THE EFFECTS OF LIGHT UPON GROWTH AND REPRODUCTION IN THE GROUSE LOCUST, *ACRYDIUM ARENOSUM ANGUSTUM* HANC. (ACRIDIDAE, TETRIGINAE)

by

CURTIS WILLIAMS SABROSKY

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INTRODUCTION

The genetic studies of the grouse locusts carried out by Nabours and his students since 1908 have offered many opportunities for observations on the biology and ecology of these insects. It has been found that the southern races breed throughout the entire year in the northern greenhouse, producing an average of four generations.

The northern forms, on the other hand, breed more slowly. In nature they produce only one full generation a year, and require a period of hibernation. Not more than two generations, at best, can be bred in the greenhouse (Nabours, Larson and Hartwig, 1933).

To facilitate studies of the genetics of the northern race, *Acrydium arenosum angustum* Hancock, attempts were made to increase the number of generations and offspring, and to maintain pedigreed stock from one breeding season to another. Experiments involving a mercury-vapor lamp were conducted by Nabours and Larson at the Kansas Agricultural Experiment Station laboratory from March, 1929, to June, 1931. The work herein reported is a continuation and an expansion of their experiment.

Although the effects of light upon organisms have been studied in many phases, there have been few controlled experiments dealing with its relation to growth and reproduction. This project was therefore planned partly as a contribution to the study of the problems, in addition to the primary purpose of endeavoring to increase the breeding rate for genetical purposes.

REVIEW OF LITERATURE

The general problem of light in relation to organisms has been attacked from numerous angles by a great many investigators. Uvarov (1931) has given a very comprehensive summary of the literature on climate and insects, including the effect of lights of various colors, intensities, and periods of illumination. Bachmetjew (1907) and Davenport (1908), in particular, have summarized the data on light as it affects rate of growth. Chapman (1927), Shelford (1929) and others have also reviewed the literature in this field.

No single worker has produced observations and data on all phases of light effects on growth and reproduction; therefore, any summary must review the problem section by section, introducing the scattered evidence at appropriate points. The present review has been limited to studies on light and insects, although such data as the work of Bissonnette (1930-1932) on light intensity and the sexual cycle in birds, and that of Garner and Allard (1920) on late flowering in plants, were considered as interesting supplements to the problem under consideration. The extensive literature on phototropism, ecology, and economic entomology has not been considered, except as it pertained to this special investigation.

According to Uvarov (1931), many of the data on the effect of light on copulation and oviposition are unreliable. Recent studies of economic insects have shown, however, that those which are normally diurnal are stimulated by light, whereas both copulation and oviposition are inhibited in the normally nocturnal insects. Chopard (1920) noted stimulation of oviposition in Mantis religiosa by sunlight, but radiant heat may have been a factor. Wille (1920) believed that copulation in cockroaches occurs only in darkness and is inhibited by light. Inhibition of oviposition in nocturnal insects is clearly shown by the results of Barber (1925) on the adults of the European corn-borer, of Isely and Ackerman (1923) and Herms (1929) on the codling moth, and of Collins and Nixon (1930) on two other species of moths.

There are few data on the effect on number of eggs and offspring produced, and these concern nocturnal insects. Gal (1898) recorded differences in the average number of eggs laid by silkworm adults under lights of different wave lengths, the number varying from 307 eggs per female under red light to 429 under white light and 456 under violet. Barber (1925) found that constant light resulted in a considerable reduction in the average number of eggs produced by corn-borer moths. Observations on the silkworm moth by

Sakurai, as reported by Shelford (1929), showed that females reared in light produced an average of 569.2 eggs, while those reared in shadow averaged 635.0 eggs. This difference was thought to be insignificant, even though the results agreed with the photic inhibition noted by other workers.

Some observations have been made (e.g., Barnes, 1930) on the apparent relation of light intensity to the emergence of insects from pupae. Some insects seem to emerge at definite times of day, but it has not been proved that light is the controlling factor.

Considerable disagreement exists as to the effect of light on the rate of growth. Schoch (1880) and Zhmuidzinovitch (1891), using different species of moths, found that rate of development differed with various colored lights. Schoch found the most rapid growth under violet light, where the larvae ate almost twice as much food and produced moths fourteen days earlier than those under blue and red glass. Japanese students of sericulture (Tazawa, 1903; Sakurai and Takemura, 1925) also found that light seems to affect rate of growth. On the other hand, Montgomery (1911), Genieys (1925) and Northrop (1926) reported that light had no effect on development. Northrop kept a *Drosophila* culture in the dark for 230 generations, and found the rate of growth at the end of that period to be the same as that of a normal culture.

Few workers have studied possible effects on size. Beclard (1858) and Linden (1899) kept larvae of flies (*Musca*) and butterflies (*Vanessa*), respectively, under colored glass, and noted differences in size, the largest individuals being produced under violet and blue glass. According to Beclard, the smallest maggots, produced under green glass, were only one-third the size of those produced under violet light.

There are few exact records on viability. Barber and others observed that moths in constant light did not live as long as those in darkness. No data have been seen on the degree of mortality up to maturity.

In general, data on the relation of light to growth and reproduction in insects are meager and contradictory. Controls were lacking in many experiments. Older work is hard to interpret in terms of wave-lengths of light. The exact causes, whether nervous or photochemical, effect on food or other factors, remain uncertain.

MATERIALS AND METHODS

Acrydium arenosum angustum Hancock, a common grouse locust in the region of Manhattan, Kansas, was used almost entirely in this experiment, although some scattered data were secured on *Apotettix eurycephalus* and *Paratettix* *texanus* from the genetical studies in the greenhouse. *A. arenosum* were collected in open, level woods, called Jones' Cabin in the records, located about two miles southeast of Manhattan at the juncture of the Blue with the Kansas River. Records of patterns were made according to the genetical study by Nabours, Larson and Hartwig (1933), but this phase was not emphasized. This northern race breeds more slowly than the southern forms used in the genetical studies, producing only one or two generations per year in the greenhouse, as compared with four in the latter species. *A. arenosum angustum* are normally in hibernation during the months (November-March) covered by the light experiment. It was believed, therefore, that any effects due to light would be more distinct in this species than in the faster breeding southern species.

In 1931-1932, groups were kept under violet and white lights, with a control group (called C in the tables) under the ordinary greenhouse conditions. Violet light was furnished by a Standard Cooper Hewitt A.C. Mercury Vapor Lamp, with plain glass tube, which produced some of the "near ultra-violet", as well as violet. It is referred to throughout the data as violet light (V. L.). "White" light (designated as E.L.) was produced by four 200-watt Sylvania clear bulbs, wired in parallel in a six-foot white enameled trough reflector. The chief components of the light are at the red end of the spectrum. All groups received approximately the same amount of sunlight through the ordinary glass of the greenhouse.

In order to equalize the groups as far as possible, the intensity of illumination of the electric lights was measured with a Leeds-Northrup Intensiometer. Approximate equality was then obtained by comparison with published data for the mercury-vapor lamp, and adjustment of the height accordingly. The height of the violet light averaged 28 inches above the table.

The lights ran continuously, except for brief interruptions for replacements or repairs, from November 28, 1931, until the experiment was discontinued, June 13, 1932. The grouping may be summarized as follows:

Control	Violet Light	Electric Light
Daylight Dark at night	Daylight plus Continuous violet light	Daylight plus Continuous Electric light

In 1932-1933, the effect of period of illumination was studied, using only violet light from Cooper-Hewitt lamps with "Corex D" tubes. These tubes transmitted more of the "near ultra-violet" than did the plain glass tubes used in 1931-1932. One group was placed under continuous violet light, one under violet light only twelve hours each day, and one was kept as a control, under the ordinary conditions of the greenhouse. The twelve-hour period was taken from 7:00 A.M. to 7:00 P.M. in order to have the violet light coincide with the daylight as closely as possible, for purposes of group comparison. These lights ran from December 4, 1932, to February 24, 1933, when the experiment was terminated because of low production and death of the experimentals. The grouping may be summarized as follows:

Control	Periodic Violet Light	Continuous Violet Light
Daylight Dark at night	Daylight plus 12 hrs.V.L. Dark at night	Daylight plus continuous V.L.

Both matings and offspring were kept in the breeding jars described by Nabours (1914, Fig. 1). The methods of mating, transferring, recording and preserving developed for the genetical studies on these insects have been applied here, as methods tested by years of use (Nabours, 1914, 1929). Some modifications were made, to suit the number of individuals available. Similar patterns or pattern complexes were used wherever possible in the three groups.

The jars were examined at least every other day for the appearance of young. Nymphs were transferred as soon as enough to form two sets had hatched, in order that each group might be reasonably homogeneous in age. This procedure often resulted in a small number of young in each jar, but it was thought necessary for accurate comparison of the growth rates within each group. Each jar was kept until all young either were mature or were dead. In this way, complete records for each jar were made on the age at maturity and on mortality up to maturity. Individual ages were recorded, in order to determine the mean age at maturity for each group, as well as the range of ages. These data made it possible to apply statistical methods for comparison of the various groups.

Conditions under the lights were controlled as carefully as was possible in the greenhouse without elaborate equipment. Constant temperature and humidity were not possible, even had such been desired. An effort was made to keep these conditions equal or nearly equal in the three groups at the same time, all being subject to the same fluctuations in the same room in the greenhouse. A fan was used to reduce the heat factor in the electric light group. Records show that barring occasional exceptions, the differences in temperature among the three groups have been kept within 3° C. Inasmuch as the violet light produced very little heat, yet gave results equal to or better than those under electric light, it appears that some cause other than heat must be operating. It is believed that the general humidity is close enough for practical purposes, due to the continual watering of the jars and the constantly moist soil.

Partitions were used to isolate the various groups from those under other conditions of light. The same treatment of feeding and watering, similar jars, comparable matings and jars of young, and equal intensities of illumination were other controls involved.

EXPERIMENTAL DATA AND DISCUSSION: 1931-1932

General

During the experiment for 1931-1932, 37 matings were made, which produced 479 offspring (Tables I, IA). In addition to these, four matings were made to test old, overwintered females (Table IV) and four to test "slow-developers". In all, 45 matings and 567 offspring were involved. Of the latter, 435 were transferred in comparable groupings for observation on the effects of light on growth and mortality, and 41 others were reared under the lights without special grouping. The few data for _P. texanus_ and _A. eurycephalus_ proved to be so incomplete that they have been omitted.

On Fertility of Matings (Tables I, IA)

The original group contained seven matings under E.L., eight under V.L., and seven as controls. Later matings increased these groups to twelve, thirteen, and twelve, respectively, as shown in Tables I and IA.

Of the twelve matings kept under E.L., seven produced offspring, for a fertility of 58.3 per cent; five matings in thirteen, or 38.4 per cent, were productive under V.L.; and only one mating in twelve, or 8.3 per cent, produced offspring in the control group. If the six matings made in April, the normal breeding season, should be disregarded, the relative fertility becomes 50 per cent (E.L.), 45.4 per cent (V.L.), and 0.0 per cent for the controls.

The difference between the results obtained from the effect of the two lights is not great enough to be significant. When the groups exposed to either light are compared with the control group, however, the difference is so marked as to be obviously significant. The lone productive control mating was made on April 6, and fertility would be expected at this time, without exposure to light. Considering only the data on the winter matings, it is evident that in no case have grouse locusts kept under the usual greenhouse conditions produced offspring during the winter,

Table I. Mating Chart: 1931-1932

Electric Light					Violet Light					Control				
Mating number	Date of mating	Date of first offspring	Period: Mating to offspring	Number of offspring	Mating number	Date of mating	Date of first offspring	Period: Mating to offspring	Number of offspring	Mating number	Date of mating	Date of first offspring	Period Mating to offspring	Number of offspring
119	11-14-31	1-11-32	58 days	71	110	11-14				103	11-12			
120	11-14-31	1-18-32	65 days	41	111	11-14	1-18	65 days	82	104	11-12			
121	11-14-31				112	11-28	1-18	51 days	8	105	11-14			
122	11-14-31	1-12-32	59 days	16	113	11-14	1-11	58 days	149	106	11-14			
123	11-14-31				114	11-14				107	11-14			
124	11-14-31				115	11-14				108	11-14			
125	11-14-31				116	11-14	1-12	59 days	49	109	11-14			
	3-21-31				117	11-14								
132	3-21-31	Inc.	Inc.	Inc.	135	3-21				138	3-21			
133	3-21-31	5-16-32	56 days	5	136	3-21	4-23	33 days	47	139	3-21			
134					137	3-21				140	3-21			
145	4-1	Inc.	Inc.	Inc.	143	4-6				141	4-6	5-30	54 days	8
146	4-6	5-21-32	45 days	3	144	4-6				142	4-6			

Table IA. Totals of Matings, 1931-1932.

Groups	Total number of matings	Number productive	Per cent of matings productive	Total number of offspring	Average per productive mating*	Largest single family	Average period: mating to offspring (days)
Electric light	12	7	58.3	136	27.2	71	56.5
Violet light	13	5	38.4	335	67.0	149	53.2
Control	12	1	8.3	8	8	8	54
Totals	37	13		479			

*Excluding incomplete matings.

whereas approximately half of the matings kept under the lights were fertile. This is in agreement with the observations of Nabours and Larson, and would seem to indicate that this effect is due to the lights.

It should be noted that the matings marked incomplete in Table I were not observed during the summer and accurate records were not kept. If productive, these matings were included in Table IA in calculating the per cent of productive matings, but the lack of observations prevented their inclusion in the columns on number of offspring and period from mating to offspring.

These data are of some interest in their bearing on the problem of the diapause in the Orthoptera. Dr. J. H. Bodine has expressed the opinion that the diapause in the grouse locusts occurs not in the egg stage, as is usual with the grasshoppers, but in the individuals themselves. In the case of many eggs, he has found that a period of cold is required before development will start again after the diapause. Such a condition may apply to the individual grouse locusts, for it is usually stated that the northern species require a period of hibernation for successful breeding. Nevertheless, four matings kept over winter in the greenhouse produced offspring in the summer (Table II). Likewise, young were produced by a number of matings in which one of the parents had not had the so-called necessary period of hibernation (Tables III, IV). This situation would indicate that a diapause is not always necessary, and that development may continue without a period of cold. On the other hand, six male nymphs, hatched in the fall of 1932 in a jar of females from nature, grew very slowly in the greenhouse, and remained in the third or fourth instar during most of the winter. One nymph, still in the fourth instar, was alive on May 20, 181 days after transfer. This is similar to the behavior of the nymphs kept as controls for growth studies, and it would indicate that a period of cold may be essential for normal rate of development. In any event, the situation is by no means clearly understood.

On Number of Offspring (Tables I, IA)

The number of offspring recorded for each mating include both the young actually transferred and those left in the mating jar.

Table I, as previously noted, shows that no offspring were produced in the control group. Seven matings under E.L. produced 136 offspring for an average of 27.2 per productive mating, whereas five matings under V.L. produced a total of 335 offspring for an average of 67.0. The difference between the control and light groups is so great as to be obviously significant, for no matings at all in the

Table II. Matings Held Over Winter and Later Productive.

Page	Source of male	Source of female	Date of mating	First offspring	Period: Mating to offspring	Number of offspring
XLI 213	XLI 207	XLI 196	8- 7-26	6- 7-27	304 days	85
XLI 216	XLI 196	XLI 194	10-25-26	5-25-27	212 days	68
LIII 219	LIII 147	LIII 146	7-25-29	4- 9-30	258 days	12
LIII 223	LIII 128	LIII 148	7-31-29	6- 7-30	311 days	35

Table III. Summary of Tests of Over-wintered

Non-hibernated Individuals, 1925-1931.

Source of parents	Number of matings	Aver. period: Mating to offspring	Number of offspring	Average per mating
Male stock Female nature	5	43.4 days	172	34.4
Male nature Female stock	9	79.5 days	459	51
Both parents from stock	4	271.25 days	200	50

Table IV. Tests of Females Overwintered Without Hibernation, 1931-1932.

Mating number	Source of male	Source of female	Collected in nature	Date of mating	First offspring	Period: Mating to offspring	Number of offspring
126	Nature 2-28-32	124 (E.L.)	11-7-31	3- 5-32	3-23	18 days	62
127	Nature 2-28-32	107 (C.)	10-3-31	3- 5-32	4- 1	27 days	13
130	Offspring 116 E.L. I	106 (C.)	11-7-31	3-12-32	6-4	84 days	6
131	Offspring 119 E.L. II	110 (V.L.)	11-7-31	3-12-32	6-27	107 days	7

former produced young. The data likewise show a distinct advantage for the violet light over the white light, as shown by the large mean difference of 39.8 per productive mating.

In this connection it may be noted that the largest family recorded, 149, occurred under the V.L., whereas the largest number recorded under the E.L. was only 71, or less than half.

On the Period from Mating to Appearance of Offspring (Tables I, IA)

Whether or not lights would affect the period between mating and hatching was not known, but it is conceivable that they might do so. There was some variation in the records taken, inasmuch as nymphs may have been several days old when first noticed in the jars, but the total results were only slightly affected. Table I gives the number of days from mating to the appearance of offspring for each mating, and Table IA gives the summary.

The average period is very similar among the three groups, the figures being 56.6 days for the E.L. group, 53.2 for the V.L., and 54 for the one productive mating in the controls. These differences are not great enough to be significant, and it is therefore concluded that light does not affect the period between mating and the appearance of offspring.

The data on the four matings recorded in Table IV should be noted. The females used were collected in nature in the fall of 1931 and kept over winter in the greenhouse, without hibernation, as part of the matings charted in Table I. None produced young during the winter. These old females were mated in the second week in March, at the beginning of the normal breeding season, to new males. The two mated to males collected in nature on February 28 (probably just emerged from hibernation) produced offspring in 18 and 27 days (mean, 22.5), whereas the two mated to males hatched in the greenhouse early in January and reared under E.L. produced offspring in 84 and 107 days (mean, 95.5). The latter period is much longer than the time required for the anomalous mid-winter generation. This would seem to indicate a weakness of the offspring of that abnormal generation, even when reared under the lights. Conversely, the periods of 18 and 27 days, respectively, obtained by using males from nature, are much shorter than the average of the winter matings. The difference in number of offspring from the two types of males should also be observed. Whatever the factor here may be -- benefits of hibernation, or the strong breeding impulse of the males just emerged from hibernation -- it seems to influence the period more than either electric or violet lights.

On Growth (Tables V, VI)

The time between date of hatching, or the date when the young were first noticed, and maturity was used in this experiment as a measure of the rate of growth. It shows neither the true rate nor the average rate, but it does represent a totality by which different groups may be compared and differences noted.

These tables, of which V is the principal one and VI a modification of V, show the groups and subgroups among which the nymphs were divided for this study. Succeeding columns give the number of the parental mating, date of hatching, number of young transferred to that group and the number of these which finally reached maturity. Under number matured, the first figure is the number of males, the second the number of females. Thus in E.L. I, for example, 13 nymphs were transferred, and 13 matured, of which ten were males and three were females. The range of age at maturity for each sex is given as a matter of interest in the variability of the species. The mean ages were calculated from the individual records which had been made. Standard deviation and error of the mean were computed in

Table V. Growth Records

Grouping	Source of offspring	Date of hatching	Number trans.	Number matured ♂ ♀	Range of age at maturity (days)	Mean age at maturity	Stand. deviation	Error of mean	Diff. (D)	Probable error of diff.	$\frac{D}{PE}$ Signif.
I	E.L.	116	1-12-32	13	10-3	♂ 51- 83	67.8	9.702	2.0692	♂ .6	2.516	o .23 (V.L.)
						♀ 83-107	92.66	10.37	4.0383			
	V.L.	113	1-11-32	13	5-5	♂ 63- 76	67.2	4.750	1.4324	♀ 20.6	4.303	o 4.801 (V.L.)
						♀ 65- 76	72	4.940	1.490			
	C.	113	1-11-32	12	0	Only half grown 5-18-32, 140 days after hatching						
II	E.L.	119	1-11-32	14	4-6	♂ 42- 44	43.5	.866	.2920	♂ 11.0	4.065	2.706 (E.L.)
						♀ 46- 55	51.5	3.041	.8375			
	V.L.	122	1-12-32	9	2-3	♂ 46-63	54.5	8.50	4.054	♀ 35.5	8.691	4.084 (E.L.)
						♀ 67-118	87	22.22	8.6531			
	C.	119	1-11-32	12	2-2	♂ 154-156	155					
						♀ 161	161					
III	E.L.	112	1-18-32	8	0-1	♂ --	--	--	--	--	--	--
						♀5 53	53	0	0			
	V.L.	111	1-18-32	12	6-5	♂ 44-61	51.33					
						♀ 67-74	68.4	2.799	.8443	♀ 15.4	.8443	18.239 (E.L.)
	C.	111	1-18-32	10	2-4	♂ 146-148	147					
						♀ 154-165	159.5					
IV	E.L.	119	1-21-32	15	5-3	♂ 44-56	51	4.647	1.401	♂ 2.62	1.808	1.449 (E.L)
						♀ 51-56	54.33	2.395	.9326			
	V.L.	119	1-21-32	15	8-4	♂ 48-62	53.62	4.795	1.1436			2.64 (E.L.)
						♀ 56-58	57	1.00	.3894	♀ 2.67		
	C.	120	1-18-32	9	1-0	♂ 123	123					
						♀ --	--	--				
V	E.L.	111	1-21-32	20	3-5	♂ 65-70	66.66	2.449	.9536	♂ 1.86	4.038	.46 (V.L.)
						♀ 65-86	73.8	8.974	2.707			
	V.L.	113	1-21-32	11	5-4	♂ 46-83	64.8	13.01	3.9245	♀ 7.3	3.103	2.35 (V.L.)
						♀ 62-74	66.5	4.5	1.5176			
	C.	116	1-21-32	19	6-7	♂ 128-144	135.83					
						♀ 142-169	152					
VI	E.L.	119	1-30-32	12	1-1	♂ 49	49	Not calculated because of the small numbers				
						♀ 55	55					
	V.L.	113	1-26-32	17	7-7	♂ 51-65	57.71					
						♀ 58-137	77.14					
	C.	113	1-26-32	17	3-0	♂ 117-137						
						♀ --	--	--	--	--	--	--
VII	E.L.	113	2- 1-32	15	7-5	♂ 40-49	46	2.777	.7078	♂ 1.83	1.074	1.703 (E.L.)
						♀ 49-70	57	7.874	2.3752			
	V.L.	111	2- 1-32	13	6-6	♂ 44-53	47.83	2.937	.8089	♀ 17.5	5.903	2.96 (E.L.)
						♀ 49-105	74.5	19.63	5.406			
	C.	116	2- 1-32	17	3-4	♂ 121-138	126.66					
						♀ 121-144	135.25					
VIII	E.L.	111	2-15-32	16	8-7	♂ 50-58	51.75	2.861	.6823	♂ 11.09	1.161	9.55 (V.L.)
						♀ 50-60	55.28	--				
	V.L.	113	2-13-32	8	3-0	♂ 39-44	40.66	2.413	.9396			
						♀ --	--	--	--	--	--	--
	C.	113	2-13-32	9	2-0	♂ 95-102	98.5					
						♀ --	--	--	--	--	--	--
IX	E.L.	113	2-27-32	11	5-4	♂ 41-46	43.2	1.939	.5848	♂ 2.6	.9724	2.67 (V.L.)
						♀ 44-53	48	3.391	1.1436			
	V.L.	113	2-27-32	11	5-4	♂ 36-44	40.6	2.577	.7773	♀ .5	1.711	.292 (V.L.)
						♀ 44-53	47.5	3.775	1.2731			

Table VI. Growth Records. (Rearrangement of Groups for Comparisons of Sibs)

Grouping	Source of off-spring	Date of hatch-ing	Num-ber trans.	Num-ber matured ♂ ♀	Range of age at maturity (days)	Mean age at maturity	Stand. devia-tion	Error of mean	Diff. (D.)	Probable error of diff.	D / P E Signif
V[1]: E.L.	111	1-21-32	20	3-5	♂ 65-70	66.66	2.449	.9536			
					♀ 65-86	73.8	8.974	2.707	♂ 15.33	2.186	♂ 7.01 (V.L.)
III: V.L.	111	1-18-32	12	6-5	♂ 44-61	51.33	7.145	1.9678	♀ 5.4	2.835	♀ 1.904 (V.L.)
					♀ 67-74	68.4	2.799	.8443			
VII[2]: E.L.	113	2- 1-32	15	7-5	♂ 40-49	46	2.777	.7078			
					♀ 49-70	57	7.874	2.3752	♂ 18.8	3.987	♂ 4.715 (E.L.)
V: V.L.	113	1-21-32	11	5-4	♂ 46-83	64.8	13.01	3.9245	♀ 9.5	2.818	♀ 3.37 (E.L.)
					♀ 62-74	66.5	4.5	1.5176			
VII[2]: E.L.	113	2- 1-32	15	7-5	♂ 40-49	46	2.777	.7078			
					♀ 49-70	57	7.874	2.3752	♂ 11.71	1.457	♂ 8.03 (E.L.)
VI: V.L.	113	1-26-32	17	7-7	♂ 51-65	57.71	5.001	1.2747	♀ 20.14	6.848	♀ 2.941 (E.L.)
					♀ 58-137	77.14	25.20	6.4238			
VII[2]: E.L.	113	2- 1-32	15	7-5	♂ 40-49	46	2.777	.7078			
					♀ 49-70	57	7.874	2.3752	♂ 5.34	1.176	♂ 4.54 (V.L.)
VIII: V.L.	113	2-13-32	8	3-0	♂ 39-44	40.66	2.413	.9396	No females		
					♀ --	--	--	--			
V[1]: E.L.	111	1-21-32	20	3-5	♂ 65-70	66.66	2.449	.9536			
					♀ 65-86	73.8	8.974	2.707	♂ 18.83	1.25	♂ 15.06 (V.L.)
VII[3]: V.L.	111	2- 1-32	13	6-6	♂ 44-53	47.83	2.937	.8089	♀ .7	6.045	♀ .115 (E.L.)
					♀ 49-105	74.5	19.63	5.406			
VIII: E.L.	111	2-15-32	16	8-7	♂ 50-58	51.75	2.861	.6823			
					♀ 50-60	55.28	4.401	1.1218	♂ 3.92	1.057	♂ 3.708 (V.L.)
VII[3]: V.L.	111	2- 1-32	13	6-6	♂ 44-53	47.83	2.937	.8089	♀ 19.22	5.52	♀ 3.48 (E.L.)
					♀ 49-105	74.5	19.63	5.406			

[1] Used twice in comparisons.

[2] Used three times in comparisons.

[3] Used twice in comparisons.

each case, to determine the probable error of the difference, so that the data might be compared by the usual statistical methods. Inasmuch as the length of the nymphal period differs in the two sexes, the males having six instars and the females seven, the data for each sex were separately calculated and compared in each group. In all cases the figure for the male is above the line, and for the female, below.

As the various families hatched at different times, only those within a single group may strictly be compared. Furthermore, since the offspring of different matings were found to vary somewhat in their rates of development, only brothers and sisters (sibs) are strictly comparable; e.g., in Group VI, those nymphs under E.L. came from mating 119, but those under V.L. and control from mating 113, and only the two latter may accurately be compared. This situation limited the value of much of the data, but in most cases the small number of offspring made this unavoidable. Some rearrangement of the data, as in Table VI, made it possible to compare sibs whose dates of transfer were near enough to be comparable. It will be noted that several of the groups were used more than once, for the purpose of comparing various sets of data.

Statistical treatment was unnecessary to show the significance of such large differences in rate of growth as existed between the controls and either of the light groups. Many of the offspring kept as controls required from 17 to 22 weeks to become adult, whereas the nymphs kept under the lights matured in six to eight weeks. Table V shows many such cases. To illustrate the high ratios of significance which would be obtained, computations were made for the data in a few groups. In Group III, for example, comparison of the V.L. and control groups gave a ratio ($\frac{D}{P\ E}$) of 47.26 for males, and 33.06 for females. Some of the results were still higher. The significance of such figures may be emphasized by considering that a ratio of 4, or even of 3.5, is regarded as a safe margin of probability for experimental purposes.

No consistent difference was noted between violet light and electric light in their effect on growth, as shown by a comparison of the ratios of significance in Tables V and VI. In some cases, one light is favored; in others, the reverse is true. It must be concluded, therefore, that there is no significant difference between the effects of the two lights on the rate of growth.

Group VI, under violet light, illustrates the natural variation in the growth of these insects. In this group, 14 of the original 17 reached maturity. All but one of these had matured by April 15, or 76 days after hatching. One female, however, did not mature until eight weeks later, on June 15, or 137 days after transfer. This unusually long nymphal period is in striking contrast to the ages of the sibs.

On Mortality (Table VII)

As each jar was observed until the last nymph had become adult, the proportion which lived to maturity, and from this the percentage of mortality, could be calculated. Data for 1931-1932 are as follows:

Table VII: Mortality Records

	Number transferred	Number matured	Per cent mortality
Electric Light	141	82	41.8
Violet Light	122	85	30.3
Control	122	36	70.4
Totals	385	203	

These totals show a slight advantage of violet light over white light and a decided advantage of both lights over the control group. Mortality up to maturity was 41.8 per cent in the E.L. groups, 30.3 per cent under the V.L. and 70.4 per cent in the control groups. The very high figure for the control group is especially noteworthy. In the spring, many insects and spiders were attracted to the lights and did considerable damage in the jars under the lights. The control jars were comparatively free from pests, and yet the mortality was much higher there than in those jars kept under the lights.

On Size and Color of Offspring

Larson believed that the offspring reared as controls, without the benefits of violet light, were smaller than their brothers and sisters reared under the light. This observation was not confirmed, as no differences were noted in the present experiment. The natural variation of the species is so great that such an effect probably would not be discernible.

No change was noticed in the color patterns during the experiment. According to Larson, the colors of the insects kept under the lights were a little brighter, due probably to more frequent molting, but later observations did not confirm this.

EXPERIMENTAL DATA, 1932-1933

The experiment for 1932-1933 was terminated before data sufficient to be considered significant had accumulated. Table VIII is a chart of the matings made at the beginning of this experiment. In general, the results support those of the preceding year (compare with Table IA). The fertility was approximately the same, five out of fourteen matings producing offspring the second year, against five out of thirteen during the first year. Likewise the times from mating to the appearance of offspring proved to be very similar in the two experiments. For some reason, however, the number of offspring produced during the second year was very small, some unknown factor having operated. No offspring were available for studies on growth and mortality.

Both light groups again showed decidedly higher fertility than the controls, as has been the case in all experiments conducted on A. arenosum. None of the control matings produced offspring, even though some lived until quite late in the spring. These data support the past observations and strengthen the conclusion that lights are responsible for the production of the mid-winter generation. Continuous light is not necessary, however, for some matings

Table VIII. Mating Chart, 1932-1933.

Continuous Violet Light					Twelve-hour Period Violet Light					Control				
Mating number	Date of mating	Date of first offspring	Period: Mating to offspring	Number of offspring	Mating number	Date of mating	Date of first offspring	Period: Mating to offspring	Number of offspring	Mating number	Date of mating	Date of first offspring	Period: Mating to offspring	Number of offspring
155	11-19-32	1-16-33	58 days	3	162	11-19-32	--	--	--	169	11-19	---	--	--
157	11-19-32	--	--	--	163	11-19-32	1-16	58	4	156	11-19	--	--	--
158	11-19-32	--	--	--	164	11-19-32	--	--	--	171	11-19	--	--	--
159	11-19-32	--	--	--	165	11-19-32	--	--	--	172	11-19	--	--	--
160	11-19-32	1-16-33	58 days	2	166	11-19-32	--	--	--	173	11-19	--	--	--
161	11-19-32	1-21-33	63 days	14	167	11-19-32	--	--	--	174	11-19	--	--	--
					168	11-19-32	1-14	56	6	175	11-19	--	--	--
					176	12-19-32	--	--	--					

exposed to only a 12 hour period of violet light produced offspring.

RESUMÉ OF DATA: 1925-1931

Acrydium arenosum has been bred in the greenhouse since 1925 and some data on the usual fertility and productivity of the species have accumulated. Violet light was tried by Nabours and Larson from March, 1929, to June, 1931, and there were limited observations on the effect on the grasshoppers, principally on productivity of matings and growth of the nymphs. Few regular groupings were made, however, and direct comparisons can seldom be made in tabular form.

Table IX. Summary of Matings, October-January (Inclusive)

	Violet Light	Control
Number of matings	23	28
Number productive	13	1
Per cent productive	56.5	3.5
Number of offspring	472	20
Average number per productive mating	36.3	20
Average period: Mating to young	54.4 days	37 days

In general, the results correspond with those obtained during the present study. A large percentage of those matings made from October to January, inclusive, and kept under the violet light, produced offspring (Table IX). Of the control matings made during the same period and not exposed to light, only one produced offspring. In this single exception, both male and female, previous to mating (January 14), had been kept under the violet light, the male for two months and the female for three months. It may therefore be stated that no mating has produced offspring during the winter unless kept under the light. The percentage of productive matings approximates that for 1931-32 (Table IA), but the average number of offspring per mating is somewhat lower. The average period from mating to the appearance of offspring is also very similar to that shown by the later data. The numbers are small, but they agree with the present work in demonstrating that light influences the appearance of an extra midwinter generation.

A few general observations on the effect of light on the growth of the nymphs were also made. Individual ages were not recorded, so the data could not be tabulated and treated statistically, but general notes were made on the group as a whole. It was concluded that the influence of light speeds up the succession of instars in <u>A. arenosum</u>, and eliminates the long passive period commonly occurring during the winter.

SUMMARY

1. The northern species of grouse locust, Acrydium arenosum angustum Hanc., has been induced to breed in the greenhouse during the winter without the normal period of hibernation. Light, either violet or "white", seems to influence the production of an anomalous, mid-winter generation.

2. There were no significant differences between the two lights in fertility of matings or in the period of time between mating and the appearance of offspring.

3. Violet light affected the number of offspring produced to a considerably greater degree than did electric light, the average per productive mating in the former being more than double that in the latter.

4. Light influences the rate of growth, as shown by a comparison of the means of the electric and violet light groups with those of the control group. Statistical treatment could demonstrate no difference between the two light groups.

5. Mortality up to maturity was slightly less in the violet light group than under the electric light, and much less than in the control group. There is a significantly greater survival under the lights.

6. The data lead to the conclusion that light exerts considerable influence on the functions connected with growth and reproduction in this insect. They agree with the results of Nabours and Larson on violet light, and they are in accord with the bulk of the data accumulated by other students of the effects of light on organisms.

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