RESPONSE OF TOBACCO- AND TOMATO-
HORNWORM MOTHS TO MONOCHROMATIC
RADIATION IN THE NEAR ULTRAVIOLET

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Abstract

Eight-hundred-three moths were irradiated with 10-second exposures of radiation in bands 100 Angstroms wide at 200 A. intervals. The main range covered was 3150 to 4550 A. Four controlled temperatures between 60 and 80 F. were used. Observations of individual moth response were combined to determine a most stimulating band, the effect of temperature, and effects of species, sex, time of testing, and moth origin.

Within the wavelength range, a band centered at 3150 A. had the most reactions and one at 4350 A. the least. The total group of moths tested over these bands had a plot of reactions versus wavelength with no reversals of slope between maximum and minimum. No definite effects of temperature, sex, time of testing, or moth origin were found.

The tomato hornworm moth was definitely the less active species, and showed greater difference between bands of maximum and minimum reactions.

An additional test found no effect due to relative intensity of radiation on different bands, which was not equalized in the main tests.

Only test groups which allowed for several hundred possible moth reactions at each treatment showed consistent trends.

TABLE OF CONTENTS

CONTENTS OF APPENDIX

LIST OF FIGURES

INTRODUCTION

The damage done by the tobacco hornworm (Protoparce sexta (Johan.)) and its close relative the tomato hornworm (P. quinquemaculata (Haw.)) has been a matter of concern to tobacco producers since commercial cultivation of the crop began. These pests exist wherever tobacco is grown, and also attack tomatoes, eggplant, peppers, and potatoes. The leaf-chewing larva is the objectionable stage of the insect's life, and tobacco, being a leaf crop, suffers more than the other named crops combined. This is compounded by the commercial downgrading of partially eaten leaves. The tobacco hornworm does more damage to tobacco, and is a larger larva than the tomato hornworm. Otherwise the two species are quite similar. The two moths are almost identical, and occur in roughly equivalent numbers (14). In this study, P.sexta and P. quinquemaculata will be referred to as tobacco and tomato (moths), respectively.

A study by Madden and Chamberlain (8) of the tobacco hornworm gave pertinent facts on the life cycle. On tobacco, eggs are deposited on the underside of leaves, the larger plants receiving more. As many as 74 eggs have been found on one leaf over the growing season, with no apparent relation to position in a field. Incubation takes about five days, and about 95 per cent of the eggs hatch into larvae, which consume leaf for 13 to 44 days at a rapidly increasing rate. The larvae then burrow about five inches underground for a pupation period of from 14 days to two years. A maximum of about half of the pupae emerge as adult moths, which rate is not known to be affected by winter temperatures. If favorable conditions prevail throughout the season from April to November, two generations may be completed in Virginia. Peak numbers of all four insect stages usually occur during July. This follows closely the abundance of growing tobacco leaf. The moths are about equally divided as to sex. They are exclusively night-flying, and it has been postulated (14) that males are more active than females, perhaps due to mating habits. Individual migrations of over a mile have been noted. There is some flight activity throughout the night, but it is mostly confined to the periods of twilight and dawn. Male moths live about seven days and females about nine. The moths feed on several night-blooming flowers with tubular corollas, and oviposition by the female is not dependent upon, though usually preceded by, feeding. Each female produces up to 300 eggs, usually distributed singly. Oviposition occurs at night and is not affected by moonlight, but is retarded by low temperature.

Natural predators of the hornworms include birds, wasps, and other insects, spiders, skunks and moles, and bacteria, none of which control the populations sufficiently for agricultural purposes.

These observations do not point out any obvious means for the desired drastic and economical control of the pests. Perhaps the greatest hindrance to control is the constant presence of all stages during the tobacco season, making one-treatment methods ineffective. Hand picking has become too costly; effective insecticides are available, and are the accepted control method, but the repeated applications necessary are objectionable both costwise and because of residues.

Chopping the plants immediately after harvesting is completed kills some larvae and eggs, and fall plowing has been shown to destroy up to half of the pupae in a field. The structure for shade-grown tobacco acts as an effective barrier to migrating moths, where this practice is used.

Destruction of the moths would be desirable, since this can be done apart from the tobacco plant, and luring the moths to traps is an obvious approach. Many species of insects have been investigated in this respect, and in some cases effective traps have resulted. The visual sense is well developed in most flying insects, and research has shown that, in general, their sensitivity range extends beyond the limits of the human eye into the near ultraviolet spectral region. The attraction of flying insects to sources of light is well known. Work with some species has indicated a maximum sensitivity or attraction for wavelengths in the near ultraviolet (4, 11, 18).

Tobacco moths and tomato moths have been studied, with an objective of determining the most attractive wavelength and evaluating interrelated factors of the physical environment (1, 7, 12, 13).

Due to the scarcity of specific information on the subject, these studies have necessarily been of an exploratory nature intended to guide subsequent work toward significant factors. The characteristics of radiation plus possibly significant environmental factors make quite a list of variables, some of which are difficult to measure and control. Further work was indicated, with emphasis on evaluation of certain variables and control of others to the limit of available means.

Determination of a radiation wavelength most effective in attracting hornworm moths, correlated with optimum values of other variables, would provide a sound basis for trap design and operation for hornworm attraction. Such data would be valuable in research on other insect attraction problems as well.

REVIEW OF LITERATURE

Study of the response of insects to radiant energy, alone and in conjunction with environmental factors, has yielded few general conclusions. One result common to most investigations is the erratic and unpredictable behavior of the specimen, both individually over time and in groups. It may be due to specimen variation or to uncontrolled experimental variables, but in any case meaningful results must be based on large samples. The hornworm moths in question seem particularly affected by this. This restriction, plus the expense of spectrophotometric apparatus, has limited analytical research, although many workers have devised and evaluated prototype traps without benefit of appraisal of separate variables.

The parameters of electromagnetic radiation of probable significance in insect irradiation studies are wavelength, intensity, bandwidth, purity, and polarization, of which wavelength is the most descriptive. Weiss (18) reported that all wavelengths between 3650 and 7200 Angstroms could attract some insect species, but considered intensity more influential than wavelength. Bell (1), working with hornworm moths, concluded that of 20 commercially available electric lamp types, five with major radiation between 3200 and 4000 A. were more attractive than those with other spectral distributions.

This agreed with results of light-trap studies by Stanley and Dominick (15), and Merkl and Phrimmer (10). Investigating within this part of the spectrum with narrow band radiation of 100 A. bandwidth, neither Kent (7), Raju (13), nor Pruitt (12) was able to determine a most attractive wavelength. However, Raju did note an unexplained peak of activity at 3150 A. in some instances.

The effect of intensity is not agreed upon. Taylor and Deay (17) found only slight increase of attractiveness with increase of intensity for corn borer moths. Assuming the insect eye to be capable of adapting it normal function over a range of intensity, the question resolves to determining response effects within and above this range.

Regarding bandwidth, there is no reason to believe that exclusion of wavelengths outside a selected band enhances attractiveness of the band, but conclusions as to wavelength must be drawn from isolated bands. Most workers have chosen 100 A. as a good compromise between fineness of test and tentative intensity requirements.

Temperature has been listed by several investigators (6, 9, 10, 18) as a factor influencing insect activity. Some studies indicate that an optimum somewhere between 65 and 80°F. is conducive to maximum activity, which lessens at temperatures lower or higher. Stirrett (16) put the optimum for the European corn borer at 70°F.

The interaction of this effect with response to radiation is not clear, although Carruth and Kerr (2) found light-trap catches of corn earworm moths to be directly influenced by mean night temperatures. A study of tobacco moths by Raju showed no variation of response to narrow band ultraviolet due to temperature ranging between 72 and 83°F. Similar studies by Kent and Pruitt included observations of temperature, although control means were not available. No significant temperature effect was reported. The three latter studies on laboratory reared tobacco moths apparently contradict reports from investigations dealing with other insects, regarding the effect of temperature. Further work with hornworm moths is needed to define any temperature effect on activity, both alone and in conjunction with radiation.

Humidity effects are even less known than those of temperature. Field observations of flight activity and light-trap catches generally include reference to humidity as a minor influence having a positive effect on activity level (6, 9, 10, 18). However, the hornworm studies (7, 12, 13) showed no significant effect within their somewhat narrow ranges of humidity.

Atmospheric inclusions, producing olfactory and perhaps other stimulations in insects, may interact with radiation effects. Stahl (14) concluded that female hornworm moths were more apt to be found in aromatic bait traps than males, while light-traps secured a larger portion of males. Any physiological effects of sex of the specimen on radiation response are unknown. Stanley and Dominick reported only 17.9 per cent tobacco moth females in light-trap catches, but 45.8 per cent of tomato moths were female. This could be an effect either of sex, or of species differences.

Treatment received by the moth prior to testing has been a factor difficult to evaluate in hornworm studies. Two sources of specimen used were laboratory rearing and trapping in existing light-traps. Pruitt reported no response difference between light-trap moths tested on first and second days after collection. However, upon investigation of time of day as a factor, he found that moth response was slightly greater after 6:00 p.m. than before, and that laboratory reared moths showed this difference to a greater extent than light-trap moths.

To sum up, no particular wavelength of radiation, nor any single environmental factor has yet been definitely evaluated for its effect on the attraction of hornworm moths to light sources. This indicated that the present study should concentrate on determining effects of the more easily measured factors, although effects and interactions of the seemingly lesser ones could not be ruled out.

OBJECTIVE

This work was done to study the response of the individual hornworm moth to short exposures of monochromatic ultraviolet radiation and visible light.

FACILITIES

APPARATUS

The study was conducted in a specially built laboratory room, 12 by 16 feet. Walls and ceiling were framed plywood sheets bolted together. Rock wool batt insulation and a one-ton air-conditioner were installed. Inside this was a chamber of pressed-board four by four feet and seven feet high in which the moths were tested. A bench adjacent to the chamber and extending into it provided instrument space (Fig. 1). Joints of both room and chamber were taped to exclude light.

Detailed recording of the individual moth response ideally would have been done by an automatic device sensitive to selected response movements, which would then be recorded on a graph. The kymograph used by Kent (7) was considered undesirable due to mutilation of the moths by piercing, and no other device was known to be available. Human observance was relied upon of necessity.

An infrared telescope, modified and used previously by Pruitt (12) was selected as the best available means of observing the moths while introducing a minimum of extraneous effects. That the moths in question were not responsive to infrared radiation was reasonably shown by Pruitt, although there was a slight heating effect in the testing cells due to infrared radiation.

The block of six testing cells (Fig. 2) was constructed of a clear acrylic plastic. This slid in a wooden channel provided with a quartz

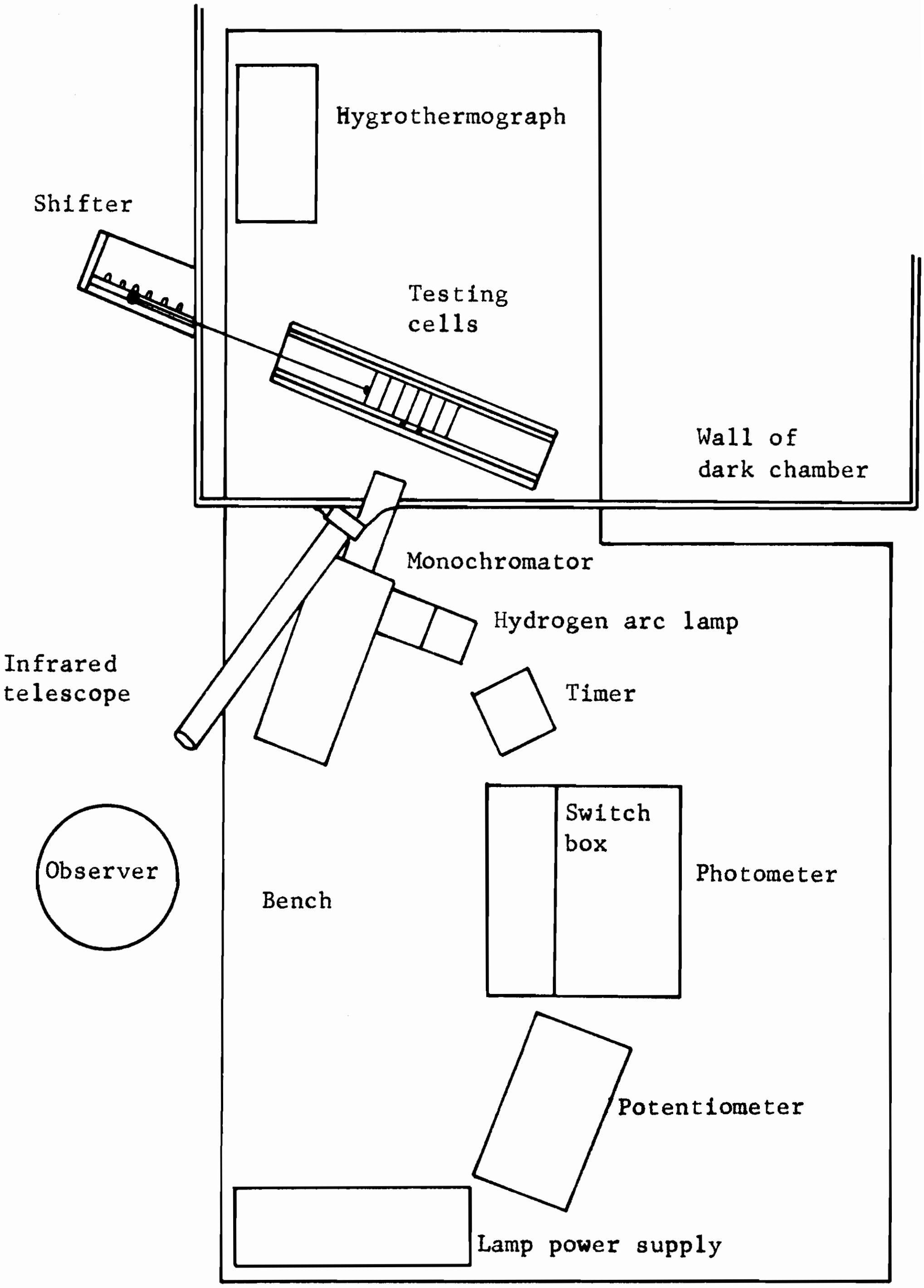


FIG.1. APPARATUS LAYOUT

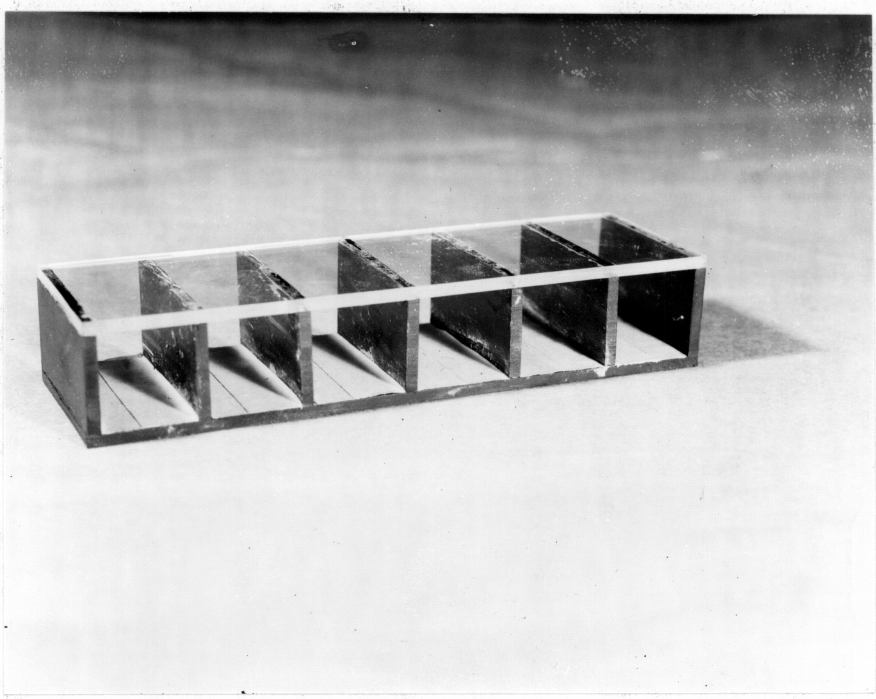


FIG. 2 **MOTH CELL BLOCK**

Each cell was 1 1/4 inches square and 3 inches long.

window the size of one cell front, so that each cell could be positioned behind the window. The channel was positioned on a base by an index pin, and the base was supported on the bench by three long screws for leveling and vertical positioning (Fig. 3). A pin in the cell block engaged a push-pull rod passing through the chamber wall to the shifting handle and index notch arrangement outside. This permitted rapid positioning of each cell from the observer's position. Provision was made for repetitive positioning of a photometer search unit behind the window, with the cell block shifted to one side.

Narrow band ultraviolet radiation was provided by a Bausch & Lomb 33-86-40 grating monochromator of focal length 250 mm., with matching 33-86-46 hydrogen arc lamp. Entrance condenser lens system and exit collective lens for the monochromator were used as furnished. The grating was ruled 600 lines per mm. and blazed at 3000 Angstroms. The hydrogen arc source was chosen for its continuity of spectrum in the near ultraviolet. Cooling water circulation for the lamp was provided by a small pump and motor unit and one-gallon reservoir. Automobile radiator rust inhibitor proved to be an excellent means of keeping the water clean. To prevent damage to the expensive lamp, its power supply was wired such that it could not be energized without the pump. A glass sight tube was inserted in the rubber water return hose near the lamp to show any air or dirt in the water.

The monochromator output was aimed through a light-tight cardboard tube in the dark chamber wall at the quartz window in the insect cell channel (Fig. 3). This was located as close as possible to the

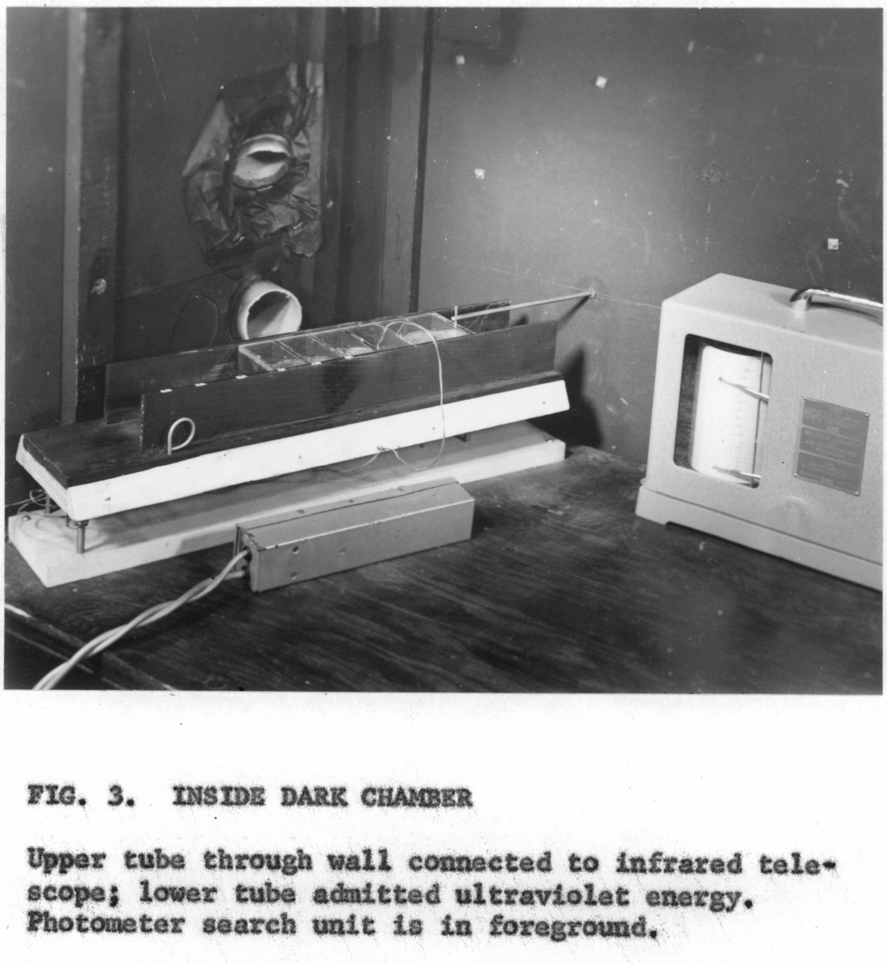


FIG. 3. INSIDE DARK CHAMBER

Upper tube through wall connected to infrared telescope; lower tube admitted ultraviolet energy. Photometer search unit is in foreground.

monochromator, to maintain intensity of the same order as used in other investigations, which used more powerful lamps. Relative intensity was measured by a Photovolt Corporation 520-A multiplier photometer, equipped with a 1P28 phototube. The search unit was left inside the dark chamber, its connecting wires passing through the wall to the body of the instrument outside on the instrument bench.

A timer was constructed to control the sequence of exposure. A one-turn-per-minute synchronous motor with a cam actuated snap switches at start and end of each exposure, and in addition a visual dial was included. The original intent had been automatic solenoid control of the monochromator exit slit and wavelength drum, but this proved impractical to arrange. In the tests, the switches served only as an audible signal for the observer to operate the slit diaphragm. The timer was placed on the instrument bench such that the observer could note the dial with the eye not occupied with the infrared telescope.

Control of temperature by the integral thermostat of the air-conditioner proved to be inadequate due to excessive heat capacity of the room and the effect of heating within the cells due to the infrared lamp. After the first two tests, a duct was run directly from the air-conditioner into the chamber. The room served as a heat reservoir or sink as required through a small blower installed in the chamber wall. By manipulation of a damper in the duct, the blower, and an electric heating element in the room, close control of temperature was possible. A thermocouple in the cell block, with potentiometer and melting ice reference, provided measurement of temperature. A hygrothermograph was placed in the chamber, although humidity was not controlled.

SOURCE OF MOTHS

The most desirable specimen was thought to be one reared from the pupa under controlled conditions. Pupae of tobacco moths were obtained from Florence, South Carolina on April 27, 1960 and put in storage at temperature 40°F. and relative humidity 35 per cent. Attempts to rear moths throughout the summer months were largely unsuccessful, both in an insulated chamber kept at 86°F., and in darkened spaces at ambient summer conditions. Of 689 pupae, only 53 emerged. These were used in tests as soon as they became capable of flight.

The bulk of the moths tested were adults caught in black-light field traps. While these moths were of unknown history and selection, there was a point in favor of using them. They should be healthy, active adults likely to propagate the next generation. The effect on the tests of their having been trapped by light is not predictable, but Bell (1) found support for the hypothesis that there is no significant effect. The traps, of a type developed by U.S.D.A. engineers and using black-light fluorescent lamps, were located near Chatham, and Blacksburg, Virginia. Moths were gathered in the early morning, three times weekly at Chatham and daily at Blacksburg. The traps caught roughly equal numbers of tobacco and tomato moths, along with assorted other insects. A disadvantage of the traps as a source of hornworm moths was that only about 20 per cent of tobacco moths were female, while the sexes are known to occur in roughly equal numbers. Moths gathered from the traps were separated as to species and sex and put in screen wire cages.

During transportation by automobile from Chatham, the cages were covered with wet burlap to retard drying of the moths. Those were subjected to 100 miles of travel and a rise in altitude of 1600 feet. All moths used in tests were in the cages less than 24 hours.

PROCEDURE

VARIABLES

Factors having possible effects on response were listed and considered for attention in this experiment, with selection based on findings of previous studies and the capabilities of available apparatus. The following resulted:

Primary variables

1. Radiation wavelength
2. Temperature

Secondary variables

3. Species
4. Sex
5. Time of day
6. Radiation intensity
7. Humidity
8. Exposure time.

Additional factors

9. Radiation bandwidth
10. Radiation purity
11. Radiation polarization
12. Barometric pressure
13. Atmospheric inclusions and phenomena
14. Time rates of change of each variable
15. Moth's previous treatment as to radiation, conditions of confinement, and physiological factors.

Determination of a wavelength most effective in attraction moths, if such exists, was of first importance. Of previous work, only that of Bell (1) allowed a conclusion as to wavelength, and that considered the near ultraviolet region as a whole as being more effective than adjacent spectral regions. The main tests of this study were assigned the wavelength range between 3150 and 4550 Angstroms, inclusive, in an effort to more narrowly define effectiveness within the near ultraviolet, and to investigate further the blue and violet region. Nominal bandwidth was set at 100 A., and bands were spaced at intervals of 200 A.

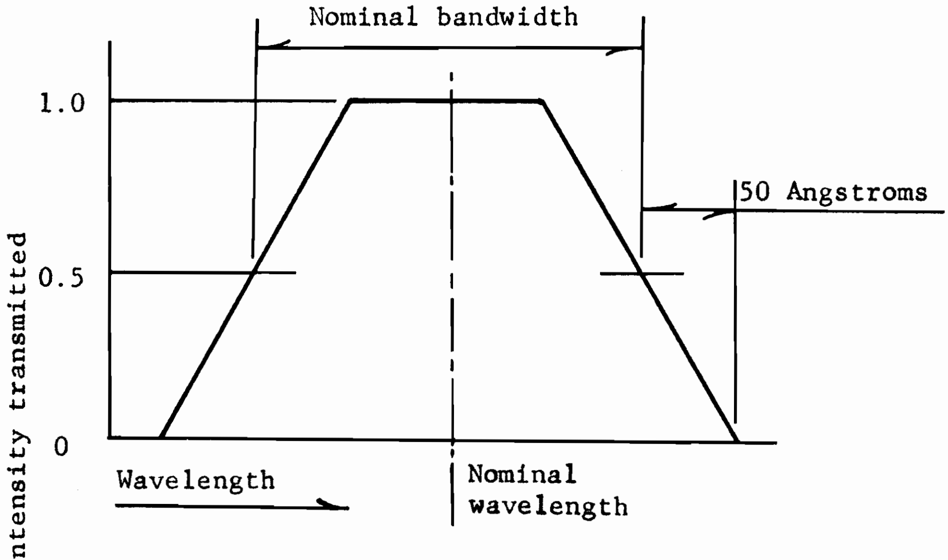
Temperature had not been dealt with previously as a primary variable, and as the evening cooling is an obvious concurrent phenomenon to moth flight, investigation was warranted. The range of 60 to 80°F. was chosen to cover average summer night temperatures.

Due to previous work with hornworm moths having shown little effect on response of relative intensity, and to the lack of suitable control for rapid adjustment, maximum output of the radiation source was used at all test bands. Humidity was considered a possibly important factor, but control means were not available. The additional factors listed were beyond the scope of this study. They were kept constant as far as practicable.

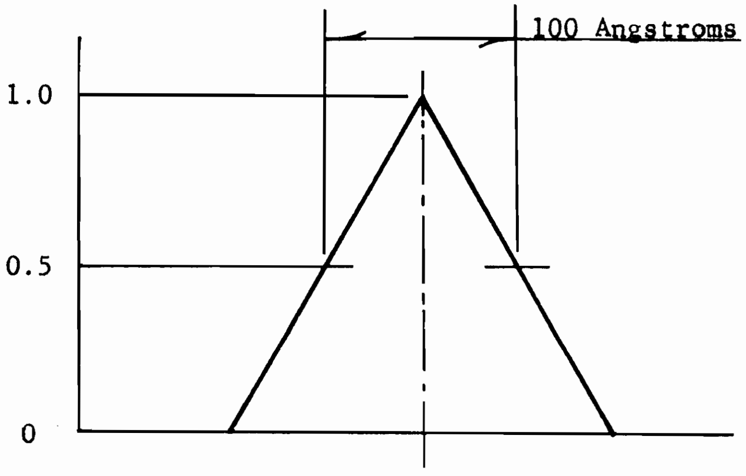
MONOCHROMATOR OPERATION

The monochromator passband characteristic (Fig. 4), with a nominal setting of 100 Angstroms, passed radiation of a bandwidth actually 200 A., with intensity dropping to zero at the fringes. Thus no overlap of wavelengths occured on adjacent bands at 200 A. intervals. As the output beam spread upon leaving the exit slit, the spectral intensity distribution over wavelength was roughly imposed on the width of the quartz window to the testing cells. Height of the beam was full slit length, 25 millimeters. The wavelength control drum was graduated on a linear scale, the smallest division being one millimicron, or 10A. Calibration was checked by peak photometer readings of the spectral lines of a mercury lamp, and according to the instrument specifications, error was less than 10 A. Calibration checks after all tests were completed showed that the wavelength drum indicated values 110 A. too high. The change was thought to have occurred as a result of a minor adjustment between tests, after which calibration was unfortunately not checked. With the bandwidth used, this error did not greatly affect response data or results.

Nominal bandwidth was set by the exit slit width and left constant for all tests. Entrance slit width was identical to that of the exit slit, according to instructions for obtaining maximum intensity output and purity. The exit slit diaphragm was used to turn the output on and off. The entrance slit diaphragm was kept fully open, except in some later tests when it was equipped with a stop which allowed one setting of reduced intensity. Relative intensity of each waveband (Fig. 5) was



(a) General form of the monochromator passband



(b) Passband form as used in the tests

FIG. 4. MONOCHROMATOR PASSBAND CHARACTERISTIC

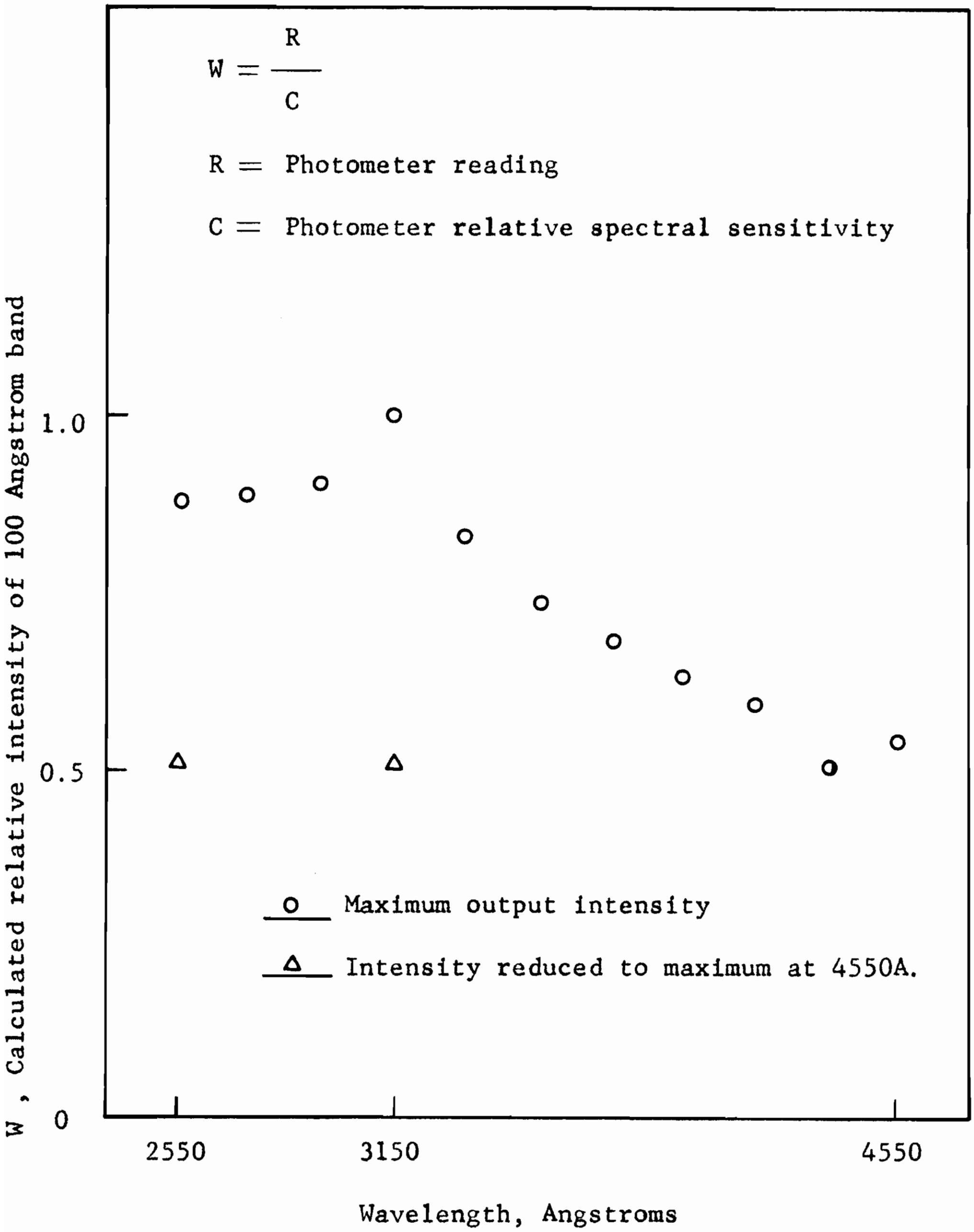


FIG. 5. RELATIVE INTENSITY OF WAVEBANDS

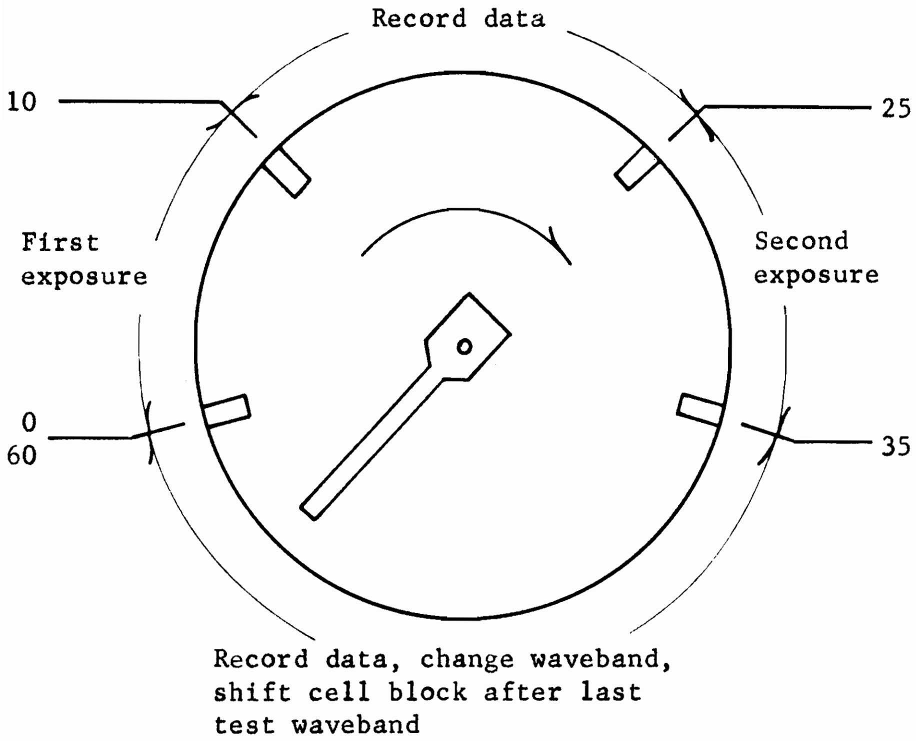
calculated from the averages of photometer readings taken throughout the tests.

TESTING ROUTINE

In order to observe a large number of moths, it was necessary to irradiate and observe each one in as short a time as practical, consistent with accurate recording of response data. Preliminary observations were made on twenty moths to determine a suitable exposure period and the types of data to be taken. It was found that of moths responding within one minute after the start of exposure, most responded immediately or after only a few seconds delay. The exposure period was set at ten seconds. To allow for the possibility of the moth not seeing the first exposure, a second was given after a rest interval. The timed exposure cycle which resulted (Fig. 6) consisted of two exposures and allowed time between for the observer to record data. Each moth received this cycle at each test waveband, and was exposed successively to all wavebands of a test in random sequence.

Six units of data were recorded for each exposure:

1. Order of band in random sequence
2. Intensity of action before exposure (none, weak, strong)
3. Time from start of irradiation to reaction (seconds)
4. Type of reaction (attracted, repelled, questionable)
5. Intensity of reaction during exposure (none, weak, strong)
6. Intensity of action after exposure (none, weak, strong).



Timer dial, showing elapsed seconds

Each moth received this cycle at each test waveband. Wavebands were in random order.

FIG. 6. EXPOSURE CYCLE

FIG. 7 OBSERVING MOTH ACTIVITY

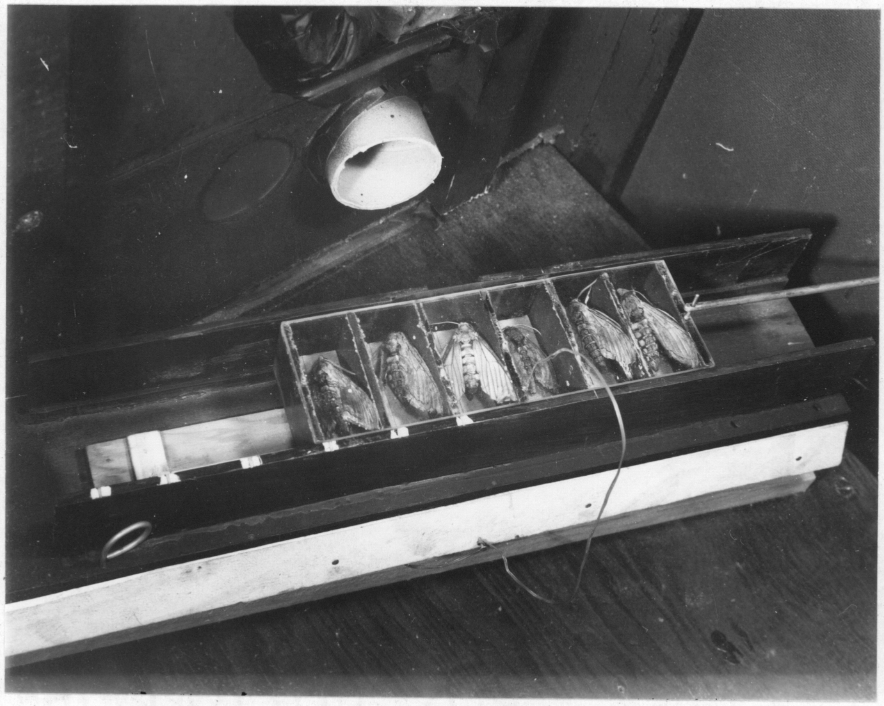


FIG. 8. MOTHS IN TESTING POSITION

EXTENT OF TESTS

Test	Temp.	Number of Moths				Total	Wavelength Range Increments of 200 A.
		Tobacco		Tomato			
		M	F	M	F		
MAIN TESTS							
1	75°	64	11	32	36	143	3150 - 4550
2	65°	32	32	32	32	128	3150 - 4550
3	80°	34	34	32	32	132	3150 - 4550
4	60°	32	26	38	32	128	3150 - 4550
						531	
INTENSITY CHECK TESTS							
5	80°	16	8	20	16	60	3150, 4550, 3150*
6	70°	16	3	16	4	39	3150, 4550, 3150*
7	60°	16	13	16	16	61	3150, 4550, 3150*
						160	
SHORTER WAVELENGTH TEST							
8	70°, 80°	32	17	29	34	112	2550 - 3150, 2550*
		TOTAL MOTHS TESTED				803	

*Intensity reduced to that used at 4550 A. band.

RESULTS

MAIN TESTS

Results were tabulated with principal emphasis on wavebands and temperature. The waveband analysis was grouped into:

Table 1. All moths, Tobacco moths, Tomato moths
Table 2. Temperature groups: 60, 65, 75, 80 F.
Table 3. Sexes: Male, Female
Table 4. Origins: Blacksburg, Chatham, Reared

The temperature analysis groups were:

Table 5. All moths, Tobacco moths, Tomato moths
Table 6. Male, Female

The method of tabulation was similar to that of Pruitt, and result designations used in that investigation were followed. Only moths which responded at least once during the test were considered in finding response and reaction percentages. In this study, "response" means the number of moths that showed activity when irradiated; "reactions" means the total number of times the responding moths showed activity, with two chances for each moth. Per cent response and per cent reaction of the responding moths were each found by two separate calculations. The first considered only those moths which received the waveband in question first in a random sequence of bands, and the second considered all moths exposed to the band throughout the sequence. A "Total" column was added to those for each band to show per cent values with all bands lumped. A sample calculation precedes the appended tables.

Separation of types and degrees of reactions were not considered in this tabulation, since inspection of the data showed no pattern dependent upon the arbitrary divisions. Concerning these divisions, the 1366 total reactions were judged about equally between "attracted" and "questionable", with only three judged as "repelled."

Of 531 moths tested, 341 responded at least once. Considering the tables as a whole, the most obvious feature with respect to wavebands was rough conformance of response and reaction percentages of all groups to the plots (Figs. 9, 10) of Table 1. In general, the larger the group, the closer was conformance to these patterns. The method of calculation which considered only the waveband received first in the random sequence of bands for each moth (Fig. 9) showed little to be considered as variation with wavebands, and little similarity between species. This might have been expected, since the average number of possible reactions per band for the "all moths" group was only 2(531)/8, or about 133. Bands in random order, with 682 possible reactions per band in the "all moths" group, showed a somewhat more definite pattern (Fig. 10). Pertinent features were: Maximum reactions at 3150 A., a sharp decrease from 3950 to 4150 A., minimum at 4350 A., and a slight increase to 4550 A. Plots for the two species follow that for "all moths" in general trend.

Both response and reaction percentages averaged approximately twice as great when first bands only were considered, as for random bands. This ratio held roughly for all groups. However, the lack of a consistent trend in first band values for any group indicates that the minimum number of possible reactions at each test treatment should be

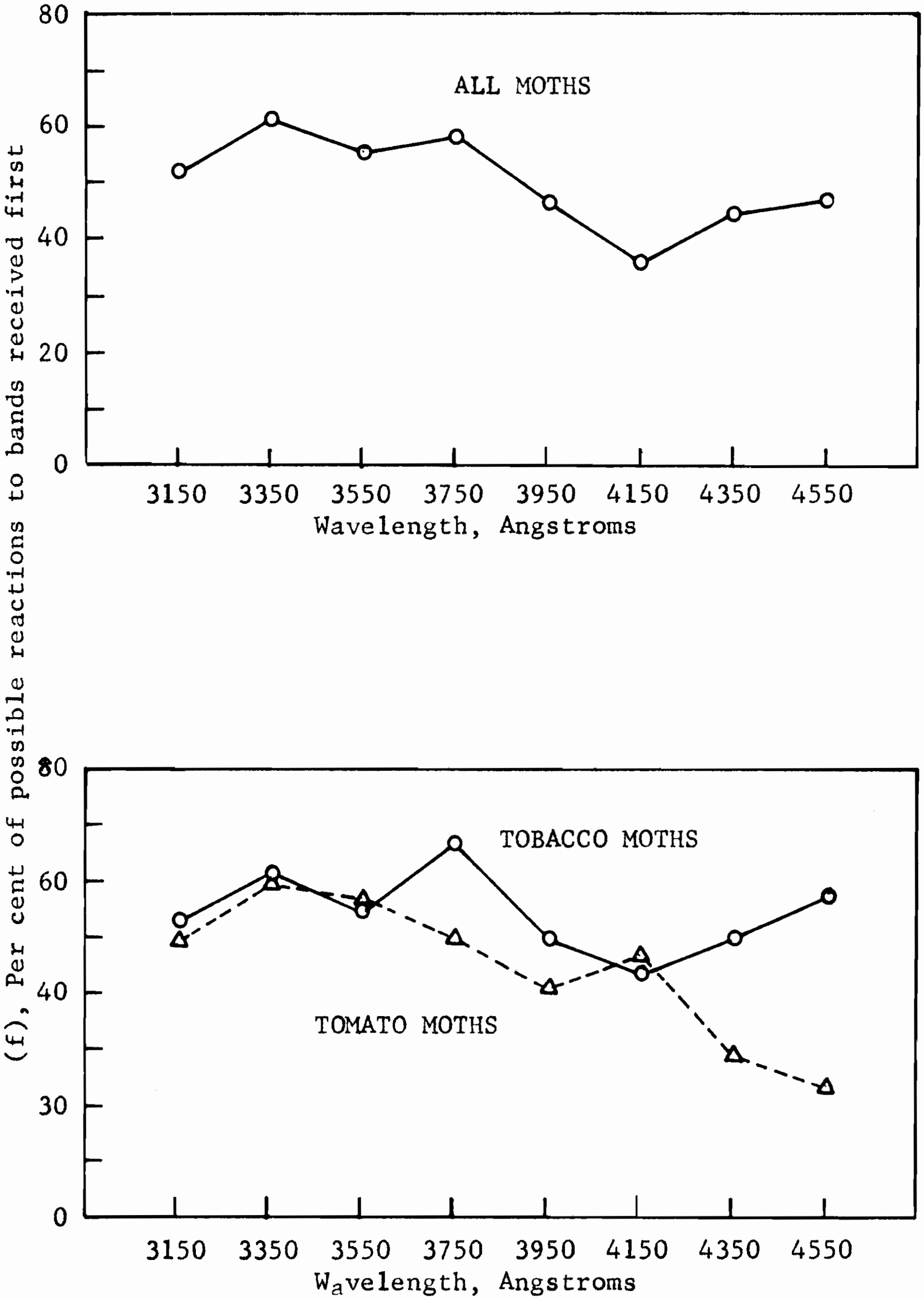


FIG. 9. REACTIONS OF MOTHS AND SPECIES TO WAVEBANDS RECEIVED FIRST

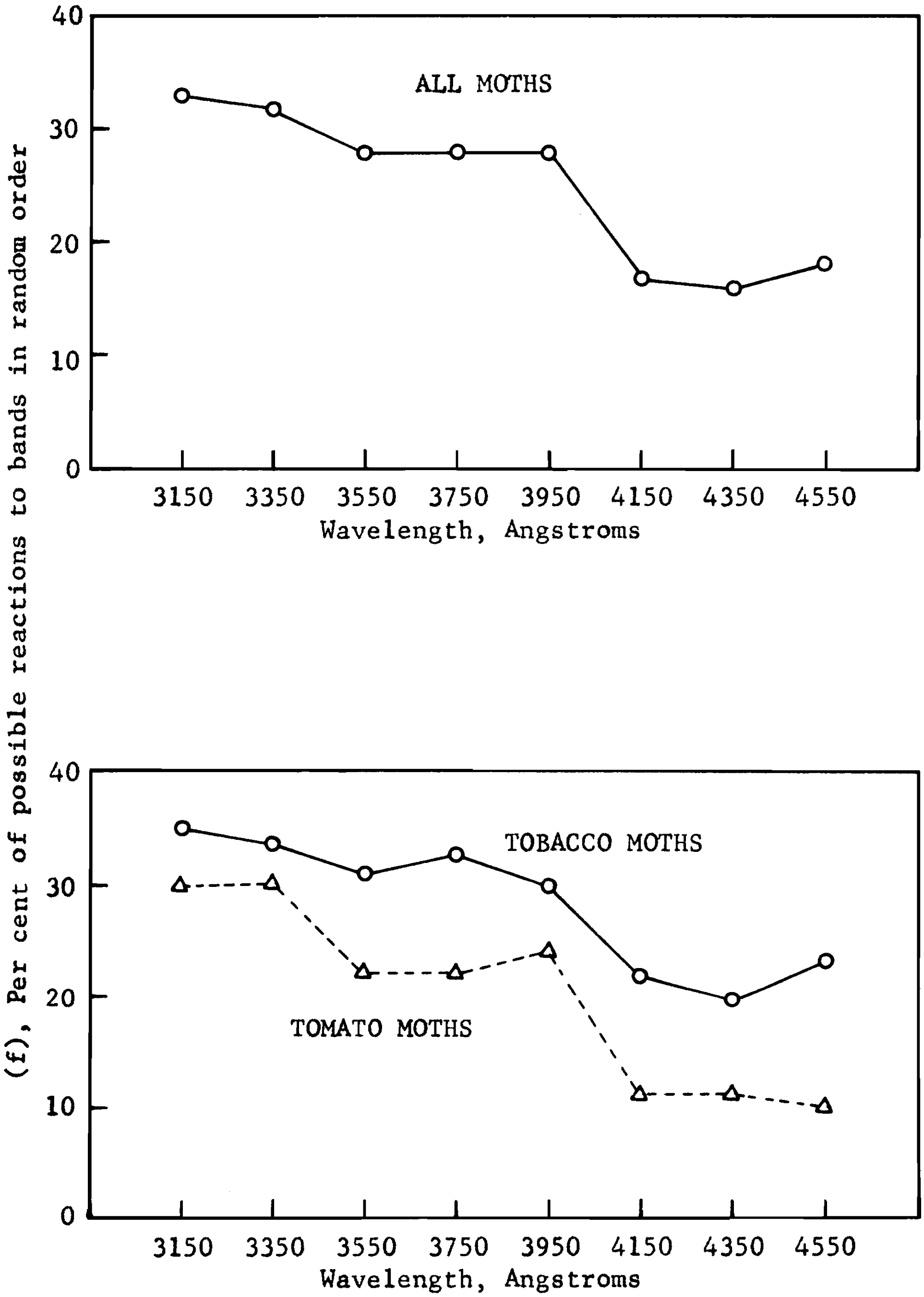


FIG. 10. REACTIONS OF MOTHS AND SPECIES TO WAVEBANDS IN RANDOM ORDER

considerably greater than that used here, for this type of study.

Table 1 indicated that the tobacco moth was definitely a more active species than the tomato in response to the wavebands used. Response and reaction percentages for tobacco moths were larger at every band for both calculations. The total column showed that the difference was more pronounced in the random band calculations. This species effect was in contrast to the findings of Bell, which indicated no significant effect of species. Another evident difference between species in this study was the greater difference in activity of tomato moths between bands of maximum and minimum response compared to tobacco moths, as shown in Figure 10.

The temperature groups of Table 2 failed to show a clear pattern of waveband response related to temperature. In the total column, first band activity was nearly equal for all temperatures, while the random band calculations indicated a slight increase of activity with rising temperature. Values for individual wavebands at each temperature varied widely, due to small numbers of moths in each. Previous investigators derived no conclusions as to the effect of temperature on wavelength response.

Females, in Table 3, were slightly more active than males at the first band, but this was not confirmed by random bands. Sex effects appear negligible, in agreement with previous work.

Day and night groups, Table 4, were separated at 6:00 p.m. No consistent difference appeared. This agrees with findings of Kent, but Pruitt found moths tested at night slightly more responsive.

Origin groups, Table 5, showed no consistent difference between reared moths and those from the two light trap locations. The reared moths gave the lowest activity at the random bands. The 53 reared moths were definitely too small a group on which to base conclusions in this study. The two groups of light-trap moths, however, with 112 and 178 responding moths, should have indicated some response difference due to place of origin or to the travel from Chatham, if such existed. Previous investigators made no comparisons between light-trap locations.

The temperature-based Tables 6 and 7 gave no indications of temperature effects on response to radiation in the near ultraviolet. First band and random band calculations within any one group failed to follow a common trend. The species separation, with the exception of first band values at 80 F., indicated greater activity for tobacco moths as found in Table 1. The sex separation showed no consistent difference.

INTENSITY EFFECT CHECK

The plots of the main test data disclosed a definite trend, and the similarity of this to the plot of calculated relative intensity output of the monochromator (Fig. 5) was noted. A series of three tests, at temperatures of 60, 70, and 80 F. was made to determine if relative intensity was responsible for the variation of moth activity over the wavelength range. Wavebands used were 3150 and 4550 A. at maximum intensity as in the main tests, plus a second 3150 A. band with intensity reduced to that used at 4550 A. Table 8 presents response and reaction percentages for the three temperatures and "all moths". Smaller groups had too few moths to consider. Within each group, the activity at both

3150 A. bands was higher than that at 4550 A.; in most instances the two 3150 A. bands showed fairly close values. This indicated that within the wavelength and intensity ranges used, relative intensity was not an important factor.

SHORTER WAVELENGTH TEST

The tendency for moth activity to increase at bands of shorter wavelength, in the main tests, pointed out a need to extend the range. A test was made using bands between 2550 and 3150 A., inclusive. A second band at 2550 A. was added to further check effects of relative radiancy (Table 9). No such variation with wavelength as found in the main tests was present. Probably due to the small number of moths in all groups, there was not even correlation between first band and random band calculations within any group. No inference of response to wavebands could be drawn here. However, the total columns for all groups agreed fairly closely, indicating no response difference between species in this range as a whole. This is contrary to the main test results, and could be due to the wavelength range, or to fewer bands being used. Another point of difference that could be attributed to either of these causes was the much larger total response and reaction values, averaging nearly twice corresponding ones of the main tests. The two bands at 2550 A. had closely agreeing figures, which strengthened the implication of the intensity check tests, that relative intensity had little effect in this study.

TRIAL OF WEIGHTED COUNT ANALYSIS

An effort to normalize response data was made, using the shorter wavelength test as a sample. This test was chosen for the extreme scatter of response. It was hypothesized that a simple count of responding moths or reactions was inadequate to describe the effect of radiation upon the moth. That is, the erratic and unpredictable results obtained in this and other experiments were in part due to arbitrary and fixed criteria for attraction to the radiation source which could give improper weight to the different qualities of a moth reaction. If a weighting system could be devised which would cause the scattered data to assume some common form for all groups, the relative importance of the qualities of a reaction could be determined. The six units of data listed on page 23 were considered as the qualities of a reaction, and numerical values were assigned to the increments of type and degree for each unit.

Taking the plot of reaction count versus wavebands for any one tabulated group as a starting point, the method used was trial-and-error assignment of weighting values to reduce the scatter. These values were then applied to the other groups. Any marked reduction of scatter for all groups indicated trial of an intensified version of the same system. Several arrangements were tried, but none smoothed out the data for all groups. Pursuance of the weighted count appeared unwarranted.

STATISTICAL TREATMENT OF MAIN TESTS

The temperature groups of the main tests were considered large enough to justify the application of statistics, and calculations were done to confirm the variation of activity with wavebands. A modified Randomized Complete Block design was applied to 128 moths at each temperature, taking wavebands as treatments and temperatures as blocks. The modification was that since the blocks were not composed for homogeneity between moths, a test of temperature effects would be valid. An observation at each band-temperature combination was the number of reactions by the 128 moths for the random band tabulation.

The "F" tests of the hypotheses "waveband effects all zero" and "temperature effects all zero" both showed significant differences from zero at the 0.01 probability level. However, the data contained as large variations within wavebands as between, and only in the waveband means was there a clear indication of consistent difference between successive bands. The value of statistical treatment is doubtful until more uniform response is obtained.

CONCLUSIONS

1. The aggregate reaction of 531 individually tested tobacco- and tomato-hornworm moths was greatest at 3150 Angstroms and least at 4350 A., within the range 3150 to 4550 A.
2. Tomato moths responded less than tobacco moths, and showed a greater difference of response between bands of maximum and minimum response.
3. No definite effect of temperature between 60 and 80 F. was found on response to radiant energy.
4. Sex, time of testing, and moth origin had no detectable effect.
5. Relative intensity, within the range used, was not a factor in response to radiation wavelength.
6. Aggregate moth reaction to a waveband received first was roughly twice that to the same band in a random sequence of eight bands.
7. No advantage was found for recording type and degree of individual moth reaction.
8. Moth groups providing for less than 200 possible reactions per treatment were too small to show consistent trends.

RECOMMENDATIONS

1. Future experiments of this type should provide for several hundred possible moth reactions at each test treatment, to smooth out the erratic response of individual moths and small groups.
2. Investigation of the cause of extreme response differences between apparently identical moths should be made.
3. Moths should be tested in a larger cell than that used here, to eliminate possible effects of close confinement.
4. Subjective judgment of moth response should be eliminated.
5. The effect of temperature on general moth activity should be investigated.
6. The environmental factors humidity, air pressure, and atmospheric inclusions should be controlled.
7. Absolute values of radiant power used should be determined, and investigation made of an optimum value for attracting moths.
8. The middle ultraviolet spectrum (2800 to 3200 Angstroms) should be investigated, preferably in the same tests with further work in the near ultraviolet.

SUMMARY

Information was needed concerning the effectiveness of ultraviolet radiation in attracting tobacco- and tomato-hornworm moths. Environmental factors were considered as possibly interacting with the qualities of radiation in the net effect on moths. An experiment was projected which would attempt to determine the most attractive wavelength between 3150 and 4550 Angstroms, and to evaluate the effects of temperature, species, sex, time of day, and moth origin on the specimen response. Attempts to rear moths from pupae were largely unsuccessful, but produced 53 moths from 689 pupae. The remainder of the 803 moths used in tests were obtained from field traps equipped with black-light fluorescent lamps.

Moths were irradiated individually in close confinement, and observed by infrared telescope. At each test waveband, each moth received two consecutive 10-second exposures to radiation. Recorded data included action before exposure, time lag before reaction, type of reaction, degree of reaction, and action after exposure. Four main tests were made at temperatures of 60, 65, 75, and 80 F., each with eight wavebands 100 A. wide at 200 A. intervals between 3150 and 4550 A. In addition, three tests were made to determine the effect of relative intensity, which was not equalized in the main tests, and a limited test was made on four wavebands between 2550 and 3150 A.

The most revealing method of data analysis was that used previously by Pruitt, giving per cent of moths responding to a band and per cent

reactions, of the moths which actually showed some response to any band. These were 341 of 531 tested, in the main tests. The two percentages were calculated at each waveband by each of two methods: moths exposed to a particular band first, and all moths exposed to the band in a random sequence of eight bands. Values for the first band were roughly double those for random bands. The first band values showed the characteristic lack of consistency for this type of study when too few moths are subjected to each treatment. The random band values showed a common trend for most groups, characterized by maximum activity at 3150 A. and minimum at 4350 A.

Tomato moths were definitely less active than tobacco moths in these tests, and showed a greater difference of response between bands of maximum and minimum response. No definite effects on response to wavebands were found due to temperature, time of testing, moth origin, or sex. A temperature-based tabulation with all wavebands lumped showed no gross radiation response pattern due to temperature. No pattern of response differences at separate temperatures was found due to species, or sex.

Relative intensity was found to have negligible effect on response to wavebands in these tests.

The shorter wavelength tests showed no consistent differences of wavelength response between various groups, but average percentages for the 2550 to 3150 A. range as a whole agreed closely between groups. This test gave response and reaction percentages for both first and random band calculations about twice corresponding values in the main tests.

An attempt to determine the most meaningful aspects of the individual moth reaction by trial-and-error weighting of recorded data was unsuccessful.

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VITA

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He attended the University of Florida during summer, 1950, then enlisted in the navy. He returned to the University in 1954 and graduated in January 1960 as Bachelor of Agricultural Engineering. He was awarded a research assistantship position at the Virginia Polytechnic Institute and there pursued studies leading to the Master of Science Degree in Agricultural Engineering. Requirements for the degree will be completed in August, 1961.

John R. Menear

APPENDIX

METHOD OF CALCULATING TABLES

Data designation:

a: Number of moths tested at the band; (a) for each random band is total (a) of all first bands.

b: Number of moths which responded at least once during test; (b) for each random band is total (b) of all first bands.

c: Number of moths which responded to the band.

d: Per cent of (b) that responded to the band: (c/b).

e: Number of reactions shown by (c); maximum possible is (2c).

f: Per cent of possible reactions shown by (c): (e/2b).

Sample calculation: 3150 Angstrom band, all moths group, main tests.

First band:

a: 73
b: 61
c: 46
d: 46/61 = 75%
e: 63
f: 63/2(61) = 52%

Random bands:

a: 531
b: 341
c: 153
d: 153/341 = 45%
e: 225
f: 225/2(341)=33%

Table 1. RESPONSE OF ALL MOTHS AND TWO SPECIES TO WAVEBANDS

Moth group and waveband considered		Waveband centered at (Angstroms)								Total
		3150	3350	3550	3750	3950	4150	4350	4550	
ALL MOTHS										
First band	a	73	81	77	43	83	62	55	57	531
	b	61	43	52	23	50	42	34	36	341
	d	75	79	81	82	70	55	68	69	72
	f	52	62	56	59	47	36	44	47	50
Random bands										
	d	45	43	40	37	39	26	23	29	35
	f	33	32	28	28	28	17	16	18	25
TOBACCO MOTHS										
First band	a	41	33	37	19	43	34	26	32	265
	b	38	21	31	11	33	27	20	25	205
	d	76	81	81	91	72	67	85	84	78
	f	53	62	55	68	52	43	50	58	54
Random bands										
	d	48	46	44	42	42	31	27	37	40
	f	35	34	31	33	30	22	20	23	28
TOMATO MOTHS										
First band	a	32	48	40	24	40	28	29	25	266
	b	23	22	21	12	17	15	14	11	136
	d	74	77	81	75	60	33	28	36	63
	f	50	61	57	50	39	47	29	23	44
Random bands										
	d	38	40	34	30	33	19	17	17	29
	f	30	30	22	22	24	11	11	10	20

Table 2. RESPONSE OF TEMPERATURE GROUPS TO WAVEBANDS

Moth group and waveband considered		Waveband centered at (Angstroms)								Total
		3150	3350	3550	3750	3950	4150	4350	4550	
60 DEGREES F.										
First band	a	22	14	18	10	16	18	12	18	128
	b	18	7	13	8	13	13	12	15	99
	d	83	72	92	88	69	46	83	73	73
	f	61	43	65	56	42	27	58	47	49
Random bands										
	d	35	36	37	35	37	26	23	30	33
	f	27	26	25	24	28	18	20	19	23
65 DEGREES F.										
First band	a	9	21	16	13	26	15	13	15	128
	b	6	10	9	4	12	8	8	7	64
	d	83	50	89	100	67	50	75	71	70
	f	50	55	44	63	33	37	62	50	51
Random bands										
	d	38	45	44	42	39	27	25	25	35
	f	27	31	29	30	27	16	18	14	24
75 DEGREES F.										
First band	a	19	20	20	15	25	19	12	13	143
	b	12	8	12	7	17	13	5	9	81
	d	67	100	92	71	77	62	40	70	74
	f	37	56	63	64	47	46	30	50	49
Random bands										
	d	48	46	37	35	44	33	38	35	38
	f	31	33	25	26	30	24	16	22	26
80 DEGREES F.										
First band	a	23	26	23	5	16	10	18	11	132
	b	25	18	18	4	8	8	9	7	97
	d	72	83	67	75	63	63	44	47	68
	f	52	75	50	50	50	31	17	43	50
Random bands										
	d	57	49	43	38	36	21	20	25	36
	f	46	40	33	33	26	13	13	16	28

Table 3. RESPONSE OF SEXES TO WAVEBANDS

Moth group and waveband considered		Waveband centered at (Angstroms)								Total
		3150	3350	3550	3750	3950	4150	4350	4550	
MALES										
First band	a	43	42	40	23	38	48	28	34	296
	b	32	21	24	12	26	33	17	22	187
	d	66	76	75	83	62	64	59	68	69
	f	44	57	52	58	42	42	38	43	46
Random bands										
	d	43	38	40	36	38	32	25	30	35
	f	31	29	26	26	24	22	16	19	24
FEMALES										
First band	a	30	39	37	20	45	14	27	23	235
	b	29	22	28	11	24	9	17	14	154
	d	81	82	86	82	79	22	71	71	77
	f	60	66	59	59	52	10	50	54	55
Random bands										
	d	47	50	40	38	40	20	23	27	35
	f	36	36	30	31	32	11	16	17	26

Table 4. RESPONSE OF DAY AND NIGHT GROUPS TO WAVEBANDS

Moth group and waveband considered		Waveband centered at (Angstroms)								Total
		3150	3350	3550	3750	3950	4150	4350	4550	
DAY TESTED										
First band	a	65	70	65	35	73	50	52	52	463
	b	55	37	45	20	47	32	31	25	301
	d	76	81	82	80	68	50	65	92	72
	f	53	62	56	55	48	30	43	62	50
Random bands										
	d	43	43	40	37	38	25	22	28	35
	f	34	33	28	29	28	17	16	18	25
NIGHT TESTED										
First band	a	8	11	12	8	9	12	3	5	68
	b	6	6	7	3	3	10	3	2	40
	d	67	67	71	100	100	70	67	100	75
	f	42	50	43	83	67	55	50	75	54
Random bands										
	d	47	45	40	40	42	37	30	37	40
	f	24	26	22	26	29	22	15	20	23

Table 5. RESPONSE OF ORIGIN GROUPS TO WAVEBANDS

Moth group and waveband considered		Waveband centered at (Angstroms)								Total
		3150	3350	3550	3750	3950	4150	4350	4550	
BLACKSBURG										
First band	a	21	22	22	14	24	28	16	19	166
	b	15	12	15	8	16	17	14	10	112
	d	80	58	80	87	81	53	50	100	78
	f	50	42	60	69	47	34	36	55	46
Random bands										
	d	40	37	36	29	38	27	16	24	31
	f	26	25	21	19	23	16	12	17	20
CHATHAM										
First band	a	40	55	49	27	50	30	30	31	312
	b	31	27	31	13	28	19	12	17	178
	d	84	89	87	77	64	58	67	65	70
	f	60	70	58	50	48	40	50	50	54
Random bands										
	d	40	48	43	41	39	25	26	31	37
	f	36	37	31	31	30	17	19	19	27
REARED										
First band	a	12	4	6	2	9	4	9	7	53
	b	15	4	6	2	6	4	8	6	51
	d	53	75	50	100	67	50	88	67	65
	f	37	63	33	75	50	25	50	50	44
Random bands										
	d	53	43	37	43	39	27	27	31	38
	f	39	33	28	38	31	22	20	22	29

Table 6. EFFECT OF TEMPERATURE ON RESPONSE OF ALL MOTHS AND SPECIES

Moth group and waveband considered		Temperature, Fahrenheit			
		60°	65°	75°	80°
ALL MOTHS					
First band	a	128	128	143	132
	b	99	64	81	97
	d	73	70	74	68
	f	49	51	49	50
Random bands					
	d	33	35	38	36
	f	23	24	26	28
TOBACCO					
First band	a	58	64	75	68
	b	51	41	48	65
	d	90	76	85	65
	f	49	56	56	47
Random bands					
	d	36	35	45	42
	f	25	24	31	32
TOMATO					
First band	a	70	64	68	64
	b	48	23	33	32
	d	60	61	58	75
	f	41	41	39	56
Random bands					
	d	27	34	25	30
	f	21	24	17	24

Table 7. EFFECT OF TEMPERATURE ON RESPONSE OF SEXES

Moth group and waveband considered		Temperature, Fahrenheit 60°	65°	75°	80°
MALE					
First band	a	70	64	96	66
	b	52	28	59	48
	d	66	68	76	61
	f	42	50	50	43
Random bands					
	d	31	32	36	39
	f	19	20	25	32
FEMALE					
First band	a	58	64	47	66
	b	47	36	22	49
	d	85	69	68	80
	f	59	49	48	60
Random bands					
	d	34	37	40	37
	f	29	28	28	28

Table 8. EFFECT OF RELATIVE INTENSITY ON RESPONSE

Moth group and waveband considered		Waveband			Total
		3150	4550	3150*	
ALL					
First band	a	60	54	46	160
	b	33	35	25	93
	d	88	66	80	76
	f	67	56	60	57
Random bands					
	d	67	46	72	62
	f	52	31	50	44
60 DEGREES F.					
First band	a	28	15	18	61
	b	16	6	7	29
	d	88	50	29	73
	f	75	42	50	62
Random bands					
	d	66	48	68	61
	f	60	26	60	48
70 DEGREES F.					
First band	a	14	17	8	39
	b	8	14	5	27
	d	75	50	80	63
	f	44	36	70	48
Random bands					
	d	56	41	89	62
	f	39	32	46	38
80 DEGREES F.					
First band	a	18	22	20	60
	b	9	15	13	37
	d	100	80	92	89
	f	72	57	62	62
Random bands					
	d	76	49	65	63
	f	55	35	49	46

*Intensity reduced to that used on 4550 A. band.

Table 9. SHORTER WAVELENGTH TEST; RESPONSE OF ALL MOTHS AND SPECIES TO WAVEBANDS

Moth group and waveband considered		Waveband centered at (Angstroms)					
		2550	2750	2950	3150	2550*	Total
ALL MOTHS							
First band	a	25	28	18	20	21	112
	b	17	20	12	13	14	76
	d	76	80	67	100	79	80
	f	65	62	46	69	71	63
Random bands							
	d	53	58	57	60	57	57
	f	40	42	41	42	41	41
TOBACCO							
First band	a	12	12	7	8	10	49
	b	9	10	7	7	8	41
	d	67	80	57	100	88	78
	f	61	65	36	71	81	63
Random bands							
	d	49	56	56	63	61	57
	f	38	43	41	44	43	41
TOMATO							
First band	a	13	16	11	12	11	63
	b	8	10	5	6	6	35
	d	88	80	80	100	67	83
	f	69	60	60	67	58	63
Random bands							
	d	57	60	57	57	51	57
	f	44	41	40	40	39	41

*Intensity reduced to that used on 4550 A. band.