6
22 Unit Total	64	77	61	72	81	103	117	120
22 Unit Average	2.90	3.50	2.77	3.27	3.68	4.68	5.31	5.45

Table 20 - Responses per Unit of Trapped Female Tomato Moths
(16 Responses Possible)

Unit Number	Waveband Centered at (Angstroms) 5780	5461	4916	4358	4047	3654	3341	3129
1	0	0	0	1	2	4	5	6
2	0	0	0	2	4	6	4	5
3	1	1	0	0	2	4	5	7
4	0	0	0	0	1	0	0	2
5	4	2	4	1	6	6	6	5
6	1	2	1	2	4	4	4	7
7	2	3	0	0	2	5	3	2
8	1	3	0	0	2	4	4	5
9	2	3	1	3	2	3	5	5
10	3	7	7	4	6	7	8	10
11	3	2	0	0	1	3	4	5
12	1	1	0	1	6	1	6	9
12 Unit Sub-total	18	24	13	14	38	46	54	68
12 Unit Average	1.50	2.00	1.08	1.17	3.17	3.83	4.50	5.67
13	3	10	4	5	11	8	7	6
14	3	0	2	3	5	6	6	7
15	4	4	2	7	6	4	6	8
16	1	2	1	0	5	4	3	2
17	5	6	5	2	6	9	9	7
18	1	2	3	2	2	4	5	7
18 Unit Total	35	48	30	33	73	81	89	105
18 Unit Average	1.94	2.66	1.66	1.83	4.05	4.50	4.94	5.83

Table 21 - Responses of 12 Units of Moths

	Number of Units	Number of Exposures	Wavebands Centered at (Angstroms)							
			5780	5461	4916	4358	4047	3654	3341	3129
To First Waveband Treatments										
Reared Male Tobacco	12	24	15	16	8	15	22	19	20	18
Reared Female Tobacco	12	24	8	14	15	12	17	15	11	17
Trapped Male Tobacco	12	24	7	13	12	8	11	15	17	15
Trapped Female Tobacco	12	24	14	10	8	13	19	16	13	17
Trapped Male Tomato	12	24	9	7	8	3	8	13	9	15
Trapped Female Tomato	12	24	9	10	4	0	9	12	10	13
To All Waveband Treatments										
Reared Male Tobacco	12	192	71	72	72	68	86	95	101	98
Reared Female Tobacco	12	192	43	54	53	60	76	68	77	73
Trapped Male Tobacco	12	192	33	29	37	35	57	56	69	81
Trapped Female Tobacco	12	192	35	34	38	49	55	58	79	81
Trapped Male Tomato	12	192	37	41	31	35	38	47	64	61
Trapped Female Tomato	12	192	18	24	13	14	38	46	54	68

Table 22 - Responses of All Units of Moths

	Number of Units	Number of Exposures	Wavebands Centered at (Angstroms) 5780	5461	4916	4358	4047	3654	3341	3129
To First Waveband Treatments										
Reared Male Tobacco	13	26	15	17	10	17	24	21	22	20
Reared Female Tobacco	16	32	10	20	20	18	25	23	14	23
Trapped Male Tobacco	25	50	20	19	24	23	22	30	44	36
Trapped Female Tobacco	12	24	14	10	8	13	19	16	13	17
Trapped Male Tomato	22	44	14	17	11	14	13	28	20	25
Trapped Female Tomato	18	36	12	13	10	2	19	20	17	22
To All Waveband Treatments										
Reared Male Tobacco	13	208	71	79	78	75	95	107	109	107
Reared Female Tobacco	16	256	67	71	77	82	101	103	116	105
Trapped Male Tobacco	25	400	80	61	89	83	133	116	143	181
Trapped Female Tobacco	12	192	35	34	38	49	55	58	79	81
Trapped Male Tomato	22	352	64	77	61	72	81	103	117	120
Trapped Female Tomato	18	288	35	48	30	33	73	81	89	105

Table 23 - Percent Response of All Units of Moths

	Number of Units	Number of Exposures	Wavebands Centered at (Angstroms) 5780	5461	4916	4358	4047	3654	3341	3129
To First Waveband Treatments										
Reared Male Tobacco	13	26	57.7	65.4	38.5	65.4	92.4	80.9	84.6	77.0
Reared Female Tobacco	16	32	31.3	62.5	62.5	56.2	78.2	71.8	43.7	71.8
Trapped Male Tobacco	25	50	40.0	38.0	48.0	46.0	44.0	60.0	88.0	72.1
Trapped Female Tobacco	12	24	58.3	41.7	33.3	54.2	79.2	66.6	54.2	70.8
Trapped Male Tomato	22	44	31.8	38.6	25.0	31.8	29.5	63.6	45.5	56.8
Trapped Female Tomato	18	36	33.3	36.1	27.8	5.5	52.8	55.5	47.3	61.1
To All Waveband Treatments										
Reared Male Tobacco	13	208	34.1	38.0	37.5	36.0	45.7	51.4	52.4	51.4
Reared Female Tobacco	16	256	26.2	27.7	30.1	32.0	39.5	40.3	43.6	41.0
Trapped Male Tobacco	25	400	20.0	15.2	22.3	20.7	33.2	29.0	35.7	45.3
Trapped Female Tobacco	12	192	18.2	17.7	19.8	25.5	28.6	30.2	41.2	42.2
Trapped Male Tobacco	22	352	18.2	21.9	17.3	20.5	23.0	29.3	33.3	34.1
Trapped Female Tobacco	18	288	12.1	16.6	10.4	11.4	25.3	28.1	30.9	36.4

Percent Response = $\frac{\text{responses possible}}{\text{responses obtained}}$

Table 24 - Percent Response of 12 Units of Moths

	Number of Units	Number of Exposures	Wavebands Centered at (Angstroms) 5780	5461	4916	4358	4047	3654	3341	3129
To First Waveband Treatments										
Reared Male Tobacco	12	24	62.5	66.7	33.3	62.5	91.8	79.2	83.5	75.0
Reared Female Tobacco	12	24	33.3	58.3	62.5	50.0	70.8	62.5	45.8	70.8
Trapped Male Tobacco	12	24	29.2	54.2	50.0	33.3	45.8	62.5	70.8	62.5
Trapped Female Tobacco	12	24	58.3	41.7	33.3	54.2	79.2	66.6	54.2	70.8
Trapped Male Tomato	12	24	37.5	29.2	33.3	12.5	33.3	54.2	37.5	62.5
Trapped Female Tomato	12	24	37.5	41.7	16.7	0	37.5	50.0	41.6	54.2
To All Waveband Treatments										
Reared Male Tobacco	12	192	37.0	37.5	37.5	35.4	44.8	49.4	52.7	51.0
Reared Female Tobacco	12	192	22.4	28.1	27.6	31.2	39.6	35.4	40.1	38.0
Trapped Male Tobacco	12	192	17.2	15.1	19.3	18.2	29.7	29.2	35.9	42.2
Trapped Female Tobacco	12	192	18.2	17.7	19.8	25.5	28.6	30.2	41.2	42.2
Trapped Male Tobacco	12	192	19.3	21.3	16.1	18.2	19.8	24.5	33.3	31.8
Trapped Female Tobacco	12	192	9.4	12.5	6.8	7.3	19.8	23.9	28.1	35.4

Percent Response = $\frac{\text{responses possible}}{\text{responses obtained}}$

RESPONSE OF HORNWORM MOTHS TO MONOCHROMATIC RADIATION IN THE VISIBLE AND NEAR ULTRAVIOLET SPECTRUM

Abstract

Eight-hundred and forty-eight tobacco (*Protoparce sexta* (Johan.)) and tomato (*P. quinquemaculata* (Haw.)) hornworm moths were irradiated individually with energy bands, nominally 33 Angstroms wide, centered at 3129, 3341, 3654, 4047, 4358, 4916, 5461, and 5780 A. Tests were made in a light-tight, air-conditioned chamber. An analysis of variance was used to determine differences in responses to treatments.

A significant difference in response to waveband treatments was found in each moth group. Generally, responses to the four shorter wavelengths were greater than to the four longer. When considering all moths or all trapped moths, best responses were to 3129 and 3341 Angstroms and second best were to 3654 and 4047 Angstroms. Reared moths were more responsive to treatments than trapped moths. Greatest response was obtained from the reared male tobacco hornworm moths.

Tomato hornworm moths were less responsive to treatments than tobacco hornworm moths. The female tomato hornworm moths were numerically, least responsive.

Numerically, more responses were elicited from first exposures than from those received later.