The field biology of Camnula pellucida Scud
by Paul W Riegert

A THESIS Submitted to the Graduate Committee In partial fulfillment of the requirements for the degree of Master of Science in Entomology
Montana State University

Abstract:
The general behavior of insects is discussed in relation to the physical environmental factors, as well as the biological; and the probable influencing factors in the behavior of Camnula pelluclda Scud, reviewed.

The work site, methods of observation and equipment used In the study of the behavior of this species are discussed and described In detail.

Population densities, within localized areas, may be correlated to the stage of morphological and sexual development, and to the activity of the insect.

Data are presented showing specific environmental factors such as temperature, humidity, light, and wind velocity, which were measured when such activities as 'start of movement', 'general movement', 'maximum movement', 'start of climbing', 'frenzied movement', 'heat torpor', 'movement stopped', and 'no activity' were noted for C. pelluclda. Such activities can best be correlated to temperature.

Data presented indicate that the feeding response, in relation to the stage of development of the insect, seems to be largely dependent upon temperature; in that, as development increases, feeding occurs at increased temperature also.

Winds having average velocities over 2-3 and 5-6 m.p.h. appear to have interrupting effects on the feeding of nymphs and the flight of adults, respectively.

Observations on migrations of C. pelluclda seem to indicate that although gregarious inertia and optical responses may keep a band migrating simultaneously, air and soil surface temperatures (within a range of 24.8-36.0 °C (76.6- 96.8 °F) and 25.5-44.2 °O (77.9-111.6 °F), respectively), a positive phototaxis and relative humidity may guide the grasshopper during migration bearing in mind its left-handed light-compass reaction to the sun and maintaining an angle of 30-110 degrees between the direction of migration and the position of the sun.

Field experiments, using crushed Agropyron smithii to evoke an olfactory stimulus-response reaction, showed that the reaction-time (and probably sensory receptivity of stimuli) is closely associated with development in that the higher instars had faster reaction-times.

Observations of their climbing habits disclosed that pelluclda appeared to respond more actively to heat (thermotaxis and thermo-kinesis), while Melanoplus bivittatus Say. appeared to respond more pronouncedly to illumination (phototaxis and photokinesis).

The color changes, from darker to lighter pigmentation of the exoskeleton of C. pelluclda. as development progresses, may be due to Increased temperature as the season advances.

Partial or complete damage of the flight appendages of the females is caused by the males when

hyperexcited during sexual stimulation.

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TABLE OF CONTENTS

	Page
INTRODUCTION	4
ACKNOWLEDGMENT	6
REVIEW OF LITERATURE	7
LOCATION AND DESCRIPTION OF WORK SITE	11
EQUIPMENT USED	14
METHODS	16
PRESENTATION OF DATA	20
DISCUSSION OF RESULTS	
I. Fluctuations in Population Densities	33
II. Movement of C. pellucida	35
III. Feeding of C. pellucida	40
IV. Effect of Wind on the behavior of C. pellucida	44
V. Migration of C. pellucida	48
VI. Moulting of C. pellucida	53
VII. Climbing habits of C. pellucida as compared to M. bivittatus	53
VIII. Responses and reaction-times of C. pellucida to a known stimulus	56
IX. Color changes with development of C. pellucida	57
X. Copulation and Oviposition	58
SUMMARY AND CONCLUSIONS	59
APPENDIX	63
BIBLIOGRAPHY	65

ABSTRACT

The general behavior of insects is discussed in relation to the physical environmental factors, as well as the biological; and the probable influencing factors in the behavior of *Camnula pellucida* Scud. reviewed.

The work site, methods of observation and equipment used in the study of the behavior of this species are discussed and described in detail.

Population densities, within localized areas, may be correlated to the stage of morphological and sexual development, and to the activity of the insect.

Data are presented showing specific environmental factors such as temperature, humidity, light, and wind velocity, which were measured when such activities as 'start of movement', 'general movement', 'maximum movement', 'start of climbing', 'frenzied movement', 'heat torpor', 'movement stopped', and 'no activity' were noted for *C. pellucida*. Such activities can best be correlated to temperature.

Data presented indicate that the feeding response, in relation to the stage of development of the insect, seems to be largely dependent upon temperature; in that, as development increases, feeding occurs at increased temperature also.

Winds having average velocities over 2-3 and 5-6 m.p.h. appear to have interrupting effects on the feeding of nymphs and the flight of adults, respectively.

Observations on migrations of *C. pellucida* seem to indicate that although gregarious inertia and optical responses may keep a band migrating simultaneously, air and soil surface temperatures (within a range of 24.8-36.0 °C (76.6- 96.8 °F) and 25.5-44.2 °C (77.9-111.6 °F), respectively), a positive phototaxis and relative humidity may guide the grasshopper during migration bearing in mind its left-handed light-compass reaction to the sun and maintaining an angle of 30-110 degrees between the direction of migration and the position of the sun.

Field experiments, using crushed *Agropyron smithii* Rydb. to evoke an olfactory stimulus-response reaction, showed that the reaction-time (and probably sensory receptivity of stimuli) is closely associated with development in that the higher instars had faster reaction-times.

Observations of their climbing habits disclosed that *C. pellucida* appeared to respond more actively to heat (thermotaxis and thermokinesis), while *Melanoplus bivittatus* Say. appeared to respond more pronouncedly to illumination (phototaxis and photokinesis).

The color changes, from darker to lighter pigmentation of the exoskeleton of *C. pellucida*, as development progresses, may be due to increased temperature as the season advances.

Partial or complete damage of the flight appendages of the females is caused by the males when hyperexcited during sexual stimulation.

INTRODUCTION

The field of insect behavior, in relation to the entire environmental complex, has received minor emphasis in past entomological studies. Only during recent years have entomologists realized the importance of knowing the fundamental behavior pattern of the insects under study.

When considering behavior it must be considered as the sum total of the responses arising as a result of stimuli received from the total environment. The total environment constitutes not only those factors which are commonly thought of as existing in nature, i.e. the external environment, but also includes the organism as part of that environment. As a result of external influences (solar radiation, heat, cold, humidity, etc.) the organism will be affected internally, either on the metabolic or on the general physiological processes. This effect in combination with the influences of the external factors on their activities initiates the characteristic type of response. Furthermore, in animal aggregations, the presence and activity of any one individual will in many instances be a stimulus for the activity of another. The individual organism will behave in accordance with such factors as optical stimuli, crowding, movement, etc., and when combined with the influence of other external factors, a specific type of behavior will result.

Since the physical environment is constantly influencing the insect, its behavior in regard to these factors may be evidenced quite readily. However, other factors must be considered . These would include, among other things, a study of the activities of the insect as they directly relate to varying populations as well as to feeding responses. In food consumption alone there may lie a vast complex of effects.*

Therefore, it seems to be of utmost importance; first, to determine which measurable and observable factors have a direct influence upon the activities of the insect; second, what the responses are to the various stimuli; third, what modifications and conditioning effects are acquired by the organism as a result of consistant environmental influences; and fourth, how the present behavior of the insect is related to and possibly responsible for future behavior and activity. (Uvarovs 'Phase Theory' (see Uvarov, 1921) or the cyclic phenomena of grasshopper abundance seems to be evidence in support of the fourth objective mentioned above.)

It is the purpose of this study to learn and interpret in so far as possible, the behavior of Camnula pellucida Scud. and to try to correlate its activities to measurable environmental factors.

C. pellucida was chosen as the subject in this investigation because it is an active insect which will produce pronounced reactions to various stimuli. This species was suggested by Dr. B.P. Uvarov as a desirable grasshopper for this study.

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* Very recently it has been demonstrated by Spiegelman (1946), that the type of material entering the cells and tissues of an organism will determine, within limits, not only the type and structure produced in that organism, but will determine the type and structure of the successive generations. This is direct evidence in favor of the theory of adaptation to a change in environment.

The project was outlined at Montana State College and the investigations were carried out in Canada during the summer of 1947 when the author was employed by the Dominion Department of Agriculture, Division of Entomology. Known infestations of C. pellucida were present in southern Saskatchewan and these offered excellent opportunities for the investigational work. The sudden increase of this roadside species of grasshopper on both sides of the international boundary in the Great Plains Region, gave the project an additional impetus due to the economic importance of this pest.

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REVIEW OF LITERATURE

Studies of the factors involved in insect reactions and behavior have been of interest to entomologists for many years. To many, the influencing factors meant only temperature and humidity, and throughout the literature a vast amount of material cam be found which deals with these two factors in relation to the behavior of insects.

Reamur (1736)*, although unknowingly, made a start on the investigation of temperature effects upon living systems when he constructed his thermometer. Hancock (1904) proposed that the gustatory stimulus provoked an oviposition response in the green meadow grasshopper, *Orchelimum glaberrimum*, Burm. From there on the bearing of physiology on economic entomology (as pointed out by Dewitz, 1912) became evident.

Sanderson and Peairs (1914) and Peairs (1914) showed a relationship between temperature and insect development, while Pierce (1916) added humidity as a possible additional influencing factor affecting cotton boll-weevil activity. Although his graphs, showing zones of development, are hypothetical to a certain extent, they illustrate the possibility of a combined influence of these two factors.

McIndoo (1922) turned his efforts towards a study of the sensory responses of insects, while Folsom (1922) studied some of the ecological aspects of insect behavior. Corkins (1922) made direct observations on the habits of the Mormon cricket, *Anabrus simplex* Hald., their mob reactions, and their responses to surface stimuli. Studies of the factors possibly affecting the oviposition response of certain Dipterous

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* reference is made by author and year to Literature Cited.

Coleopterous, Lepidopterous, and Hymenopterous insects were outlined by Richardson (1925).

Up to this time not much attention had been given to the underlying causes for the responses of insects to environmental stimuli. Scientists were merely interested in knowing if such responses were capable of being evoked by certain stimuli.

Temperature and moisture, however, still received the greatest attention. Margulis (1924), in his studies on the effect of environmental temperature on metabolism showed that a relationship existed between this factor and the rate of metabolism. Other workers such as Peairs (1927) and Bodine (1925) showed that temperature was a directing factor in the rate of development of insects. The latter states,".... other factors being constant, the increment in rate (of development) seems to increase in direct proportion to the increase in temperature within the normal limits of development."

In connection with humidity and water relationships, Buxton (1932) has summarized the information up to his time. Johnson (1942), concluded that water loss from insects is proportional to the saturation deficit.* Alexander et al (1944) have concluded, from their studies

* Some controversy is apparent in the opinion of workers as to whether relative humidity or saturation deficiency should be used in determining the effects of moisture on insect behavior. Kennedy (1939) states,"Thus it seems that relative humidity is more relevant to behavior than saturation deficiency, and that insects are 'equipped with special sense organs for the perception of humidity'". He proposes this working hypothesis, "Although metabolic processes may often be better related to saturation deficiency than relative humidity, the humidity receptors carried by insects are more in the nature of hygroscopes than evaporimeters."

of desiccation, that the transmission of water through the cuticle of the insect is greatly enhanced by the use of inert dusts. They state, "...according to Robinson (1928) the water content of insects of different species is directly proportional to the food on which they live, and in the case of the grain weevil he found that about half of its water exists in a free state, while the other half is 'bound' to colloids. Our experiments show ..... 90% of the water content of the insect is given off at a constant rate. ...this evidence suggests that the proportion of their content water is 'bound' in a manner distinguishable from 'free water' cannot exceed about 10%". This therefore, seemed to indicate the interaction of physiological and physico-chemical factors as related to moisture in its effect on the behavior of insects.

C. pellucida has not received extensive investigation although the Acrididae in general have been prominent subjects of study. Ball (1915) outlined some of the migratory habits and appearances of C. pellucida nymphs and adults and also described some of his observations on the rate and method of travel. Henderson (1924) states," The migratory habits as described by E.D. Ball are accurate as regards methods and rate of movement, but not as concerns the direction of movement as described by him." He pointed out "that movement actually occurred in nearly all directions at the same time," whereas Ball maintained that a definite relationship existed between the direction of movement and the position of the sun.

Parker (1924) and (1930), has, by detailed study in the field and in the laboratory, shown that temperature directly affects the type of movement made by C. pellucida; that it has a marked effect upon coloration and the amount of food consumed per day; and also bears a relationship to the time of hatching and the development of the species.

Criddle (1933) made some notable observations on the food and oviposition habits of C. pellucida. He states,"...... it shows a very strong preference for a comparitively few grasses", and goes on to mention that these are Agropyron smithii Rydb., Poa pratensis L., barley grass, Hordeum jubatum L., and brome grass, Bromus inermis, Leyss..

Some of the work done on the behavior of grasshoppers and locusts was that performed by Dr. J.S. Kennedy. His papers (1939) and (1945) give evidence of the environmental factors which influence the activity and behavior of the desert locust, Schistocerca gregaria Forsk. In his earlier paper such features of locust behavior as concentration, aggregation, and gregarization receive attention. He also offers evidence as to the cause of these activities. In his later paper he suggests that the factors involved and bearing influence upon migrant hoppers are, optical responses, gregarious inertia, light-compass-reactions to the sun, and 'the tendency to follow the line of maximum mutual visibility'.

Since Uvarov (1921) proposed the Theory of Phases, considerable investigations have been undertaken in the study of the behavior of locusts in the Middle East and Africa. Faure (1932, 1934) studied the swarming habits and phases of Schistocerca gregaria in South Africa. Maxwell-Darling (1934, 1936, 1937) made observations of the solitary phase and outbreak centers of the same species in the Sudan and in Arabia; while Kennedy (1937) studied the humidity reactions of the gregarious phase of Locusta migratoria migratorioides R & F. Further investigations of the occurrence and phases of L. migratorioides were made in Sudan by Johnson and Maxwell-Darling (1931), while Lean (1931) studied the effect of climate on the migration and breeding of L. migratorioides in Nigeria.

These locusts of the Middle East and Africa, because of their widespread presence and international economic importance, have become the most popular insect for the investigation of insect behavior. Therefore, most of our present day knowledge of the activities of grasshoppers and locusts in respect to environmental influences, comes from the work done on the Schistocerca and Locusta species.

LOCATION AND DESCRIPTION OF WORK SITE

The observational work was carried out in the Shaunavon district, north and west of Shaunavon, Saskatchewan during the summer months of 1947. This area, lying in the Great Plains Region of western Canada, is distinctly treeless and relatively flat, lying at the base of the eastern bench of the Cypress Hills. The soil is mainly loam to sandy clay loam with an intermingling of glacial till on the western border due to its close proximity to the Cypress Hills. The average annual precipitation is 12-20 inches, most of which falls in the winter and early spring. Drought conditions in summer have prevailed during the past four years.

Six sites were chosen in this district to serve as focal points for the observations of behavior of C. pellucida. These sites were selected bearing in mind population densities, vegetation type and accessibility.

Area I

This was located 6 miles north and 0.3 miles west of Shaunavon. This was a road allowance 120x20 feet, covered with green western wheat grass, (Agropyron smithii Rydb.), 3-6 inches high. On either end of the area was tansey mustard, (Sophia incisa (Engelm.) Greene), 6-12 inches in height. The roadside ditch was 2 feet deep, V-shaped, with no vegetation on its southern exposed slope. The road allowance ran east and west with a barley field on the south side.

Area II

This road allowance was located 8.5 miles north and one mile west of Shaunavon. This area was the southeast corner of a quarter section, vegetated by a mixture of Timothy grass, (Phleum pratense L.) 8-12 inches high, and Agropyron smithii, 2-4 inches in height. The latter was curly and somewhat dried out but still green at the base of the stems. Interspersed in this was tansey mustard, (Sophia incisa) 6 inches tall, which was green and flowering. Along the outer margin of the wheat field covering the quarter section of land was a single row of tumbling mustard, (Sisymbrium altissimum L.) approximately 18 inches high. The wheat was green, 6-8 inches in height and quite luxurient.

Area III

This road allowance was located 10 miles north and 1.8 miles west of Shaunavon. Vegetation was Agropyron smithii, curly and browned at the tips, about 2-3 inches tall. About 50% of the vegetation on this east-west road allowance was Sophia incisa, which was rather defoliated 4-6 inches high, but still green. The field adjacent to the road was summerfallowed.

Area IV

This area was a north-south road allowance located 8.9 miles north and two miles west of Shaunavon, at the northeast corner of a section of summerfallow. The entire corner was about 80x20 feet and covered with a dense stand of Sophia incisa, approximately 12-18 inches high but rather defoliated by the mixed population of Melanoplus bivittatus Say. (40%) and C. pellucida (60%). Agropyron smithii, short, about 2 inches in height and still green was interspersed at the base of these weeds.

Area V

This area was located 8.1 miles north and 2 miles west of Shaunavon and was a dry slough bottom through which a road ran. The area comprised about two acres, covered with a dense growth of vegetation consisting of brome grass, (Bromus inermis Leyss.) and wild barley, (Hordeum jubatum L.). Hardly any bare ground was visible between the grass stems for the vegetation was approximately 12-18 inches high, green and flowering.

Area VI

This area, a roadside ditch 4 feet deep and 8x50 feet in area, was located 12 miles north and 0.7 miles west of Shaunavon. The vegetation was slough sedge,,(*Carex* spp.) 8-12 inches high, very green and succulent. The slough extended south covering an area of about two acres.

These were all roadside areas in which *C. pellucida* was very abundant. Only in one area was there a mixed population namely Area IV. The above descriptions are of the areas as they appeared during the latter part of June, 1947. Observations continued through July and August during which time extreme heat and drought conditions caused excessive drying of the vegetation, so that by the beginning of September no green vegetation was in evidence except in Area VI. In all the other Areas only on the lower part of the stems to about one-half inch above the ground did any green plant material remain visible.

EQUIPMENT USED

The following equipment was used to make measurements of the various physical environmental factors thought to influence grasshopper behavior:

1. A Thermocouple Potentiometer, General Electric PJ-1B, was used with constantin-copper thermocouples. Air and soil surface temperatures were measured.

2. A Bulb Aspirated Psychrometer, 'Julien P. Friez & Son Inc. Baltimore

M.D.', was used to measure the relative humidity of the air.

3. A 'Taylor' Fan Anemometer was used to measure the wind velocity in feet per minute. These readings were taken at the three feet and the six inch levels. All wind velocity data will be for the six inch level* unless otherwise specified.

4. Field Binoculars were used to observe the activity of the grasshopper from a distance, so that the observer would not influence the behavior by becoming an additional stimulus.

5. A Stop Watch was used to measure time whenever it was necessary to do so.

The one factor which was not specifically measured was that of sunlight intensity. Workers in the field have shown that light intensity is an important factor in the behavior of grasshoppers. Since no instrument was available to take these readings in this project, the only information obtained was a general description of cloudiness, hazyness, or clear skies.

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* Since it was extremely difficult and at times impossible to take wind velocity readings with type of an instrument at the exact microhabitat of the observed grasshopper, an arbitrary standard, the six inch level, was chosen for all readings. Furthermore, it was felt that differences in the measured wind velocity at specific heights within the '0-6 inch level' would not be significant in view of the accuracy of the anemometer used.

METHODS

Continuity of observation was an essential factor, therefore, the investigations were begun as soon as possible after hatching was complete. Furthermore, continuity was of importance because one object was to determine if nymphal behavior differed from adult behavior and in what respects it differed. Observations were started when most of the grasshoppers were in the third instar of development although some data was obtained concerning first and second instar nymphs. Attempts were made to make these observations at various times of the day and night and under as many climatic conditions as possible.

Observations of the behavior of C. pellucida were always accompanied by measurements of as many of the various influencing physical environmental factors as possible. When a specific type of activity, such as 'Start of Climbing' (see below), was observed, the individual specimen was regarded rather than the masses. The observer watched the individual grasshopper and when it moved or fed, started to climb weeds, etc., the air and soil surface temperatures were taken at the location where the reaction of the individual was noted. The relative humidity and wind velocity were then measured. Time of day and sunlight intensity were also recorded, together with the behavior activity observed. By observation of the behavior of the individual grasshopper, information as to the behavior of the masses was anticipated.

One objective to be gained by making observations of movement of individual grasshoppers of the various instars was to determine if possible, what environmental factors were operating, what differences in the intensity of these factors (stimuli) were present for the various types of behavior, and in what respect the movements of the various instars differed from one another. After the first several observations it became evident that no true concept of the activity differences between instars could be obtained.

This was due to what appeared to be, and what Kennedy (1945) called "optical responses" and "compensation-reactions to fellow hoppers". These factors caused the behavior to be very complex and difficult to analyze. The movement of one individual may be the stimulus for the second one to move, and in this respect the measurement of the environmental influences would not be sufficient to warrant a basis for the second 'hoppers activity. Furthermore, these 'optical responses' and 'compensation-reactions' appeared to result in the activity of the individual instars occurring over wide ranges of temperature, relative humidity, wind velocity, etc., thereby not showing a conclusive difference in the reactions to these stimuli. The data obtained was therefore not analyzed as to the movement responses of the individual instars in relation to the measured environmental stimuli, but rather lumped showing only the variation in activity and movement of all nymphs in relation to these factors.

In making observations on the movement behavior of C. pellucida, several rather well defined types of activity could be recognized. These were "Start of Movement", "General Movement", "Maximum Movement", "Start of Climbing", "Frenzied Movement", "Heat Torpor", "Stop Movement", and "No Activity". These categories of activity are closely related to those made by Parker (1930).

When migrations of C. pellucida were noticed, it was evident that these were not of great duration of movement, (usually one-half to one hour) nor was the distance travelled very great. The point of origin of the migration was usually a 'concentration center' such as the egg laying sites, and the area into which they migrated was usually more heavily vegetated or was a cropped field (except in the case of evening migrations when the reverse was noted). Air and soil surface temperatures, relative humidity, wind velocity and direction were recorded in the areas from and to which the migrations occurred. The position of the sun and the direction of these mass movements was carefully considered and recorded.

Field Experiment with Agropyron smithii

Whether or not the reactivity of all instars was similar was a doubtful question. The following experiment was conducted in an effort to determine if the reactions of the various instars were similar and if their reaction-times were the same.

The stimulus used here to evoke a response, was crushed Agropyron smithii, a grass to which this species of grasshopper seems to have a great affinity. Green, succulent leaves of this grass were crushed by hand so that the plant cells were ruptured and the vegetation became a moist mass. This 'ball' of leaves was then placed among the vegetation (in Area I), while the observer retreated to observe the reaction of the insects to this stimulus, through field binoculars.

The reaction-time was noted for the first positive response to the source of stimulation. A 'positive response' as used her, was the first orientation of a hopper to the stimulus, i.e. pointing its head in the direction of the 'ball' of <u>A. smithii</u>. The time interval between the first placing of the crushed grass on the ground and the first orientation of any 'hopper within an approximate three yard radius of the source, was designated as the "reaction-time for a positive response". The time interval between the first placing of the crushed grass on the ground and the complete orientation of all the grasshoppers within the above mentioned radius, was designated as the "reaction-time for a general response".

Since the tests were carried out in the same manner, from the same positions in Area I, such factors as the observers presence, optical responses, and 'compensation-reactions to fellow hoppers' remained standard influencing factors. As far as could be determined, wind velocity, temperature, humidity and sunlight were the only variable factors. The trials were executed on three consecutive days.

During the course of the observations mentioned above, notes were made on any phase of activity or behavior which seemed to be specific for <u>C. pellucida</u>. Some interesting observations were made and these are included in this paper.

PRESENTATION OF DATA

The data presented in Table I shows the relative population densities of C. pellucida in Areas I and V during the period June 27 to August 20, 1947. Complete data for Area V, over that period of time was not obtained.

Table II presents the air and soil surface temperatures, light, relative humidity, and wind velocity at which "Start of Movement" was noted for C. pellucida nymphs. Similarly, Tables III to Ix present the measured external factors operating at which "General Movement", "Maximum Movement", "Start of Climbing", "Frenzied Movement", "Heat Torpor", "Movement Stopped", and "No Activity", respectively, was noted for C. pellucida nymphs. These categories were based principally on those established by Parker (1930). Although they are somewhat arbitrary, they nevertheless are types of activity which can most easily be recognized when observing the behavior of this species. Data listed in these tables are recorded chronologically.

The data presented in Tables X to XV show the air and soil surface temperatures, relative humidity and wind velocity at which first to sixth instar 'hoppers, respectively, were observed as starting to feed. These factors and their respective probable influence on feeding will be discussed later. Again, data listed in these tables are recorded chronologically.

Data accrued on the migration of C. pellucida are presented in Table XVI. Some of the environmental factors measured are listed and it seems to indicate that the temperature-sunlight-humidity complex may be the major influencing factor in the migration of this species of grasshopper.

The results of the experiment conducted using crushed *Agropyron smithii* to evoke an olfactory stimulus-response reaction, are presented in Table XVII.

Table I - The relative population densities of *C. pellucida* in Areas I and V, during the period June 27 to August 20, 1947.

Date	Instar	Area I Population per sq.yd.	Area V Population per sq.yd.
June 27	3-4, some 5	200	---
June 30	3-5	200	---
July 2	3-5	50	---
July 8	5,6,3&4	10	250
July 12	6, some 4&5	5	250
July 31	6	550	600
Aug. 20	6	25	30

Table II - Air and soil surface temperatures, light, relative humidity, and wind velocity at which a 'start of movement' was noted for C. pellucida nymphs.

Observation Number	Air Temp. °C °F	Soil Temp. °C °F	Light	R.H. %	Wind m.p.h.
1	19.5(67.1)	32.5(90.5)	in sun	50	2.9
2	22.0(71.6)	35.0(95.0)	in sun	50	2.9
3	22,9(73.2)	36.5(97.5)	in sun	41	3.9
4	22.0(71.6)	33.0(91.4)	in sun	45	2.8
5	20.0(68.0)	29.7(85.5)	in sun	48	2.2
6	23.4(74.1)	33.0(91.4)	in sun	23	2.2
7	20.0(68.0)	31.4(88.5)	in sun	36	3.9
8	23.0(73.4)	32.8(91.0)	in sun	36	1.0
9	31.0(87.8)	39.0(102.2)	in sun	30	3.2
10	28.2(82.8)	31.2(88.2)	in sun	35	2.6
11	29.0(84.2)	34.5(94.1)	in sun	32	1.1
12	28.4(83.1)	34.5(94.1)	in shade	13	nil
Average	24.1(75.4)	33.6(92.5)		36.6	2.4
Minimum	19.5(67.1)	29.7(85.5)		13	nil
Maximum	31.0(87.8)	39.0(102.2)		50	3.9

Table III - Air and soil surface temperatures, light, relative humidity, and wind velocity at which a 'general movement' of *C. pellucida* nymphs was observed.

Observation Number	Air Temp. °C °F	Soil Temp. °C °F	Light	R.H. %	Wind m.p.h.
1	20.0(68.0)	34.8(95.0)	in sun	46	2.9
2	19.8(67.6)	34.0(93.2)	in sun	45	2.8
3	22.9(73.2)	36.5(97.5)	in sun	45	2.8
4	22.0(71.6)	28.0(82.4)	in sun	48	2.2
5	27.5(81.5)	35.5(95.9)	in sun	36	3.9
6	26.5(79.7)	33.8(92.8)	in sun	36	3.9
7	29.4(84.9)	37.0(98.6)	in sun	29.5	2.0
8	33.8(92.8)	35.8(96.4)	in sun	50	3.0
9	31.5(88.7)	38.2(100.8)	hazy	23	nil
10	31.0(87.8)	33.8(92.8)	hazy	22.5	2.6
11	34.0(93.2)	31.0(87.8)	in sun	35	2.6
12	30.0(86.0)	36.5(97.7)	in sun	22.5	2.6
13	31.5(88.7)	33.5(92.3)	in sun	21.5	1.0
14	32.8(91.0)	25.5(95.9)	in sun	27.5	1.1
Average	28.0(82.4)	34.6(94.3)		34.8	2.4
Minimum	19.8(67.6)	28.0(82.4)		21.5	nil
Maximum	34.0(93.2)	38.2(100.8)		50	3.9

Table IV - Air and soil surface temperatures, light, relative humidity, and wind velocity at which 'maximum movement' of *C. pellucida* nymphs was observed.

Observation Number	Air Temp. °C °F	Soil Temp. °C °F	Light	R.H. %	Wind m.p.h.
1	29.4(84.9)	41.0(105.8)	in sun	29.5	2.0
2	30.5(86.9)	42.0(107.6)	in sun	30	3.2
3	31.0(87.8)	37.5(99.5)	in sun	58	1.0
4	31.5(88.7)	39.0(102.2)	hazy	23	nil
5	35.5(95.9)	42.0(107.6)	in sun	13	nil
Average	31.6(88.9)	40.3(104.5)		30.7	1.2
Minimum	29.4(84.9)	37.5(99.5)		13	nil
Maximum	35.5(95.9)	42.0(107.6)		58	3.2

Table V - Air and soil surface temperatures, light, relative humidity, and wind velocity at which 'start of climbing' of *C. pellucida* nymphs was observed.

Height of Climb	Air Temp. °C °F	Soil Temp. °C °F	Light	R.H. %	Wind m.p.h.
2 inches	38.5(101.3)	42.5(108.5)	in sun	45	2.8
½ "	31.0(87.8)	42.5(108.5)	in sun	45	2.8
1½ "	31.7(89.1)	36.7(98.1)	in sun	48	2.2
6 "	30.5(86.9)	36.0(96.8)	in sun	19.5	0.4
3-6 "	29.4(84.9)	41.0(105.8)	in sun	29.5	2.0
6 "	30.5(86.9)	33.0(91.4)	in sun	33	0.5
½ "	33.5(92.3)	37.5(99.5)	in sun	58	1.0
1 "	29.0(84.2)	32.8(91.0)	in sun	52.5	1.0
6 "	34.0(93.2)	38.0(100.4)	in sun	35	2.6
3-6 "	32.0(89.6)	28.5(83.3)	in sun	21	0.9
6 "	30.0(86.0)	35.0(95.0)	in sun	32	1.1
6 "	30.5(86.9)	36.0(96.8)	in sun	27.5	1.1
Average	31.7(89.1)	36.6(97.9)		37.2	1.5
Minimum	29.0(84.2)	28.5(83.3)		19.5	0.4
Maximum	38.5(101.3)	42.5(108.5)		58	2.8

Table VI - Air and soil surface temperatures, light, relative humidity, and wind velocity at which 'frenzied movement' of *C. pellucida* nymphs was observed.

Observation Number	Air Temp. °C °F	Soil Temp. °C °F	Light	R.H. %	Wind m.p.h.
1	33.5(92.3)	43.0(109.4)	in sun	29.5	2.0
2	34.0(93.2)	44.0(111.2)	in sun	19.5	3.4
3	38.0(100.4)	42.8(109.0)	in sun	38.5	nil
4	44.0(111.2)	49.2(120.6)	in sun	38.5	nil
5	32.8(91.8)	45.2(113.4)	in sun	27.5	1.1
6	38.0(100.4)	42.0(107.6)	in sun	30	4.0
7	32.8(91.8)	42.8(109.0)	in sun	19.5	nil
8	44.0(111.2)	49.2(120.6)	in sun	38.5	3.4
Average	37.1(98.8)	44.8(112.6)		30.2	1.7
Minimum	32.8(91.8)	42.0(107.6)		19.5	nil
Maximum	44.0(111.2)	49.2(120.6)		38.5	4.0

Table VII - Air and soil surface temperatures, light, relative humidity, and wind velocity at which 'heat torpor' of C. pellucida nymphs was observed.

Observation Number	Air Temp. °C °F	Soil Temp. °C °F	Light	R.H. %	Wind m.p.h.
1	34.0(93.2)	44.0(111.2)	in sun	19.5	nil
2	38.0(100.4)	42.8(109.0)	in sun	38.5	nil
3	44.0(111.2)	49.2(120.6)	in sun	38.5	nil
4	42.5(108.5)	46.5(115.7)	in sun	10	3.0
Average	39.6(103.4)	45.6(114.1)		26.6	0.8
Minimum	34.0(93.2)	42.8(109.0)		10	nil
Maximum	44.0(111.2)	49.2(120.6)		38.5	3.0

Table VIII - Air and soil surface temperatures, light, relative humidity, and wind velocity at which 'movement stopped' in observed C. pellucida nymphs.

Observation Number	Air Temp. °C °F	Soil Temp. °C °F	Light	R.H. %	Wind m.p.h.
1	21.9(71.4)	32.0(89.6)	shade, cloud	45	2.8
2	23.0(73.4)	29.0(84.2)	shade, cloud	23	2.2
3	22.0(71.6)	26.0(78.8)	shade, cloud	45	1.1
4	20.4(68.7)	31.8(89.2)	shade, cloud	36	3.9
5	23.0(73.4)	29.0(84.2)	shade, cloud	36	1.0
6	23.8(74.8)	30.5(86.9)	shade, cloud	30	3.2
Average	22.4(72.3)	29.7(85.5)		35.8	2.4
Minimum	20.4(68.7)	26.0(78.8)		23	1.0
Maximum	23.8(74.8)	32.0(89.6)		45	3.9

Table IX - Air and soil surface temperatures, light, relative humidity, and wind velocity at which 'no activity' was observed in *C. pellucida* nymphs.

Time of Day	Air Temp. °C °F	Soil Temp. °C °F	Light	R.H. %	Wind m.p.h.
3:30 P.M.	19.0(66.2)	27.2(90.0)	shade	45	3.3
1:45 P.M.	16.5(61.7)	19.5(67.1)	shade	68	1.7
7:20 A.M.	16.2(61.2)	19.0(66.2)	in sun	70	3.4
8:00 A.M.	17.0(62.6)	20.0(68.0)	in sun	70	5.8
8:45 A.M.	17.5(63.5)	26.0(78.8)	shade	58	4.3
8:45 A.M.	20.0(68.0)	23.5(74.3)	shade	68	1.0
4:30 P.M.	30.5(86.9)	33.0(91.4)	hazy	20	nil
8:00 A.M.	28.5(83.3)	33.0(91.4)	in sun	33	0.5
8:30 P.M.	23.0(73.4)	25.5(77.9)	no sun	24	1.1
8:30 P.M.	23.2(73.8)	24.0(75.2)	no sun	26	1.1
3:00 A.M.	14.5(58.1)	16.0(60.8)	no sun	86	nil
3:30 A.M.	14.0(57.2)	15.2(59.4)	no sun	88	nil
4:00 A.M.	14.5(58.1)	15.2(59.4)	no sun	89	0.2
4:30 A.M.	13.5(56.3)	14.5(58.1)	no sun	92	0.7
5:00 A.M.	12.8(55.0)	14.0(57.2)	in sun	97.5	nil
5:30 A.M.	16.3(61.3)	15.0(59.0)	in sun	94	nil
6:00 A.M.	17.0(62.6)	17.8(64.0)	in sun	85	nil
7:00 A.M.	23.0(73.4)	20.1(68.2)	in sun	66	nil
4:45 P.M.	28.0(82.4)	31.5(88.7)	in sun	26	nil
8:00 A.M.	28.2(82.8)	31.2(88.2)	in sun	35	2.6
1:30 P.M.	33.2(91.8)	38.1(100.4)	hazy	38.5	nil
1:00 P.M.	30.0(86.0)	33.0(91.4)	hazy	38.5	nil
2:00 P.M.	27.0(80.6)	37.0(98.6)	shade	36	nil
4:00 P.M.	28.0(82.4)	31.0(87.8)	shade	30.5	0.5
2:00 P.M.	27.8(82.0)	30.5(86.9)	shade	28.5	3.4
3:00 P.M.	26.2(79.2)	28.0(82.4)	shade	53	nil
9:30 A.M.	23.8(74.8)	21.8(71.2)	in sun	42.5	0.9
3:00 A.M.	13.2(55.8)	14.8(58.6)	no sun	61	nil
Average	21.5(70.7)	24.1(76.3)		56	1.1
Minimum	12.8(55.0)	14.0(57.2)		20	nil
Maximum	33.2(91.8)	38.1(100.4)		97.5	5.8

Table X - Air and soil surface temperatures, relative humidity, and wind velocity at which observed first instar nymphs of *C. pellucida* started to feed.

Time of Day	Air Temp. °C °F	Soil Temp. °C °F	R.H. %	Wind m.p.h.	Food
2:30 P.M.	20.0(68.0)	34.8(95.0)	46	2.9	Agropyron
1:45 P.M.	29.0(84.2)	36.2(97.2)	36	1.0	Wheat
2:30 P.M.	27.4(81.3)	31.8(89.2)	33	nil	Agropyron
10:00 A.M.	24.4(75.9)	28.0(82.4)	38.5	nil	Agropyron
Average	25.2(77.3)	32.7(91.0)	38.4	1.0	
Minimum	20.0(68.0)	28.0(82.4)	33	nil	
Maximum	29.0(84.2)	36.2(97.2)	46	2.9	

Table XI - Air and soil surface temperatures, relative humidity, and wind velocity at which observed second instar nymphs of *C. pellucida* started to feed.

Time of Day	Air Temp. °C °F	Soil Temp. °C °F	R.H. %	Wind m.p.h.	Food
2:30 P.M.	20.0(68.0)	34.8(95.0)	46	2.9	Agropyron
1:45 P.M.	29.0(84.2)	36.2(97.2)	36	1.0	Wheat
3:35 P.M.	29.0(84.2)	36.0(96.8)	19.5	0.4	Tansey Mustard
3:55 P.M.	28.0(82.4)	34.0(93.2)	19.5	0.4	Tansey Mustard
9:30 A.M.	33.5(92.3)	37.5(99.5)	58	1.0	Barley
2:30 P.M.	27.4(81.3)	31.8(89.2)	33	nil	Agropyron
10:00 A.M.	24.4(75.9)	28.0(82.4)	38.5	nil	Agropyron
Average	27.3(81.2)	34.0(93.3)	35.8	0.8	
Minimum	20.0(68.0)	28.0(82.4)	19.5	nil	
Maximum	33.5(92.3)	37.5(99.5)	46	2.9	

Table XII - Air and soil surface temperatures, relative humidity, and wind velocity at which observed third instar nymphs of C. pellucida started to feed.

Time of Day	Air Temp. °C °F	Soil Temp. °C °F	R.H. %	Wind m.p.h.	Food
1:00 P.M.	19.5(67.1)	32.5(90.5)	50	2.9	Agropyron
2:00 P.M.	24.5(76.1)	34.5(94.1)	50	2.9	Agropyron
2:30 P.M.	20.0(68.0)	34.8(95.0)	46	2.9	Agropyron
10:45 A.M.	31.0(87.80	42.5(108.5)	45	2.8	Agropyron
9:30 A.M.	31.7(89.1)	36.7(98.1)	48	2.2	Agropyron
10:30 A.M.	24.0(75.2)	36.8(98.2)	48	1.1	Barley
10:30 A.M.	26.0(78.8)	34,0(93.2)	45	1.1	Barley
1:45 P.M.	25.0(77.0)	34.0(93.2)	36	1.0	Wheat
3:35 P.M.	29.0(84.2)	36.0(96.8)	19.5	0.4	Tansey Mustard
3:55 P.M.	28.0(82.4)	34.0(93.2)	19.5	0.4	Tansey Mustard
8:45 A.M.	29.4(84.9)	37.0(98.6)	29.5	2.0	Agropyron
8:30 A.M.	30.5(86.9)	33.0(91.4)	33	0.5	Tansey Mustard
10:15 A.M.	29.0(84.2)	32.8(91.0)	52.5	1.0	Barley
9:00 A.M.	33.5(92.3)	36.5(97.7)	22.5	nil	Agropyron
9:00 A.M.	29.0(84.2)	34.5(94.1)	32	1.1	Taasey Mustard
10:00 A.M.	24.4(75.9)	28.0(82.4)	38.5	nil	Agropyron
Average	27.4(81.4)	34.9(94.9)	39	1.5	
Minimum	19.5(67.1)	28.0(82.4)	19.5	nil	
Maximum	33.5(92.3)	42.5(108.5)	52.5	2.9	

Table XIII - Air and soil surface temperatures, relative humidity, and wind velocity at which observed fourth instar numphs of C. pellucida started to feed.

Time of Day	Air Temp. °C °F	Soil Temp. °C °F	R.H. %	Wind m.p.h.	Food
2:30 P.M.	20.0(68.0)	34.8(95.0)	46	2.9	Agropyron
9:15 A.M.	23.0(73.4)	34.5(94.1)	48	2.2	Agropyron
9:30 A.M.	31.7(89.1)	36.7(98.1)	48	2.2	Agropyron
10:30 A.M.	24.0(75.2)	36.8(98.2)	48	1.1	Barley
10:30 A.M.	27.5(81.5)	34.5(94.1)	45	1.1	Barley
10:30 A.M.	26.0(78.8)	34.0(93.2)	45	1.1	Barley
3:35 P.M.	30.5(86.9)	36.0(96.8)	19.5	0.4	Tansey Mustard
3:55 P.M.	29.0(84.2)	34.0(93.2)	19.5	0.4	Tansey Mustard
4:30 P.M.	30.5(86.9)	33.0(91.4)	20	0.4	Tansey Mustard
8:45 A.M.	29.4(84.9)	37.0(98.6)	29.5	2.0	Agropyron
8:30 A.M.	34.0(93.2)	31.0(87.8)	35	2.6	Tansey Mustard
8:30 A.M.	31.0(87.8)	38.0(100.4)	35	nil	Tansey Mustard
9:00 A.M.	33.5(92.3)	36.5(97.7)	22.5	nil	Agropyron
10:00 A.M.	32.0(89.6)	31.8(98.2)	21	0.9	Agropyron
1:30 P.M.	44.0(111.2)	49.2(120.6)	38.5	nil	Slough sedge
9:00 A.M.	29.0(84.2)	34.5(94.1)	32	1.1	Tansey Mustard
10::00 A.M.	24.4(75.9)	28.0(82.4)	38.5	nil	Agropyron
Average	29.5(85.1)	35.4(95.7)	35.5	1.2	
Minimum	20.0(68.0)	28.0(82.4)	19.5	nil	
Maximum	44.0(111.2)	49.2(120.6)	48	2.9	

Table XIV - Air and soil surface temperatures, relative humidity, and wind velocity at which observed fifth instar nymphs of C. pellucida started to feed.

Time of Day	Air Temp. °C °F	Soil Temp. °C °F	R.H. %	Wind m.p.h.	Food
9:30 A.M.	31.7(89.1)	36.7(98.1)	48	2.2	Agropyron
3:35 P.M.	33.2(91.8)	36.0(96.8)	19.5	0.4	Tansey Mustard
3:55 P.M.	29.0(84.2)	34.0(93.2)	19.5	0.4	Tansey Mustard
8:45 A.M.	29.4(84.9)	37.0(98.6)	29.5	2.0	Agropyron
9:30 A.M.	30.5(86.9)	33.0(91.4)	33	0.5	Tansey Mustard
10:30 A.M.	33.0(91.4)	30.2(86.4)	20.5	1.0	Wheat
9:00 A.M.	33.5(92.3)	36.5(97.7)	22.5	nil	Agropyron
10:00 A.M.	32.0(89.6)	31.8(89.2)	21	0.9	Agropyron
1:30 P.M.	44.0(111.2)	49.2(120.6)	38.5	nil	Slough sedge
9:30 A.M.	30.0(86.0)	35.0(95.0)	29	1.1	Tansey Mustard
9:30 A.M.	30.5(86.9)	36.0(96.8)	29	1.1	Tansey Mustard
10:30 A.M.	35.5(95.9)	45.2(113.4)	27.5	1.1	Agropyron
9:40 A.M.	25.2(77.4)	24.0(75.2)	42.5	0.9	Agropyron
10:00 A.M.	24.4(75.9)	28.0(82.4)	38.5	nil	Agropyron
Average	31.6(88.8)	35.3(95.5)	31.1	0.9	
Minimum	24.4(75.9)	24.0(75.2)	19.5	nil	
Maximum	44.0(111.2)	49.2(120.6)	48	2.2	

Table XV - Air and soil surface temperatures, relative humidity, and wind velocity at which observed sixth instar (adults) of C. pellucida started to feed.

Time of Day	Air Temp. °C °F	Soil Temp. °C °F	R.H. %	Wind m.p.h.	Food
9:00 A.M.	33.5(92.3)	36.5(97.7)	22.5	nil	Agropyron
9:30 A.M.	30.5(86.9)	36.0(96.8)	29	1.1	Tansey Mustard
10:30 A.M.	35.5(95.9)	45.2(113.4)	27.5	1.1	Agropyron
Average	33.2(91.7)	39.2(102.6)	26.3	0.8	
Minimum	30.5(86.9)	36.0(96.8)	22.5	nil	
Maximum	35.5(95.9)	45.2(113.4)	29	1.1	

Table XVI (a) - Conditions of wind velocity, temperature and relative humidity in areas from which migrations of C. pellucida occurred; as well as direction of migration and the time of day when observations were made.

Wind direction & velocity in m.p.h.	Time of Day	Migration from listed vegetation				
		Air Temp. °C °F	Soil Temp. °C °F	R.H. %	Migration	Vegetation
W 1.0	10:30 A.M.	33.0(91.4)	41.5(106.7)	12.5	W	Agropyron
WNW 3.4	4:00 P.M.	36.0(96.8)	44.2(111.6)	9.0	WNW	Agropyron
WNW 3.4	4:00 P.M.	36.0(96.8)	44.2(111.6)	9.0	WNW	Agropyron
NNW trace	7:30 P.M.	24.8(76.6)	25.5(77.9)	19.0	N	Barley
NNW trace	7:30 P.M.	24.8(76.6)	25.5(77.9)	19.0	N	Barley
SW 0.5	1:00 P.M.	28.0(82.4)	40.0(104.0)	4.0	S	Agropyron
SW 0.7	3:00 P.M.	31.5(88.7)	38.2(100.8)	23.0	nil	Agropyron
W trace	9:00 A.M.	33.0(91.4)	42.0(107.6)	22.5	SW	Agropyron
Average		30.9(87.6)	37.7(99.9)	14.8		
Minimum		24.8(76.6)	25.5(77.9)	4.0		
Maximum		36.0(96.8)	44.2(111.6)	23.0		

Table XVI (b) - Conditions of wind velocity, temperature and relative humidity in areas to which the above migrations of C. pellucida occurred; as well as the time of day when observations were made.

Wind direction & velocity in m.p.h.	Time of Day	Migration to listed vegetation			
		Air Temp. °C °F	Soil Temp. °C °F	R.H. %	Vegetation
W 1.0	10:30 A.M.	33.0(91.4)	30.2(86.4)	20.5	Wheat
WNW 3.4	4:00 P.M.	34.0(93.2)	31.6(88.9)	17.0	Agropyron and Tansey Mustard
WNW 3.4	4:00 P.M.	35.1(95.2)	35.0(95.0)	13.0	Barley
NNW trace	7:30 P.M.	27.0(80.6)	29.2(84.6)	25.5	Agropyron
NNW trace	7:30 P.M.	26.0(78.8)	27.8(82.0)	25.5	Agropyron and Tansey Mustard
SW 0.5	1:00 P.M.	27.0(80.6)	32.0(89.6)	21.0	Wheat
SW 0.7	3:00 P.M.	31.0(87.8)	33.8(92.8)	22.5	Barley
W trace	9:00 A.M.	30.2(86.4)	23.8(74.8)	24.0	Agropyron 12"
Average		30.4(86.7)	30.8(87.4)	21.1	
Minimum		26.0(78.8)	27.8(82.0)	13.0	
Maximum		35.1(95.2)	35.0(95.0)	25.5	

Table XVII - Reaction time of *C. pellucida* nymphs to a crushed-*Agropyron* stimulus under measured conditions of wind velocity, temperature and relative humidity.

Date	Time of Day	Air Temp. °C °F	Soil Temp. °C °F	Wind m.p.h.	R.H. %	Time for positive response	Time for general response
June 27	2:30 P.M.	20.0(68.0)	34.8(95.0)	2.9	46	0:30 min.	2:00 min.
June 28	3:00 P.M.	16.5(61.7)	19.5(67.1)	1.7	68	0:35 "	2:00 "
June 29	9:30 A.M.	22.0(71.6)	35.0(95.0)	3.9	41	0:30 "	2:00 "
June 29	1:30 P.M.	22.9(73.2)	36.5(97.5)	3.9	41	0:35 "	2:15 "

DISCUSSION OF RESULTS

I. Fluctuation in Population Densities:

The natural population fluctuations of *C. pellucida* have been of interest and also something of a mystery to many people. Observations were made and counts of population recorded in the hope that some explanation could be forwarded for the apparent rise and fall of grasshopper populations over a period of time in a localized area.

The data presented in Table I shows the variation in population in Area I and V over a period of 55 and 44 days respectively. Both these areas are typical egg laying sites, such as described by Ball (1915) and Criddle (1933), for *C. pellucida*. Unfortunately observations were begun after hatching was completed and no information was obtained as to the population of the first instar nymphs in these areas. However, on the basis of the previous fall grasshopper egg survey in this area, the egg population had been well over 1000 eggs per square yard, thus the first instar population must have been within that range also. On July 12, in Area I, the 'hopper population was only 2.5% of that present on June 27. About two weeks later the population had increased tremendously but fell off again towards the end of August.

By observation of the population present at various intervals of time, a rather feasable explanation may be offered for the somewhat phenomenal variations in numbers within one localized area. The hatching site may be regarded as a focal point. As development increased, movement and distance of travel were increased also. At the same time the amount of succulent food within the area became less as the season advanced. Consequently the 'hoppers moved out, by migration, etc., probably in search of better food, so that by the time the 'hoppers had reached the fourth to the sixth instar of development, the outward movement from the 'focal point' was at its maximum while the population within any small portion of this 'maximum occupied area' had decreased considerably in respect to the preceeding population present. This decrease, however, only represented a wider distribution of the original population.

The point of lowest population density and the largest distribution of population seems to be correlated with development of the species. In Area I, on July 12, the lowest population of 5 per square yard, coincided with the time when most of the grasshoppers had reached maturity. Criddle (1933) pointed out that there is a period of about ten days between morphological maturity and sexual maturity. He also stated that the adults which have reached sexual maturity have a tendency to return to some suitable egg laying site for copulation and oviposition. This seems to be borne out by the data in Table I, for on July 31 many mature adults had returned to the original 'focal point', thereby producing the remarkable increase in population. It may be assumed that sexual maturity enhanced a gregarious tendency and caused the 'hoppers to accumulate in such large concentrations in localized areas.

By the time oviposition had been completed, the population gradually decreased as the adults died; so that by the end of August relativly few grasshoppers remained.

II. Movement of *C. pellucida*:

Movement of this species of grasshopper was so varied and the number of possible influencing factors so numerous and complex that considerable difficulty was experienced in explaining adequately the factors responsible. Parker (1930) recognized several behavior patterns and activities of *C. pellucida* and gave evidence in support of his statements. He correlated movement with temperature.

The data obtained in this study indicated that *C. pellucida* movements cannot adequately and accurately be linked with one factor alone, such as temperature. However, fig. I. seems to show some correlation between the activities observed and temperature. The data seems to indicate that with a steady rise in temperature activity is increased also, i.e. no activity resulted at air temperatures of 21.5 °C (70.7 °F), while movement started at 24.1 °C (75.4 °F), with a 'general movement' of the species at 28.0 °C (82.4 °F) and a 'maximum movement' at 31.6 °C (88.9 °F). Hoppers began to climb the vegetation at 31.7 °C (89.1 °F) and were greatly excited at 37.1 °C (98.8 °F) while some went into 'heat torpor' at 39.6 °C (103.3 °F). As soon as the temperatures dropped, the usual activities resumed at the above temperature but all activity ceased at 22.4 °C (72.3 °F). Therefore, from this data, (average air temperatures were quoted above) temperature appeared to be the most plausable factor to be correlated with the activity of the insect.

However, the possible influence of light and solar radiation

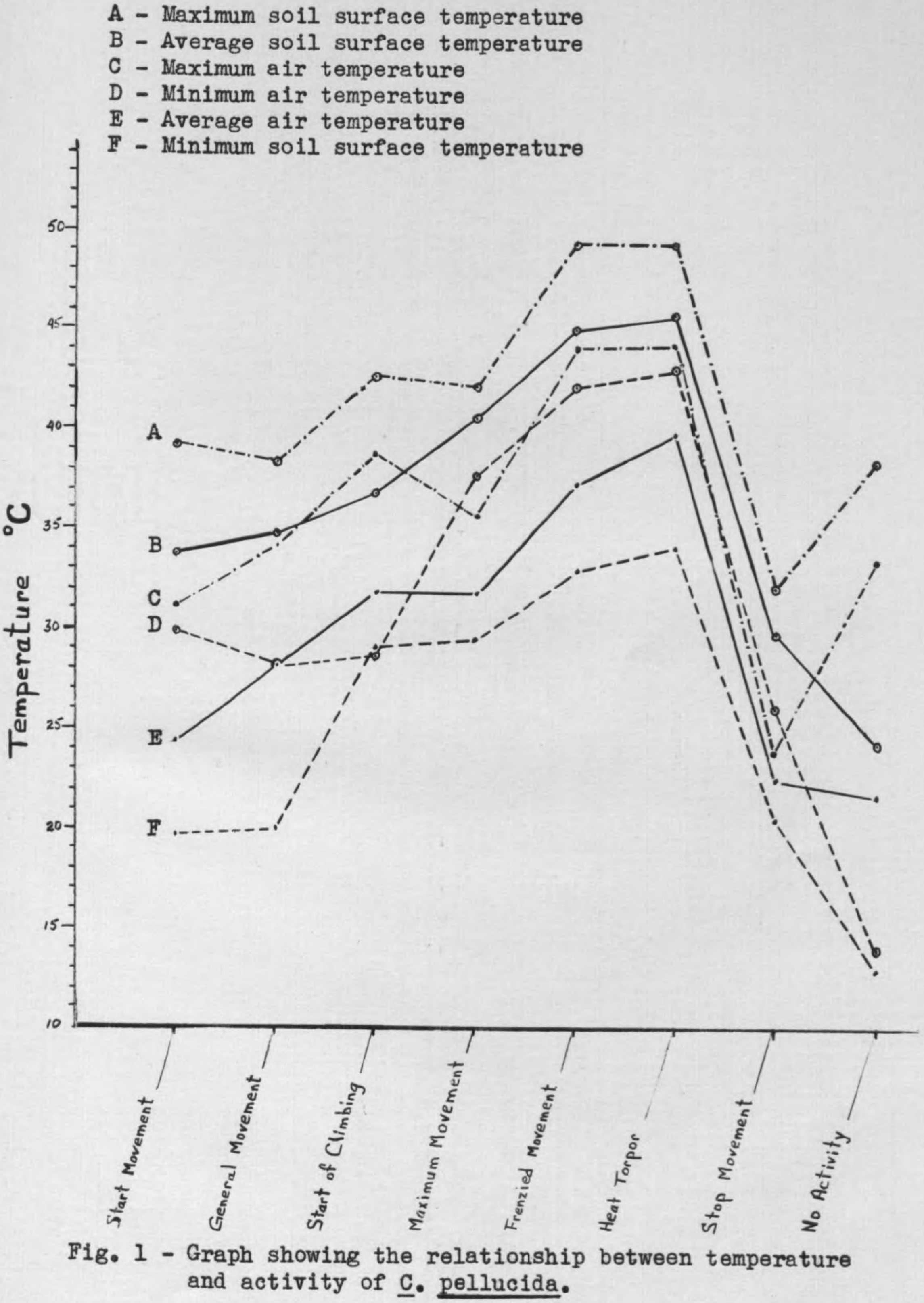

Fig. 1 - Graph showing the relationship between temperature and activity of C. pellucida.

should not be overlooked. In almost all instances where activity was observed, this action had taken place at a time when the sun was shining. Table VII, showing the various conditions of temperature, light, relative humidity and wind velocity during which movement of *C. pellucida* stopped, indicates that movement ceased when the sun was obscured by a cloud. Therefore a possible positive photokinesis displayed by the insect may be as vital a factor as temperature in determining the cause for certain activities. Since temperature will decrease with a decreased intensity of light, such as is produced by a cloud passing before the sun, the insect may also be caused to stop its activity due to positive thermokinesis which would produce variation of locomotion proportional to the variation in temperature.

No precise and well defined division could be attained between the influence of sunlight intensity and temperature, but from the data accrued and presented it seems evident that both these factors form a complex of which neither can be designated as being the principle factor but both being complimentary factors in the production of movement responses.

It is known that a grasshoppers internal temperature varies with the external temperature, (grasshoppers being poikilothermic), but it also varies in relation to the intensity of solar radiation. It may then be assumed that *C. pellucida* stopped its activities when the sun was obscured by a cloud (Table VII) because the adsorption of solar rays (heat) by the insect was not the same as that of the earth or the air. The air temperature may not have decreased as sharply due to the decrease in sunlight intensity, as that of the insects body temperature. In this respect the intensity of sunlight seems to play a larger role in governing the activities of the insect than does temperature; in that the insect may be more photokinetic than thermokinetic.

Similarily, since air temperatures may not change much while the grasshoppers temperature may change considerably, the sunlight intensity factor may also be a cause for the overlapping of temperature ranges in which various behavior activities were observed. For example in fig. 1, the highest air temperature at which 'general movement' was observed was 34.0 °C (93.2 °F) while the lowest air temperature at which 'maximum movement' of the nymphs was noted was 29.4 °C (84.9 °F). Other measured factors were not at great variance, therefore, the sunlight intensity factor may be of importance when viewing activity as a result of a phototaxis supplemented by a thermotaxis.

Kennedy (1939) says,"In literature on diurnal behavior it is sometimes mentioned that humidity is important but, owing to the difficulty of separating humidity and temperature, proof is hard to obtain." The data obtained in this project showed that a minimum relative humidity of 10% was present when C. pellucida were observed as being in 'heat torpor', a maximum relative humidity of 97.5% was present when 'no activity' was observed, while all other movement activities were noted as taking place within a relative humidity range of 24 to 38.5 %. It appears then that little evidence is present to show that relative humidity is specifically important here, and its influence on behavior of C. pellucida remains doubtful.

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