ANALYSIS AND EVALUATION OF RESULTS AND METHODS REPORTED IN THE LITERATURE ON POULTRY LIGHTING AND INVESTIGATION OF LIGHT INTENSITIES FOR ROOSTING AND RISING OF WHITE ROCK HENS

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Allen Frederick Butchbaker

ABSTRACT

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Since 1900, the use of artificial lights to supplement natural daylength has improved the egg production of hens. Research in the 1930's found that the increased egg production was not a result of the increased time to feed, but a physiological response. Because of the preponderance of applied research rather than basic research, fundamental information is needed on the effect of light on certain responses of chickens under carefully controlled conditions.

A review of the many articles on poultry lighting revealed some contradictory results. The most outstanding difference between experiments was in light intensity. This difference may be accounted for by lack of uniformity in pen design, lamp wattage, lamp location, luminaire, or season of year. Methods of measuring light intensity may not have been comparable.

In this study, preliminary investigations of roosting and rising of White Rock hens under natural light conditions showed that the time of roosting did not correlate with sunset time. The chickens tended to roost at a light intensity dependent upon the degree of cloudiness. The time of rising correlated with sunrise time.

Investigations with artificial lights showed that chickens roosted at a light intensity dependent upon the light intensity to which they had become adapted. With no light at night, significant differences did not exist between the various light intensity treatments for rising.

Chickens see mainly reflected light, therefore reflectance measurements should be the criteria for measuring light intensity within a poultry house. Incident light readings in footcandles averaged about five times higher than comparable reflectance readings in footlamberts. A brightness meter showed that white chickens reflect the most light of any objects in the pen which fact might account for some of the behavior of chickens.

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INTRODUCTION

> And God said, Let there be light: and there was light. And God saw the light, that it was good: and God divided the light from the darkness. And God called the light Day, and the darkness he called Night.
>
> Genesis 1: 3-5

This is the biblical explanation of the beginning of light. Light is truly one of the greatest phenomenas in nature. Nearly all life is either directly or indirectly dependent upon light. Plants use light through the process of photosynthesis to synthesize sugars from carbon dioxide and water. Higher forms of life, such as the vertebrate animals, use plants as their food supply. Some of the highest forms of animals use other animals or both animals and plants for their food.

Light not only sustains life through the process of photosynthesis, but also permits animals to see their surroundings. The awareness of most animals of their surroundings or changes in their surroundings, is the result of reflection or emission of light toward them by external objects and the reception of this light by special photoreceptive organs, (Walls, 1941). In the higher forms of animal life these organs are called eyes. The eyes do not see the objects but animals see through the use of eyes. Seeing is a phenomenon of the mind plus the eye and not of the eye alone.

Vision is a complex and sometimes deceptive product of the interaction of the simple information which travels along the optic nerve, and the manipulations which this information undergoes in the brain, before it is presented to the consiousness for action or other disposal. "Nothing is in the mind which is not first in the senses" but the sense organs, and particularly the eye, may offer the mind much more than the latter can assimilate. It is this interpretation that is the cause of much research by physiologists and psychologists. We do not know what animals see in their minds. We can not adequately interpret results for animals, as the human eye and mind visions objects. Animals may see only blurs of objects and not distinct colors, whereas the human eye may distinguish the same objects very clearly. Therefore, one should not interpret what an animal sees in terms of a person's photoreceptiveness in either color, sensitivity, or acuity.

There is much evidence to indicate that light controls many of the reproductive cycles in plants and animals. For instance some plants are called short-day plants and others long-day plants. Many animals also exhibit this photoperiodicity. Some insects go into a dormant stage of life due to changes in day length. The hair of a Snowshoe Hare changes to white when days are shortening. Birds migrate towards the North during the spring in the Northern hemisphere when days become longer.

Domestic chickens exhibit a photoperiodic performance. In order to increase egg production, artificial lights are used to lengthen the natural day.

The effect of light on the performance of chickens has been the interest of many experimenters. Duration of light, rate of change of daylength, light intensity, and wavelength have been the main points of investigation.

The optimum length of day has been the main interest of researchers. There are many conflicting reports in the literature, but many researchers claim that 13 to 14 hours of light achieves the highest egg production.

The second point frequently investigated is the intensity of light needed for poultry. The usual recommended light intensity is one footcandle which is primarily based upon some investigations performed in 1924. However, the full lighting regime was not investigated. Most investigations stopped before a light intensity of 40 footcandles was reached.

The effect of wavelength of light on egg production has not been investigated very thoroughly. Most experiments in this phase of research failed to balance the energy for different parts of the chicken's visible spectrum. Red and yellow light appear to be the most desirable, and blue light the least desirable.

Many investigators noticed that egg production falls off during periods of downward changing daylengths, and increases during increasing daylengths. Other investigators used this fact to delay the sexual maturity of pullets and increase egg production and egg quality.

Physical factors, other than light, may also have a bearing on the reactions of chickens. Air temperature and wall temperatures have an effect on the dissipation of heat by chickens. Humidity, either directly or indirectly, may affect chickens in certain responses. Chickens are easily frightened, so strange or familiar noises may also affect their behavior.

When conducting an experiment with chickens one should recognize several physiological and socialogical factors. Different breeds or strains may react to a stimulus in different ways. The birds may react differently depending on their age. The previous history of chickens may affect their reactions to a certain stimulus. Chicks grown under different types of lighting conditions may react differently to the same stimulus when mature. Chickens have a definite peck order (social order). The top chicken will peck at all of the other chickens and so on down the order until the bottom chicken in the social order is pecked at by all of the others. This social order may affect an experiment wherever a group of chickens is studied.

The performance of chickens may be measured in several different ways: total egg production, feed consumption, age at maturity, rate of lay, time of lay, clutch length, activity, mortality, molt, egg size, egg quality, live weight, and physical reaction (response) to a stimulus.

There are several contradictions in the literature as to the effect of light on some of the performance responses of chickens. Also, some of the recommendations of poultry specialists are based upon research conducted several years ago. Most of the experiments reported in the literature were conducted as an applied type of research rather than basic research.

The aim of this thesis is to provide more basic information on the effect of light on the habits of chickens. One way to investigate the effects of light on chickens is to study the actions of chickens under natural light conditions. A conspicuous point to investigate is the act of rising and roosting of chickens. Under natural conditions, chickens rise when the light intensity increases from darkness, and roost upon the approach of sunset. This study will investigate the effect of light on chickens at the time of rising and the time of roosting.

Another aim of this thesis is to investigate the environment of a poultry house as a chicken sees it. Since chickens see objects because of light reflected from the objects, measurements of the light reflected from objects in a poultry house will be made.

After considering the above aims, definite objectives can be set up. Broad objectives are made as well as objectives concerned with the investigations included in this thesis.

OBJECTIVES

The objectives of this study are divided into two sections: overall and specific.

The overall objectives are:

(1) Ultimate goal by the use of light of increasing the performance of chickens, i.e., egg production, growth, feed conversion.

(2) Increase the knowledge about the influence of light on chickens.

The specific objectives are:

(1) Evaluate articles in the literature concerning the effect of light on poultry.

(2) Investigate the effect of a changing light intensity on chickens at rising and roosting.

(3) Investigate the environment of a poultry house as a chicken sees it.

LITERATURE REVIEW

The articles in the literature on the subject of light for poultry are innumerable. Many of the articles of a more technical nature are presented in this literature review, whereas, the non-technical articles (trade and popular farm magazine articles) are generally omitted.

The review is presented in nine sections: History, Daylength, Light Intensity, Wavelength of Light, Frequency of Lighting Periods, Activity of Chickens, Time of Lay, Physiology of the Eye, and Photochemistry of Vision.

History

A paper presented by Roberts and Carver in 1941 at an American Society of Agricultural Engineers meeting states that the first use of artificial lighting of poultry houses in this country dates to the backyard experiments of Dr. E. C. Waldorf in Buffalo, New York, in 1889. In these early experiments gas burners were used as a source of light. Press notices of this work created a sensation when it was reported that for a three month period, each hen laid an average of ten eggs per week. Roberts and Carver also mention that the first commercial application of artificial lighting is credited to Mr. and Mrs. George Shoup (1918), formerly in charge of the Poultry Department of the Western Washington Experiment Station, Puyallup. The experiment started in 1912, and continued for six years.

George G. Newell (1916), an auditor, wrote a book entitled, "A Revolution in Egg Production." His use of electric lights to further the chickens' "business day" created a lot of unfavorable, derogatory, and sarcastic publicity in the newspapers for tampering with the chickens' normal living habits. He used two chicken houses in the backyard of his Brookfield, Illinois home (a suburb of Chicago). He noticed that there was a difference of six hours and twelve minutes between the maximum daylight hours in June and the minimum in December. This affected the chickens' "business day." He solved the problem of low egg production during the winter months by installing electric lights on January 21, 1914. He used two sockets in each house. One Benjamin socket (contains two outlets) held one eight candle power lamp and one sixty candle power tungsten lamp. The eight candle power lamps were to simulate dusk to promote roosting of the hens, but they had to be replaced with two candle power lamps. By lengthening the day he doubled the output of the hens in 12 days.

Dougherty (1917) reported that morning lights were as satisfactory as either evening or a combination of morning and evening.

Curtis (1920) reported that Professor Rice of Cornell University carried on experiments to determine the optimum intensity of illumination.

Credit for first use of all-night lighting for laying hens is given to J. E. Morris in Southeastern Ohio in 1925 (Kennard, 1929). He used natural gas for lighting his poultry house. Unable to turn off the gas automatically, he left the lights on all night with satisfactory results. The egg production of the hens increased from 10 percent to 40-50 percent.

Day Length

The effect of natural day length on the domestic fowl has been known for several years. Lewis, et al., (1919) noted the seasonal variations in egg production and hours of daylight for hens kept through two laying years. Whetham (1933) described the correlation between day length and rate of egg production for fowls over a wide range of latitudes under natural conditions. Maximum production accompanied seasons with longest days.

Many of the early experimenters merely studied the effects of artificial lighting on the chickens' increase in egg production during the winter months without regard to why the chickens produced more eggs. They tried to approach the natural day length where the egg production is greatest, normally a 13 to 14 hour light day. Kable (1926) used two pens of yearling White Leghorn hens for a laying experiment. He lighted one pen and left one pen unlighted. He gives feed cost, power cost, and egg production curves, but does not mention the type of lamps, the number of lamps, light intensity, or the length of operating time used in the experiments.

There have been many experiments, such as Kable's, to determine if egg production increased by using artificial light.

Fairbanks and Rice (1924) recommended a morning and evening lighting schedule. This provided a uniform day of 13 to 14 hours of light despite changes in the times of sunrise and sunset throughout the season. One common practice was to turn the lights on at 4:00 a.m. and off at daylight.

Ebbel (1940) subjected hens of several breeds to artificial illumination during a period from December to March, thereby increasing winter egg production and consequently the number of early chicks.

Byerly and Moore (1941) described the effect of several different light periods (normal day and night, 6 hours light - 18 darkness, continuous 14 hours of light - 12 darkness) on length of clutch and rate of egg production of a cross of New Hampshire-Barred Plymouth Rock chickens. The 14 hour light - 12 hour dark period lengthened the clutches without a following decline in egg production. Continuously lighted birds produced well at first but soon declined. The birds receiving 6 hours light - 18 darkness began to molt heavily and ceased laying early. The light intensity was approximately 11 footcandles in each group.

One of the most extensive investigations on day length was conducted by Roberts and Carver (1941). The experiments were conducted in a windowless poultry house using artificial light only. No mention was made of the breed, but they say that birds of similar breeding were used. With a 7.5 footcandle light intensity, they found that 13 hours of light was optimum for egg production. There appeared to be no significant difference between 13 and 19 hours of light. Anything below 13 hours of light resulted in a decrease in rate of egg production.

Riley and Byerly (1943) concluded that while increased light periods are capable of stimulating reproductive activity in yearling Rhode Island Red hens, which have not finished molting, the progress of molt is not affected. Warren, et al., (1950) summarized the performance of laying hens under varying environmental conditions. Molting was inhibited or delayed for birds receiving 12 hours of light daily throughout the laying year.

Mueller, et al., (1951) states that sexual maturity was attained earliest by pullets receiving more than 12 hours of light per day. Pullets kept under controlled light conditions, but subjected to variation in temperature, laid as well as pullets for which both light and temperature were controlled at constant levels.

D. C. Kennard (1929) used all-night lights for Leghorn pullets in 1928-29. He reported a prompt response in egg production for each of the test groups and no ill effects. The peak production with continuous light occurred in October, November, and December. No mention is made of the annual egg production.

Penquite and Thompson (1933) studied the influence of continuous light on Leghorns. They found that continuous light did not increase or decrease to a significant degree the total number of eggs laid annually. The hens with lights laid more eggs in November, December, and January than the controls, the peak of production coming in November and December. The peak for the controls came in March and April. Apparently, the continuous light did not have a deleterious effect upon the birds.

Weinmiller and Mantel (1940) treated hens with all-night lights from November 1 to May 31 and reported a marked increase in egg production for the first four months of the experimental period. They also report a significant reduction of molt of illuminated birds.

Ryan, et al., (1959) conducted a 48 week experiment to find the effect of all night lighting vs a 14 hour day on pullet egg production using S.C.W.L., W. P.R., B.P.R., Cr. Bd., R.I.R., and Conn. Controls. They found that for the first 12 weeks rate of lay for the all-night group was 5 percent higher than the 14 hour group. The advantage declined to 1.8 percent for the 48 week period. There was evidence of a variation to the two light treatments among strains and breeds. No mention is made of the previous lighting history or the age of the pullets at start of the experiment. Also, the light intensity is not mentioned.

Heywang (1946) found that chicks reared to 12 weeks of age under continuous light showed greater weight gains than chicks reared under the usual daylight and night conditions.

In England, Hutchinson and Taylor (1957) studied the seasonal variation in the egg production of fowls. They concluded that a downward change of day length can induce molting and cause cessation of laying even when the final absolute day length is adequate.

Sykes (1956) studied the effect of short, unchanging daylength of six hours on age at sexual maturity and egg production. He concluded that age at sexual maturity is not affected by the absolute length of the day, but egg production is affected both by the absolute length and rate of change in length of day.

Callenbach, et al., (1944) studied the influence of light on age at sexual maturity and ovulation rate of White Leghorn pullets. They found that the continuous 24 hours per day illumination during the growing period did not result in sexual maturity at a younger age. Constant 24 hours per day illumination during the growing period and thereafter appeared to inhibit the expression of sexual maturity of a considerable number of exposed pullets and prevented a high rate of ovulation during the entire laying period. Growth, feed consumption, and mortality were either entirely unaffected by variations in light treatment or indirectly influenced by reproductive activity.

Tomhave, (1954) investigated the influence of artificial lights during the growing period upon the sexual maturity and subsequent egg production of October hatched New Hampshire chicks. He found that sexual maturity was delayed 7 to 14 days by the use of artificial lights.

T. C. Byerly (1957) developed an egg laying equation which uses light as one of the dependent variables.

$$R = A + (B) \log_{10} X + CY + DZ$$

Where:

R equals the monthly rate of egg production in percent of total number of hen-days

A, B, C, & D are constants calculated by the method of least squares

Log_{10} of X is the logarithm of the length of daily light period in hours

Y is length of the night or dark period in hours

Z is the number of months elapsed since laying commenced.

The rate of production is proportional to the daily light period and the daily dark period so the maximum production is reached at 13 to 14 hours of illumination.

In England, Coles (1959) showed that the relative amount of light is more important than the absolute amount of light. He compared chickens receiving 12 hours of light after the start of laying with chickens receiving 23½ hours of light. After two months the chickens under 23½ hours of light were cut back to 12 hours of light. The reduction in hours of light caused a fall in egg production and an increase in molt.

Light Intensity

One of the earliest reports of light intensity investigations is published in a bulletin on the artificial illumination of poultry houses for winter egg production by Fairbanks and Rice (1924). They investigated the threshold intensity of light on the floor above which the activity of chickens would be increased, and below which the activity would be decreased. They revealed that the general illumination of the pen was quite as important as the illumination of the floor. It was determined that the intensity of light on the floor necessary for active feeding was from eight-tenths (0.8) to one (1.0) footcandle. They said that a 40 watt Mazda bulb with a 16 inch reflector six feet from the floor would give sufficient lighting for approximately 200 square feet of floor area. No mention was made of the breed of hens used in the experiment.

Roberts and Carver (1941) observed rate of egg production with light intensities of 1.0 to 31.3 footcandles at the feed troughs with 13 hours of light per day. They found no significant difference due to increasing the intensity of light over 1.0 footcandle. However, no mention is made of the breed of hens used in the tests, or the instrument used for measuring light intensity.

Nicholas, et al., (1944) found that varying the intensity of illumination from 0.5 to 38.0 footcandles at a central point in the "working area" and from 0.0

to 27.0 at a central point on the roosting perches had no effect on the degree of reproductive response. Variable intensity did not cause variable egg production.

A study by Moreng, et al., (1956) indicated that a limited light environment may be more stimulating to the anterior pituitary function of chicks than an abundant light environment.

Wilson, et al., (1958) studied the effect upon egg production of keeping chickens in darkness. Single Comb White Leghorn hens kept in continuous darkness for five weeks continued to lay eggs. Some of the hens did not cease egg production, while others, previously pausing, started to lay again. The hens that paused for no longer than five days, laid at a rate of 60.2 and 77.1 percent in two tests. The decline in egg production was greatest in the hens losing the largest percentage of body weight. An intensity of 0.0002 footcandles was determined by exposing film in the room for one hour and then developing it. A hen does not need light for either ovulation or oviposition. The psychic factors regulating ovulation and oviposition are more important than the amount of light a bird receives.

Wavelength

Piper (1905) found that vertebrates such as the hen and buzzard, gave maximal responses to a wavelength of 600 millimicrons both when light adapted and dark adapted. He recorded the retinal currents under monochromatic lights.

Hess (1912) believed that birds are blind to violet and blue. By sprinkling rice grains in a spectrum projected upon a white floor, he found that fowls would eat the rice from the red end to the junction of the green and blue, but would peck no grains in the blue and violet.

Hahn, Honigmann, and Blasser (1916, 1926) painted a different picture by staining rice grains with different dyes or by illuminating them with colored lights, gluing down the grains to which it was desired to train the birds negatively. They said that the domestic hen has partial blue-blindness which increases during growth. They contended that the hen must be convinced that blue objects are good to eat. In other words, there is "no blue food in nature."

Watson and Lashley (1915 and 1916) used superlative apparatus giving brilliant beams of pure spectral lights. Watson fixed the spectral limits of the chick as lying between 700 and 715 millimicrons at one end and between 395 and 405 millimicrons at the other.

Lashley trained his bantam cocks to discriminate various wavelength bands and found that they had about the same number of maxima hue-discrimination, and in about the same locations as the corresponding graph for man. Man distinguished 160 spectral segments in this visible spectrum whereas a bird, such as a pigeon (Hamilton and Coleman, 1933) can discriminate only 20 spectral segments between 700 millimicrons and 460 millimicrons.

Laurens (1923) found that the pigeon has a Purkinje phenomenon, but that it takes all of 45 minutes for any discernable effects of dark-adaptation to manifest themselves. Piper had not waited long enough to get actual dark-adaptation, and consequently missed the Purkinje phenomenon; nor had he, like Laurens, used light beams of equal energy content, and he therefore obtained fallacious maxima. With equalized lights, Laurens found that the pupil of the light-adapted pigeon responded between 704 millimicrons and 424 millimicrons, maximally at 564 millimicrons. Scotopically, the spectrum was shortened at the red end to 664.5 millimicrons and the maximum was shifted to 524.5 millimicrons.

Dakan (1934) studied the effect of light on feed consumption and the urge of hens to lay. He used light filters from the Corning Glass Company for the colored light source. All daylight was excluded from the experimental pens. He found that red was the best light source for laying.

Table I Dakan's Results of Effect of Color on Egg Production

Pen No.	Color	Total Production August 1 - January 15
1	White	70.5
2	Red	78.0
3	Yellow	69.9
4	Blue	56.0

Dakan does not mention the intensity of the light source, reflectance characteristics of the walls, transmittance characteristics of filters, the distribution of the light in the pen, or the breed of chicken used in the tests. He states also that the gonadal activity was increased by red absorption as indicated by Bissonette (1932) and Rowan (1938).

Dobie, et al., (1946) in one of their experiments tried different types of lights. They tried Mazda incandescent, Mazda plus CX ultraviolet, Ruby Red, and Red fluorescent lighting. The egg production was respectively: 71.2%, 72.9%, 69.8%, and 71.0%. This experiment was conducted with 13 hours of light and six footcandles at the feed trough.

Hammond and Titus (1941) studied the effect of colored light and colored walls on the growth and mortality of Rhode Island Red chicks. They used 16 pens with 40 day-old chicks in each pen. The floors were painted medium gray and were covered with shavings. The walls and ceilings were painted as follows: 4 white, 2 violet-blue, 2 flat-black, 2 gray, 2 yellowish-green, 2 red (carmine) and dark green. Tungsten filament lamps were used in most of the rooms.

It was observed that from 15 to 60 percent of the

the chicks in the black, blue, and red rooms never ate; they never learned to eat. This was consistent throughout five tests. Rooms of these colors had lower light intensities. Chicks do not learn to eat readily in a low light intensity environment.

They concluded that the color of light in the environment of growing chickens is less important than the intensity of the light. Also, neither the color nor the intensity of the light to which pullets are subjected during the first 16 weeks of their life, affect the live weight, egg production, egg fertility, or hatchability of eggs.

It appears that the spectral effects on chicks had not been tested thoroughly. The effect in some pens was of low intensities rather than a direct consequence of the color. Chicks may be receiving enough light from the desirable portion of the spectrum from the light source for adequate growth, etc. The spectral reflectance of the walls was not fully known so even the walls may have been reflecting the desirable wavelengths.

Dim red lights were used to maintain winter egg production of White Leghorn pullets in New Jersey as reported by Platt (1953). This was prompted by the war blackout along the coastline. All night lighting was accomplished by using 15 watt red bulbs centered 18 inches above the perch spaced four (4) feet apart. Ten watt bulbs used 8 hours, from 8 p.m. to 4 a.m., were just as satisfactory in maintaining winter egg production as the standard incandescent filament lamps for a 14 hour day.

Carson, et al., (1958) studied sexual maturity and productivity in the chicken as affected by the quality of illumination during the growing period. Their findings did not agree with Callenbach (1944) and Hutt et al., (1955) in that one of the effects of lengthening the day of pullets with artificial light was a decrease in the rate of lay after maturity. The chickens were illuminated from 15 weeks through maturity with red, gold, green, blue, soft white, or cool white fluorescent for 24 hours per day. Controls of continuous lighting with 60 watt incandescent and of normal daylight were used. There was no evidence to show that continuous illumination with 60 watt incandescent from day-old through maturity produced any harmful effects on livability or subsequent egg production. Any quality of light stimulated the onset of egg production as evidenced by the fact that all lighted pullets reached 50 percent production at least three weeks prior to the unlighted control.

Frequency of Lighting Periods

Common lighting practices provide a day length of approximately 13 hours of continuous light. Roberts and Carver (1941) reported that 3 hours of intermittent light daily (1 light, 5 dark - 1 light, 4 dark - 1 light, 12 dark) yielded production above that of 10 hours continuous light.

Wilson and Abplanalp (1956) studied the effect of intermittent light stimuli on egg production of Single Comb White Leghorn pullets. The intermittent light was provided at regular cycles of four hours. Quantity of light was set at 90, 60, 45, 15, 2, and 1 minutes in a series of tests. They made the following conclusions:

(1) Intermittent lighting generally gave higher

egg production than the same amount of continuous lighting.

(2) Egg production obtained under short photoperiods was not proportionate to the amount of light.

(3) The minimum amount of light needed for an all-or-none response for maintaining egg production in pullets is probably less than six evenly spaced one-minute photoperiods in 24 hours.

(4) Hens were more susceptible than pullets to light changes and possibly to other environmental factors.

(5) Good layers were more resistant to shocks from light changes than poor layers.

(6) The time of oviposition is influenced by light and management factors.

Wilson explains that a considerable variation in light intensities existed in the rooms so it might be conceivable that some of the results might be due to the combination of time and intensity or just of intensity.

High-intensity light for one or a few short periods (5 to 20 seconds) during the night has been shown to stimulate or maintain high egg production in the hen (Staffe, 1950, 1951; Weber, 1951). This effect is comparable to those with more conventional forms of intermittent lighting, though intensity possibly plays a role with this method.

At the University of Nottingham, Nightall (1955) increased egg production 5 to 6 percent by using flash lighting. His method was to produce light periods of 20 seconds duration at 2:00, 3:25, and 4:50 a.m. He used a car battery and 25 volt lamps with 40, 60, and 100 watt ratings.

Shutze, et al., (1959) used continuous lighting on New Hampshire pullets for the first 8 weeks, then reared them on the range. The pullets came into production at a slower rate and peaked at 59.2 percent as compared to 73.2 percent for pullets on 12 hour light, 12 hour dark period from hatching to 8 weeks. They found that continuous light to either 8 weeks or 20 weeks depressed the subsequent egg production.

At Edinburgh, Coles (1959) conducted experiments with day-old chicks receiving six hours of light to maturity and then gradually increased amounts of light per day until 18 months of age. This resulted in a consistently high egg production pattern. A practical means of achieving this lighting plan is to rear November-hatched chicks under the natural short days until April. At the point of lay increase the light by 15 minutes per day each week. Thus, the birds are subjected to the increasing light pattern.

Stimulight is a term applied to a method of raising pullets on restricted light. D. F. King (1959) developed this method of lighting by working with White Leghorn pullets. The method consists of restricting the light to six hours per day until the pullets reach 21 weeks of age. Then 18 minutes of light are added each week until the total amount of light reaches 21½ hours per day.

The chief advantages claimed for this method of lighting are more eggs than 14 hour lighting schedule, less feed per dozen eggs, larger eggs, stronger shells, and greater hatchability.

An article in the December, 1959 issue of the Farm Journal, "How Stimulight is Working Out," says that Harold Biellier, University of Missouri, got the same result as King, but other researchers failed to verify the results. C. E. Ostrander, Cornell University, reported no increase in total production by "Stimulight" in either the light or heavy breeds. W. C. Skoglund, New Hampshire, did not get the same result as King but got the most eggs from "normal" light (14 hour day).

Nothing is mentioned about the intensity of light during the light cycle or dark cycle. In other words, was the dark cycle actually dark or was some light infiltrating the building? Did the researchers have their experiments on a comparable basis?

McClary (1960), a geneticist for a commercial hatchery firm, conducted tests with a step-down step-up lighting plan using Leghorn pullets. Conversion of existing structures to follow the lighting plan is accomplished easier than in King's plan since natural daylight can be used to its fullest extent. No windowless houses are needed in this plan. The light per day is decreased in increments of 15 to 20 minutes per week until the pullets are 22 weeks old. Then, the procedure is reversed, and the light-period is stepped-up each week to stimulate pullets into production.

The results of step-down step-up lighting, as compared to constant 15 hour per day lighting showed that:

(1) Sexual maturity was delayed two to three weeks.

(2) Pullets gave a significant increase in rate of lay after nine months.

(3) There was a significant reduction in mortality.

(4) It resulted in an increased egg weight of 1 ounce per dozen at 7 to 8 months and $\frac{1}{2}$ ounce per dozen advantage at nine months.

Activity

The effectiveness of supplemental light on egg production for many years was believed to afford increased opportunity of the chickens to feed. Fairbanks and Rice (1924) assumed that egg production depended on the activity of the chickens (speed of feeding). Goodale (1923) questioned this view. Whetham (1933) suggested stimulation through the anterior pituitary body. About the same time Bissonette (1933) came to a similar conclusion, reasoning from his experiments on the European starling.

Dakan (1934) says that birds can eat all the feed they need in ten hours. He found no difference in egg production between two pens; one at ten hours of light and hoppers covered and the other with light at night and uncovered hoppers. The stimulatory effects of light were shown by Rider (1938) to be independent of the availability of feed during hours of artificial lighting. Rider's results were confirmed by Callenbach, et al., (1943). They state that a daily feeding period of 10 hours was adequate for maximal egg production. Therefore, light is a positive physiological influence stimulating reproductive activity in mature female chickens.

Wilbur O. Wilson (1958) experimented with the effect of light on egg production and growth. He says that light per se (by itself) rather than the increase in feeding time is the factor affecting growth and egg production.

Time of Lay

Under natural lighting the hen lays only during daylight hours. The eggs constituting a sequence are not laid at the same time on consecutive days. The first egg may be laid in the early hours, the last may be laid in mid or late afternoon (Withrow, 1959).

One role of photoperiodicity in the hen's ovulation cycle is to time the appearance of a period of low thresholds to ovarian hormones in the neural component of the mechanism controlling the release of ovulation-inducing hormone from the pituitary. The period of low thresholds has a duration of not over 8 or 9 hours, and its onset is thought to follow rather closely (1 to 3 hours) upon the onset of darkness.

Fraps (1954) proposed an hypothesis to explain the mechanism of the time of ovulation with regards to photoperiods. He suggests that the nervous component of the ovulation-inducing release mechanism exhibits a diurnally recurrent rythmicity. The blood concentrations of ovarian hormones "exciting" the neural component of the ovulation-inducing hormone release apparatus increase by substantially the same course after each release of ovulation-inducing hormone in cycles of given length. Each curve of increasing excitation hormone concentration beyond that associated with the first excitation of a sequence is retarded, in time of day, by the extent of lag at the preceding ovulation-inducing hormone release.

Bastian and Zarrow (1955) proposed a slightly different hypothesis than Fraps to account for the asynchronous ovulatory cycle of the domestic hen. They recognize two separate and independent cycles which interact to produce the ovulatory cycle. (1) The release of an ovulation-inducing hormone is assumed to be continuous over a relatively long period (e.g., 8 hours) during the same hours every night. (2) The maturation of ovarian follicles is assumed to be gradually completed at more or less regular intervals.

Physiology of the Eye

In general, eyes vary only slightly in structure from one animal to another. Basically, the eye resembles a camera in structure. The retina is similar to film in that it is the photosensitive part of the eye. The cornea plus crystalline lens simulates the lens on a camera. The lid is similar to a shutter. The pupil resembles the diaphragm aperature. The interior of the eye is darkened by a chorioid pigment just as the interior of the camera is painted with a dead black paint. Some parts of the eye are automatically adjusted for changes in environment. The eye has accomodation; a way of automatically varying the distance between lens and film by changing from one lens shape to another.

The visual angle for a single eye of a vertebrate is rarely much greater or much less than 170° according to Walls (1942) in his book, The Vertebrate Eye. A hen has eyes which are at a divergence angle of 144° from the optic axis of the eyes. This causes a very slight convergence of overlapping of the visual angle of each eye of around 13°.

Retina Light waves coming to the eye are absorbed in the retina. The retina is a relatively transparent membrane containing millions of energy-sensitive nerve endings. These nerve endings are attached individually or in groups to fibers of the optic nerve.

Cones and rods are the two kinds of nerve endings and are named after their shapes. The cones are concentrated in the fovea, a slight depression in the retina slightly off the optical axis of the eye. They also exist throughout the retina but in lesser density. Cone vision is called photopic vision and is used for discrimination of fine detail and hues of color. The cones function only at higher levels of radiant-energy stimuli.

The rods exist only in the retina outside of the fovea. Rod vision is called scotopic vision. The details are neither sharp nor are hues of color discriminated with this type of vision. Vision is fuzzy and gray.

In general, the relative number of cones-per-rod are high in diurnal forms and low in nocturnal forms of vertebrates (Wall, 1942). In many birds, only a few rods can be found and these may be present over only a part of the whole retina area. Cones greatly outnumber rods in all diurnal birds which have any rods at all. The adoption of diurnality entails a sacrifice of sensitivity. At the same time diurnality is an adaptation for sharp vision.

There is a difference in the spectral response curve of the eye between scotopic vision (rods) and photopic vision (cones). The curve tends to shift to the shorter wavelengths for scotopic vision. This is called the Purkinje Effect. Scotopic vision is effective below the threshold of seeing for photopic vision.

In vertebrates the area of the brain which receives the impulses from the retina is called the hypothalmus. This region of the brain also influences temperature regulation, sugar and fat metabolism, the states of sleeping and waking, and sexual activities. It is generally believed that the hypothalmus stimulates the pituitary gland in chickens. The pituitary then induces ovulation in the hen.

Photochemistry of Vision If the retina were removed in the presence of red light greater than 650 millimicrons wavelength it would be magenta in color. This is due to the light-sensitive pigment, the visual purple (rhodopsin), which is contained in the rods. The cones do not contain this pigment. The rhodopsin is largely responsible for the ability of the rod to "dark-adapt" or lower its threshold until the amount of light needed to stimulate it is a tiny part of that required to arouse a cone. Under ordinary daylight, the rhodopsin breaks down or in essence its synthesis and breakdown are in equilibrium. Under dim light the higher concentration of rhodopsin makes the light appear brighter. In the presence of light it bleaches to a pale yellow substance named retinene.

The hypothetical pigment in the cones has been named iodopsin because of the nature of the absorption spectrum attributed to it. Studnitz (1930) calls the photochemical: zapfensubstanz, i.e., cone-substance. The absorption spectrum of zapfensubstanz is similar to the electrical responsitivity of the photopic retina.

Earlier experimenters said that human vision was trichromatic. The Young-Helmholtz theory calls for three "somethings" in color vision. Young said that there were three sets of receptors in the retina. Helmholtz said that there were three photochemical substances or processes in each cone. Studnitz recognized the possibility that what he had called one substance might really be a group of three which his solvents cannot separate from each other.

Polyak's (1941) painstaking studies of the microscopic structure of the retina led him to the conclusion that all cones are essentially alike. This does not rule out the possibility of triply differentiated patterns of nerve impulses. He mentions that a host of other structures in the retina may give clues to the visual process since they are interconnected and must be there for a purpose.

A color vision theory was advanced by Krause (1863). His theory is called the oil-droplet function. Oil droplets are located just inside the cone layer. This theory proposes that each color of oil droplet makes possible the independent sensation of the corresponding color in the spectrum. The supposition was that the bird has but one (not three) photochemical substances in its cone outer segments, and that this undifferentiated substance would be affected equally by any and all visible wavelengths of light. Color vision would be possible only by a certain wavelength, others by another wavelength, and so on.

Only red, orange, and yellow droplets occur in birds, along with some colorless droplets. The pigments in a chicken's retina are the carotenoids; astacin, sarcinene, and xanthophyll. The cones of a birds fovea contain only yellow droplets, the red ones stopping at the margin of the retinal pit.

Most birds are such early risers that they expose themselves to Rayleigh scattering of light by molecules of water and gases in the atmosphere on even the clearest of sunrises. It seems that the shorter wavelengths are scattered the most and red the least. This is one reason for the red colored sunrises and sunsets.

The bird, aided by red droplets, gets in most of the day's work at dawn and shortly after. As the day wears on the yellow droplets (colorless ones on dull days) take over. The orange ones give a smooth transition. Primarily the oil droplets act as colored filters. The yellow filter reduces the effects of chromatic aberration and reduces glare and dazzle.

Hecht (1937) developed a chemical basis of vision. He discusses the process with the aid of simple stationary state photochemical reactions. By using the basic equation:

$$KI = x^n/(a - x)^m$$

Where:

x = concentration of photoproducts

a = concentration of photosensitive substance

I = intensity of light

m = order of primary chemical reaction

n = order of primary dark regenerating reaction

K = constant

he developed equations for (1) intensity discrimination and photo reaction rates and concentration, (2) visual acuity, and (3) flicker or intermittent light stimulation which closely approximated experimental data. Many of his relationships involved reaction rates. Hecht's chemical theory considers only the concentration of the photoproducts of visual purple (rhodopsin) in the rods.

Hecht(1942) determined the threshold vision of the rods to require between 2.1 and 5.7×10^{-10} ergs at the cornea. This amounts to between 54 and 148 quanta of blue-green light. He states that the corneal reflection is approximately 4 percent, the ocular media absorption 50 percent, and the retinal transmission 80 percent. Therefore, 54 to 148 quanta becomes 5 to 14 quanta by the retinal rods. He further states that one quantum must be absorbed by each of 5 to 14 rods in the retina since a large number of rods (500) is involved in order to produce a visual effect in a 10 minute circular field.

Hugo de Vries (1943) states that the threshold of vision can be defined as the smallest number of quanta giving rise to a sensation of light. He assumes that rods and cones act like counters of light quanta. He says that the sensitivity of rods at 510 millimicrons is approximately 7.5×10^{-10} erg/sec based upon several experimenters' results plus his own results. The energy of one quantum at 510 millimicrons is 4.3×10^{-12} erg. The smallest amount of energy for vision is 3.0×10^{-10} erg if supplied in less than 0.1 seconds. At 510 millimicrons 3.0×10^{-10} represents 70 quanta. The threshold of vision is then at 70 quanta. However, only 50 percent of the quanta passing through the pupil reach the retina. At full dark adaptation approximately 15 percent of the light is absorbed by the visual purple (rhodopsin). If only about 14 percent of the visual purple is active then one can assume a sensation with one quantum of light and it follows that 69 quanta are lost for every quantum hitting a rod. Also, it follows that 5 molecules of visual purple are decomposed by 70 quanta passing through the pupil. These 5 molecules generally lie on different rods. The minimum number of rods to see in the human equals approximately 1600 rods in the retina. Sensitivity for different wavelengths is proportional to the absorption coefficient of visual purple. According to Reeves (1918) the angle at which the light spot is seen may be increased to about 30 minutes before the minimum visible energy increases. This corresponds to about 1600 rods in the human retina. The number of quanta observed at the retina for rod vision is given by the expression:

$$N_R = N_p/70$$

Where N_p = the number of quanta passing through the pupil per second

N_R = quanta observed at the retina

The ratio of cone sensitivity to rod sensitivity is 1:60. The cones react on one quantum out of 4200 passing through the pupil. The expression for cone vision is:

$$N_r = N_p/4200$$

An expression for the number of quanta observed per second was formulated by deVries. A surface of S cm^2 with L millilambert brightness (1 ml = $10/\pi$ candles/m^2) emits LS/10^3 π lumens per unit solid angle. At 510 millimicrons wavelength, 1 lumen equals 1.33 x 10^4 erg/sec equals 3.2 x 10^{15} quanta/sec. The total number of quanta emitted equals 1.0 x 10^{12} LS/sec. With N_p = number quanta passing through the pupil with surface Sp then

$$N_p = (1.0 \times 10^{12})\ SLSp\ 1/a^2 \cos b$$

Where:

a = distance of object to eye

b = angle between normal to surface and line to eye

When L = candles/m^2 & Sp in mm^2, then Lsp is called the "retinal illumination," P. Therefore; $N_p = \pi \times 10^9$ (SP) cos b/a^2. When an object is seen as a circular spot at an angle of c, then $N_p = 250\ P\ c^2$.

It follows that the number of observed quanta per second in half of a circular field of 31 minutes with a retinal illumination of 10 photons is:

$$
\begin{aligned}
N_r &= (1/2)N_p/4200 \\
&= (1/2)\ (250)\ (P)\ c^2/4200 \\
&= (1/2)\ 2500/4200\ (31)^2 \\
&= 300 \text{ quanta/sec}
\end{aligned}
$$

The effective number is (0.2)(300) = 60 quanta, since the effective time of observation is approximately 0.2 seconds.

For an intensity discrimination of 10 photons, the number of quanta to be found on one cone is

$2500/4200\ (1.5)^2 = 1.3$/sec. (One cone equals approximately a 1.5 minute angle.)

The maxima of visual acuity and intensity discriminations are reached between 3,000 and 10,000 photons. For one cone (about 1.5 minutes) this is 500 to 1600 quanta per second with no adaptation.

DISCUSSION OF LITERATURE REVIEW

Summaries of the articles on the effect of light on rate of lay, total annual egg production, age at maturity, activity, and molting are presented respectively in Tables II, III, IV, V and VI. Factors of light listed in the first column are day length, light intensity, frequency of lighting periods, and wavelength. The headings of the other columns give the effect of the light treatment factor on the particular response of the chickens as listed in the title of the table.

The following discussions attempt to analyze the literature. Some possible fallacies in past research are discussed. Also, analytical comparisons are made of experiments where differences are reported for the same general type of experiment. The discussions are divided into the following sections: General Discussion; Daylength; Light Intensity; Wavelength of Light; and Frequency of Lighting Periods.

Table II Summary of Results of Articles in the Literature on Rate of Lay

Factor	Inhibited	Improved	Optimum	No Effect
Day length	1. Below 13 hours 2. Downward change in day length 3. Continuous light on pullets on ultimate egg production	All-night on peak production	13 hrs.	Continuous light on pullet's ultimate egg production
Light Intensity	Less than 1 f.c.	Over 1 f.c.	1 f.c.	1. Varying intensities from 1 f.c. to 30 f.c. 2. Some hens can lay in darkness
		1. Intermittent 2. Light flashes of 5 to 20 sec. 3. Restricted light of 6 hrs. until 21 wks. old then adding 18 min. per week until day length is $21\frac{1}{2}$ hrs/day	6 evenly spaced 1 minute periods in 24 hours	
Wavelength	Blue	Red		Yellow & white the same

Table III Summary of Results of Articles in the Literature on Total Annual Egg Production

Factor	Inhibited	Improved	Optimum	No Effect
Day length				1. Continuous light had no significant effect

Table IV Summary of Results of Articles in the Literature on Age at Maturity

Factor	Inhibited	Improved	Optimum	No Effect
Day length	1. Continuous 24 hr. day - (but also contradicted)	1. More than 12 hours		1. Absolute day length
	2. Use of artificial lights delayed 7 to 14 days			
Wavelength		Any quality of light improved when used continuously		

Table V Summary of Results of Articles in the Literature on Activity

Factor	Inhibited	Maximum	Range	Minimum
Light Intensity				1. 1 f.c. for feeding
Wavelength	1. Blind to violet and blue 2. Partial blue blindness, increasing with growth	1. 600 mμ for both dark and light adapted 2. 564 mμ for photopic 3. 524.5 mμ for scotopic	1. 700-715 mμ to 395 - 405 mμ range of spectrum 2. 704 mμ to 424 mμ photopic vision 3. 664.5 mμ at red end scotopic	
Day length				1. 10 hours needed for feeding

Table VI Summary of Results of Articles in the Literature on Molting

Factor	Inhibited	Optimum	Increased	No Effect
Day length	1. 12 hours throughout year 2. All-night		1. Downward change of day length	1. Increased length of light periods did not affect progress of molt

General Discussion

It is difficult to compare experimental results of poultry lighting of several years ago with experimental results of today. For instance, egg production has improved through better breeding. Also, better feeding practices have played a major role in obtaining higher egg production. Some of the experiments a few years ago were concerned mainly with maintaining a high rate of egg production during the winter months. Today, the yearly egg production is considerably higher than it was a few years ago. Therefore, we are not as seriously concerned with boosting peak production during the winter months as previously, as we are interested in obtaining a higher rate of lay and a higher annual egg production. Research is needed to establish lighting recommendations for present day chickens.

Generally speaking, many of the experiments on the effects of light on chickens were not a basic research type of experiment. Instead, most experiments were an applied type of research with little precision in the control of their source of light or in their measurement of light intensity. The intensity and spectral characteristics of light varied considerably from one experiment to the next depending upon the following conditions: wattage of the electric light source, the size and location of windows, the spectral transmission characteristics of the windows, the reflectance of the environment in both energy and wavelength, time of day, size of pen, and season of the year.

Many articles mention the lamp wattage used in the pens, and frequently state the size of the pens. The light intensity, in footcandles, is often given in the more recent articles. However, the reflectance of the environment should be included. A chicken (or any other vertebrate with an eye) does not see light. He sees only objects from which the light is reflected. Therefore, the reflectance of the environment is important since it is the reflected light that a chicken generally sees, and not the emitted light which most researchers have tried to measure. Actually, results should not be measured in terms of footcandles since the footcandle is based upon the spectral sensitivity curve of the human eye. A unit of light intensity or reflectance based upon the spectral sensitivity curve of the chicken eye should be the basis for making light measurements.

Daylength

It appears that 13 to 14 hours of light per day are needed to maintain a good rate of egg production. Primarily, this recommendation is based on the hours of day light received during the months of March and April when the hens lay the best under normal conditions. During the first six months of the year the days become progressively longer. This positive rate of change of daylength tends to promote or maintain rate of lay. A negative rate of change of daylength appears to cause a decrease in egg production and an increase in molting.

Any additional daylength over a normal 14 hour day delays sexual maturity. Callenbach (1944) and Carson (1958) obtained different results on the rate of lay after sexual maturity of pullets by using continuous light. Callenbach found that constant 24 hours per day illumination during the growing period and thereafter appeared to inhibit the expression of sexual maturity and prevented a high rate of ovulation during the entire laying period. However, there are differences between their experiments. Callenbach used June-hatched White Leghorn pullets; Carson used unrelated strains of a Columbian-patterned bird of a September hatch. No information is given on the intensity of light under the natural daylight condition for either experiment. Different results might be attributed to this factor, since the light intensity may have varied considerably in each instance. The length of day and the natural outdoor light intensity would have been different in each case since Callenbach's experiment started in June and Carson's started in September. Probably more overcast weather prevailed during Carson's experiment, so it is possible that low outdoor light intensities prevailed.

Callenbach used a lower level of artificial illumination than Carson. He used a 40 watt incandescent filment lamp in a 10 x 12 foot (120 sq. ft.) pen, whereas Carson used a 60 watt incandescent filament lamp in a

6 x 13½ foot (111 sq. ft.) pen. Therefore, Carson's pen had higher light intensity.

Callenbach moved his pullets to a lower light intensity pen (12 x 20 foot or 240 sq. ft.) which may have affected their age at sexual maturity. Carson separated his pullets at 10½ weeks into different pens. The pens were of the same size before and after separation. The light intensity probably remained the same for all of Carson's pens.

Light Intensity

The commonly recommended minimum light intensity is one footcandle. This recommendation is based upon research conducted in 1924 by Fairbanks and Rice. Common measuring instruments used at that time were probably not very accurate, at least the researchers did not report the accuracy of the light intensity readings. They did not mention the breed of chickens used in the experiment. A difference probably existed between the various breeds of chickens in their response to light. Some breeds of hens can produce eggs when subjected to continuous darkness as evidenced by Wilson (1958).

Light intensity investigations on chickens have been limited primarily to light intensities below 40 footcandles. Perhaps higher intensities would have a more pronounced effect on the chickens than the lower intensities which have been used for many years. Chickens live outdoors quite successfully even in brilliant sunshine when the light intensity approaches 10,000 footcandles. The effect on chickens of light intensities from 0 footcandles to 10,000 footcandles has not been thoroughly investigated.

The combinations of various light intensities with various time periods have not been investigated. Both Roberts, et al., and Nicholas, et al., investigated the effects of light intensity on the egg production of hens and found no significant difference between different light intensities. However, the experiments were below forty footcandles maximum light intensity. Each experiment used a nearly constant day length of 13 to 14 hours. Different combinations of light intensities and day lengths were not tried. Possibly the effect of the total light energy received by the chickens would be a more meaningful way of exploring the effects of light on chickens.

Wavelength of Light

The spectral limits of a chick's eye have been established with fairly good experimental techniques. A chick sees from approximately 4000 Angstroms to 7000 Angstroms, or just about the same as the human eye. The spectral sensitivity curve of the chick peaks at nearly the same place as man's. However, certain articles in the literature indicate that birds tend to respond to red light better than other wavelengths of light. Blue light appears to be the least desirable for chickens. It appears as if the chicken's eye becomes less sensitive to blue light with increasing age.

In general, the experiments on the effect of wavelength of light on egg production or age at maturity were not very precise. None of the experiments balanced the energy in different parts of the chicken's visible spectrum. Incandescent filament lamps were used predominately, therefore the energy in the red end of the spectrum was the highest. A few experimenters tried to isolate the various wavelengths by means of filters, but they failed to balance the energy transmitted through the filters.

Some experiments consisted of using different colors of fluorescent lighting. Fluorescent tubes generally emit more light in the greens and blues than the filament lamps, and less in the reds. Therefore, comparisons between filament and fluorescent lamps may be fallacious unless the spectral characteristics of the two light sources are considered.

Frequency of Light Periods

Higher egg production of hens is apparently obtained by breaking up the day into several light periods. There are many types of lighting plans for the rearing of pullets and for laying hens. Most plans are primarily interested in the duration of the light period. With the exception of flash lighting (or shock lighting), little mention is made of the light intensity. Flash lighting is accomplished by high intensity light for a duration of a few seconds. Some of the other intermittent lighting plans apparently follow the normal recommended light intensity of at least one footcandle. However, little mention is made of the intensity or dominant wavelength of light. Perhaps, the total energy of light received per day by the chicken is the important factor and not just the duration, intensity, or wavelength of the light.

The darkness cycles are probably nearly as effective in stimulating egg production as the corresponding light cycles. At least the onset of darkness supposedly initiates the ovulation process. Information on the dark cycle is lacking, especially the intensity of light during the dark periods. One experimenter found that some hens lay in total darkness. From this information one might be led to believe that even a few photons of light might be enough to stimulate hens to lay. It is difficult to compare results from the different studies, since each is conducted under different environmental conditions. Buildings are difficult to seal from light so different degrees of darkness likely prevail between the various experiments.

PRELIMINARY STUDIES OF LIGHT INTENSITIES AT ROOSTING AND RISING

The motive behind this preliminary study was to explore various facets of the effect of light on poultry. This study was confined to the effect of natural daylight on chickens. A conspicuous point to investigate was the light intensity at roosting[1] and rising[2] of chickens at dusk and dawn respectively, because of chickens' apparent reaction to light intensity changes at those times.

Location and Apparatus

The investigations were conducted with 20 White Rock hens in pen 205 of the Commercial House of the Poultry Science Department, Michigan State University. This pen is 20' x 24'. The walls are a medium gray color. Two standard windows are located on the east side of the pen with a small window located in the door

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[1]Roosting, as defined in this study, is the act of a chicken hopping onto a roost.

[2]Rising is defined as the act of a chicken hopping off a roost.

on the west side of the pen (See Fig. 1).

A phototube was mounted in a box on the roosts near the south wall. Light passed through a three inch square hole in the box and then through a two and one-half inch square opening in a disk inside the box before it reached the phototube. Car window weatherstripping was fastened to the inside of the box between the box and the disk to inhibit light leaks into the interior. The inside of the box was painted with a flat black paint to increase the absorption of light and reduce reflection of light.

A disk contained a series of eight openings, six of which were covered with Kodak Wratten Filters. The seventh opening was covered to permit measurements of the phototube dark current. The eighth opening allowed all available wavelengths of light to reach the phototube. A pipe extended from the center of the disk through the south wall to the adjoining feed room. A handle on the end of the pipe aided in positioning the various openings on the disk. Also, copper lead wires from the phototube passed through the wall near the pipe and connected to the microammeter and the voltage supply

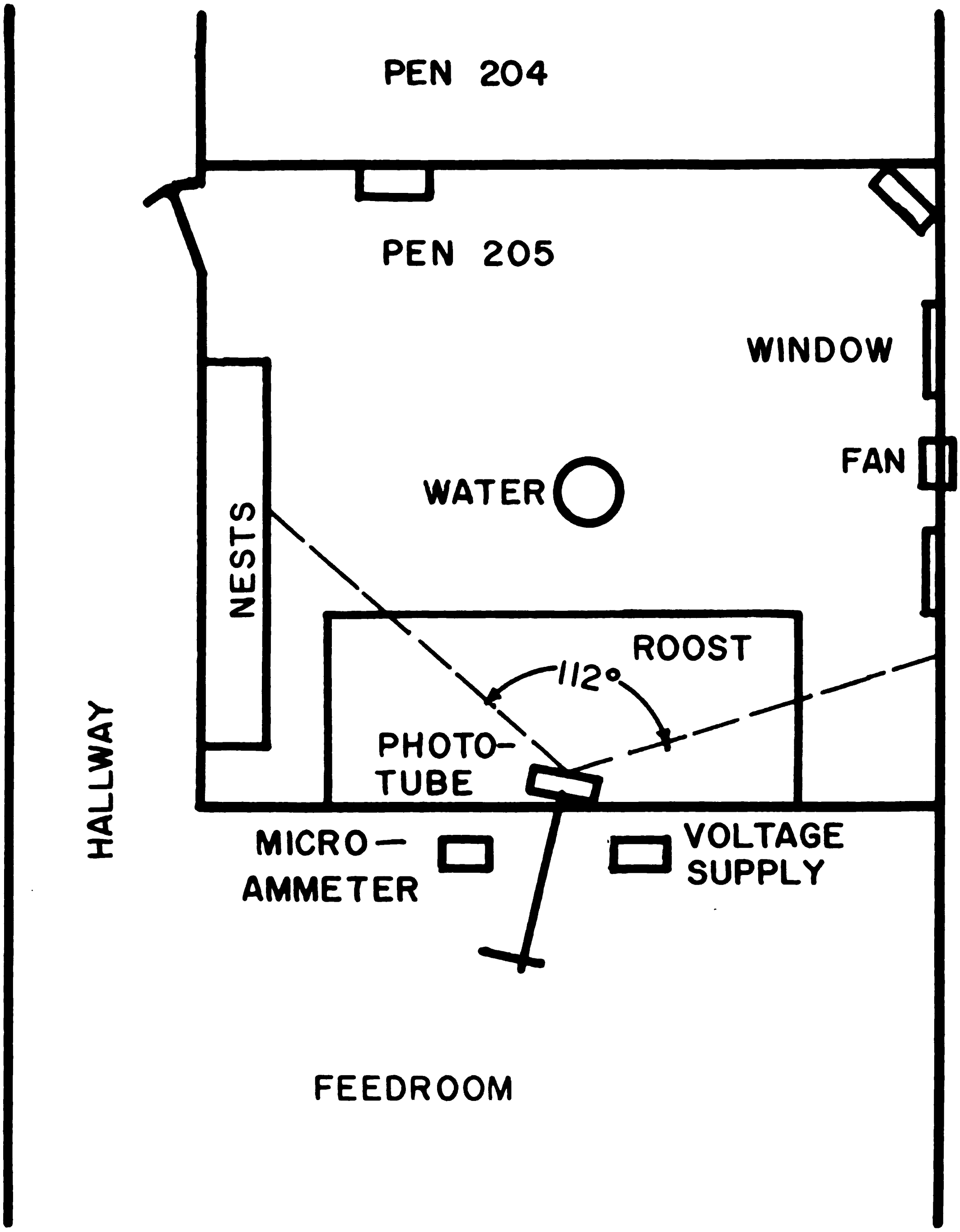

FIG. 1. LOCATION OF APPARATUS IN PEN 205 OF COMMERCIAL POULTRY HOUSE

located in the adjoining feed room.

The height of the phototube was just slightly above the height of a head of a chicken standing on the roost. The phototube has a visual field of 112° horizontally and 129° vertically. This angle includes the windows along the east side and the window in the door.

<u>Light Sensing Apparatus</u>

The basic electrical circuit consists of three components as shown in Fig. 2: microammeter, d-c power supply, and phototube.

The microammeter is a Keithly Vacuum Tube Electrometer Model 210, with a Keithly Decade Shunt Model 2008, which permits accurate measurements as low as 5×10^{-14} ampere. With very high shunt resistances small currents representing levels of illumination in the order of hundreths of a footcandle can be measured.

The d-c voltage for the circuit was supplied by a Heathkit variable voltage regulated power supply. A constant d-c voltage of 250 volts was supplied to the phototube since that is the maximum anode voltage rating of the tube.

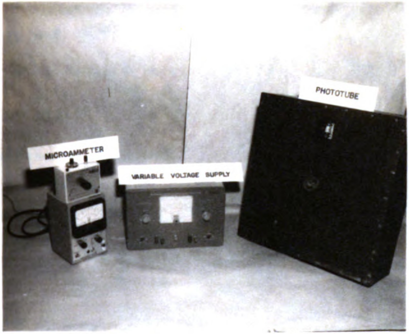

FIG. 2. LIGHT MEASURING APPARATUS CONSISTING OF MICROAMMETER, D-C POWER SUPPLY AND PHOTOTUBE

A RCA vacuum cartridge type phototube was used. This tube is used primarily for colorimetric applications. The cathode has a silver-rubidium oxide-rubidium surface with a maximum response near 4200 Angstroms. The spectral response curve of this cathode shown in Fig. 3 is called an S-3 curve. The curve approximates relatively close the response of the human eye. The absolute luminous sensitivity is given in microamperes per lumen with an incandescent tungsten filament at a color temperature of 2870°K serving as a light source.

Phototube Characteristics

Type	RCA 926
Surface Area	0.4 in^2
Spectral Response	S-3
Wavelength of Maximum Spectral Response	4200°A
Sensitivity	
μa/μ watt at response peak	0.0016
μa/lumen, 2870°K	6.5
Anode Voltage	250 d-c
Maximum Ratings	
Anode Supply Voltage	
dc or peak ac volts	500

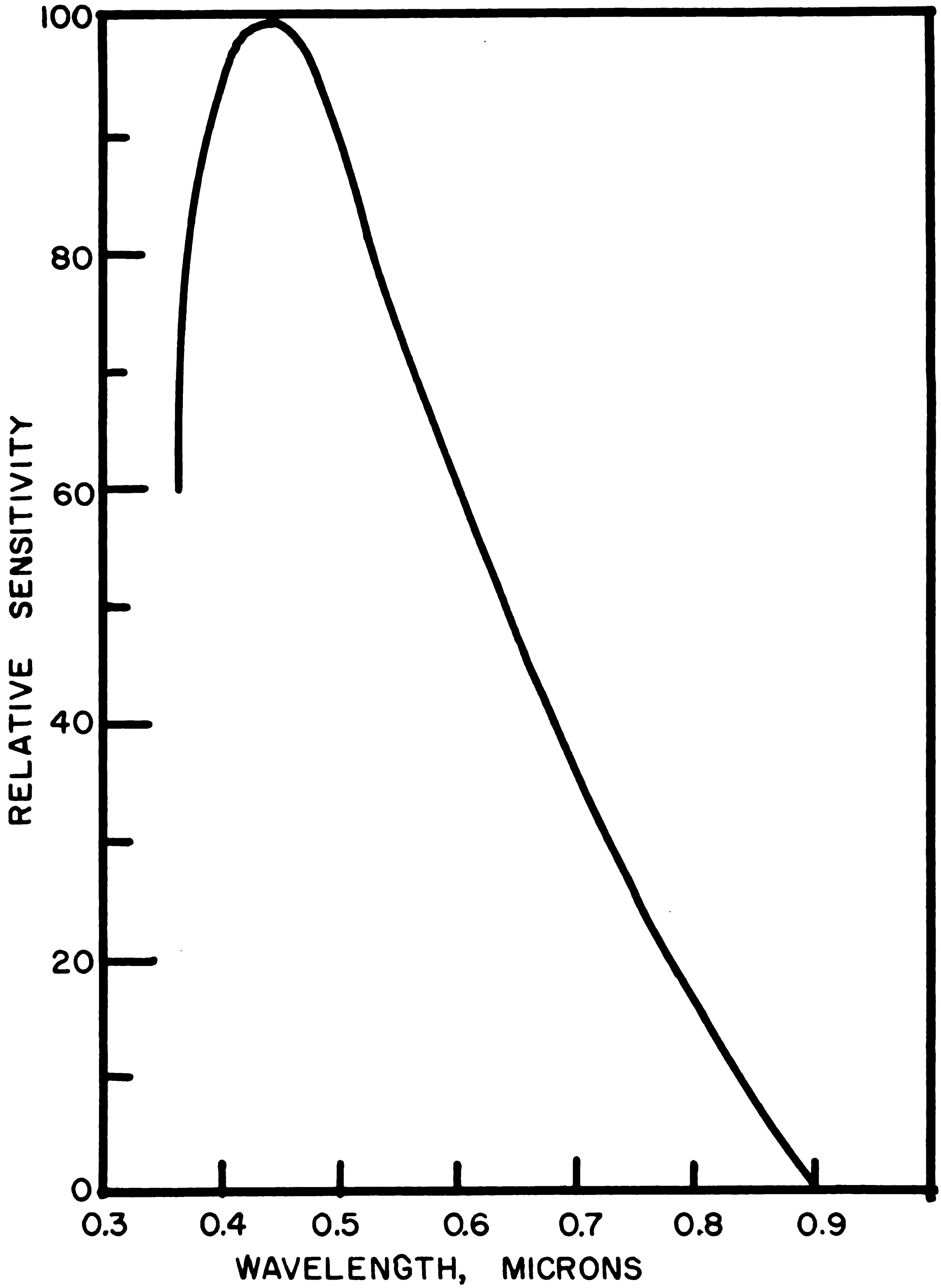

FIG. 3. SPECTRAL RESPONSE CURVE FOR RCA-926 PHOTOTUBE

Average Cathode - Current Density $\mu a/in^2$	30
Average Cathode Current μa	5
Ambient Temperature C^o	100
Maximum Anode Dark Current at 25^oC μa	0.005

The response of a vacuum phototube to incident light signals is exceedingly rapid due to: (1) The time which elapses between the incidence of a light quantum and the ejection of a photoelectron has been found to be too brief for measurement; (2) The time of transit of the electron between cathode and anode is exceedingly short due to the fact that the electron has a large ratio of charge to mass. A vacuum phototube has essentially a linear response compared to a gas-filled phototube. However, the amplification is several times higher in a gas-filled tube than in a vacuum tube.

Any phototube to which voltage is applied will pass a certain amount of current even if the photocathode is unilluminated. Sources of dark current in an electron tube are:

(1) Ohmic leakage between electrodes, both inside and on the outside of the tube envelope.

(2) Thermionic emission from the photocathode.

(3) Current generated by positive ion impact on the photocathode.

Calibration of Phototube

Facilities of the Michigan Highway Research Photometric Laboratory were used to calibrate the phototube. A 124.3 candlepower 100 watt 120 volt standard lamp was used at a voltage of 105 volts as recommended by the Bureau of Standards. The lamp was used as a point source of light by allowing the light to pass through a small slit in the container holding the standard lamp.

The intensity of light received by the phototube was calibrated against the calculated footcandles from the standard lamp by using the inverse square law for the distance. The distance was measured from the filament of the lamp to the photocathode of the phototube.

The calibration curve is linear in response (See Fig. 4). The equation for the calibration curve is

$$X = 63.7\ Y - 0.32$$

Where:

Y = microamperes reading of microammeter

X = footcandles calculated from standard lamp and distance

At the time of calibration the dark current was 0.005 microamperes.

Infrared Sensing Equipment

A U.S. Army Corps of Engineers Metascope, Image Model T-6 was used to detect the movement of chickens on the roost at night. It contains a 1½ volt dry battery as a power source. This metascope is a near infrared viewer.

An infrared light source has to supply the needed infrared energy at night. The metascope will not pick up the natural long wave infrared radiations emitted by the surroundings. A 75 watt lamp in a medium bowl reflector was used as the infrared source to illuminate the roosting area. Filter paper was placed over the reflector so that all visible light was filtered out allowing only infrared energy to illuminate the room.

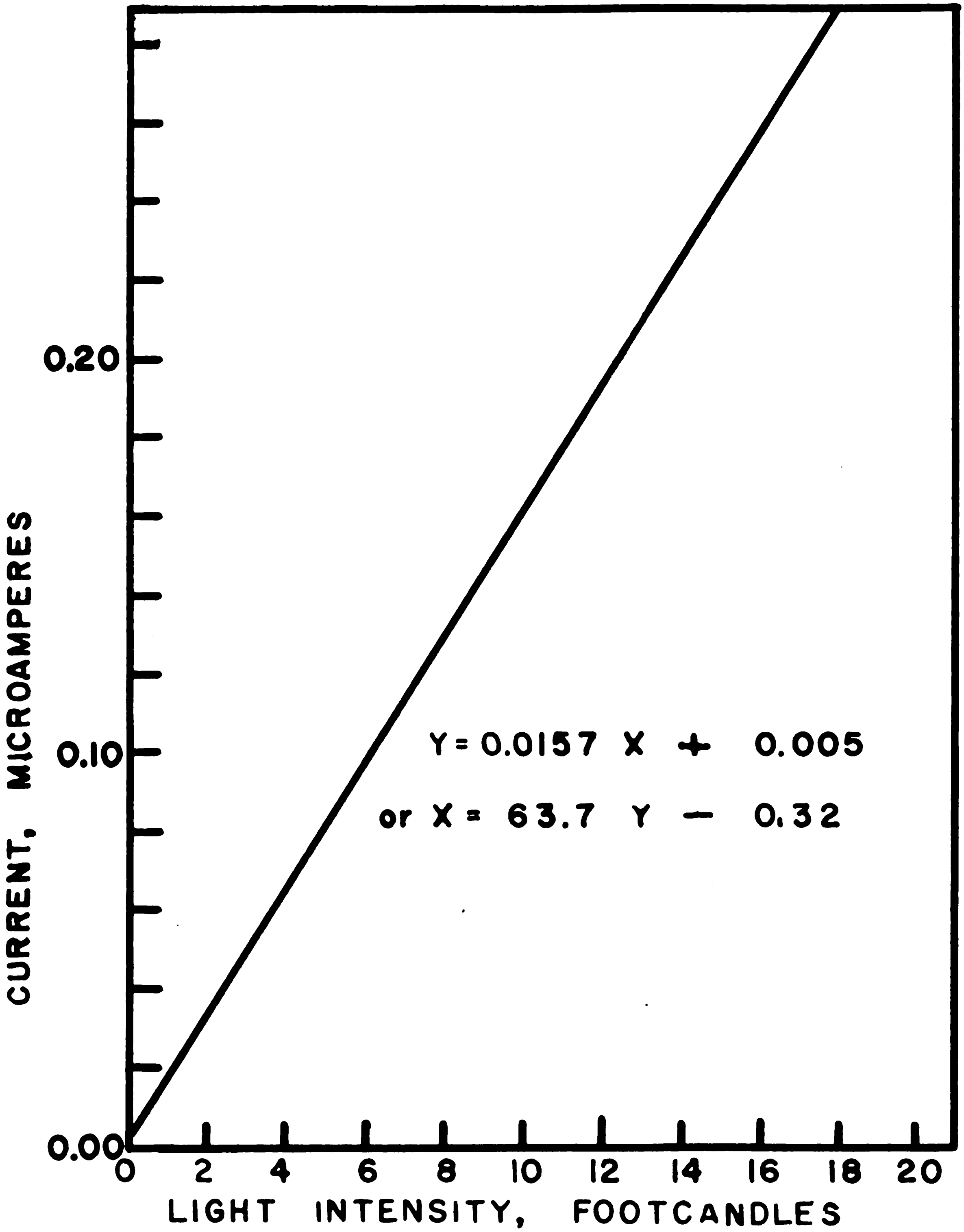

FIG. 4. CALIBRATION CURVE FOR RCA 926 PHOTOTUBE AND MICROAMMETER

Results of Roosting Investigations

Roosting light intensities of the pen of 20 White Rock hens were investigated during two different periods: from April 14 to 25, 1960 and from April 30 to May 6, 1960. Data collected for roosting times and light intensities under natural conditions is presented in Table VII.

Analysis of Roosting Time vs Sunset Time A plot of sunset time and roosting time vs day of the month is presented in Fig. 5. The slope of sunset time is 0.863 minutes per day for this period of the year.

The slopes of the time of roosting were determined statistically for the first, median, and last chicken on the roost. A sample calculation of the slope is given as follows for the median chicken on the roost:

X = number of the day beginning with April 14 as day number 1 and ending May 6 as day number 23

Y = number of minutes from 6:00 p.m.

Table VII Results of Roosting Investigations With Natural Light

Date	Sunset Time	Time of 1st chicken on roost	Time of median chicken on roost	Time of last chicken on roost	Light intensity at 1st chicken on roost (f.c.)	Light intensity at median chicken on roost (f.c.)	Light intensity at last chicken on roost (f.c.)	Weather
4-14	7:19	5:10	6:08	6:37	1.05	0.08	0.25	overcast
4-15	7:20	6:08	6:58	7:12	1.30	0.45	0.25	cloudy
4-16	7:21	6:18	6:48	7:09	0.55	0.25	0.15	overcast
4-17	7:22	6:03	6:58	7:22	0.70	1.10	0.30	cloudy - clear
4-18	7:23	6:10	6:53	7:18	3.40	1.30	0.13	clear
4-19	7:24	5:53	6:30	7:05	3.80	3.00	0.75	clear
4-20	7:25	5:54	6:46	7:07	2.70	1.00	0.35	clear - hazy
4-21	7:27	6:10	6:54	7:20	3.20	1.40	0.30	clear
4-22	7:28	5:46	6:45	7:14	3.60	2.20	0.20	clear - hazy
4-23	7:29	6:05	6:56	7:08	3.70	1.30	0.80	clear - hazy
4-25	7:31	5:40	6:39	7:02	2.60	0.40	0.20	overcast
4-30	7:37	5:45	6:31	6:48	0.90	0.40	0.30	overcast, rainy
5-1	7:38	6:10	6:40	7:00	4.20	2.40	1.40	cloudy - clear
5-2	7:39	5:50	6:30	7:12	4.40	2.70	0.90	clear - hazy
5-3	7:40	5:55	6:35	7:26	4.50	2.70	0.60	partly cloudy
5-4	7:41	5:53	6:45	7:10	2.90	1.30	0.70	light overcast
5-5	7:42	6:08	6:48	7:12	1.80	0.80	0.30	medium overcast
5-6	7:43	5:53	6:30	7:04	0.70	0.40	1.10	showers - clear

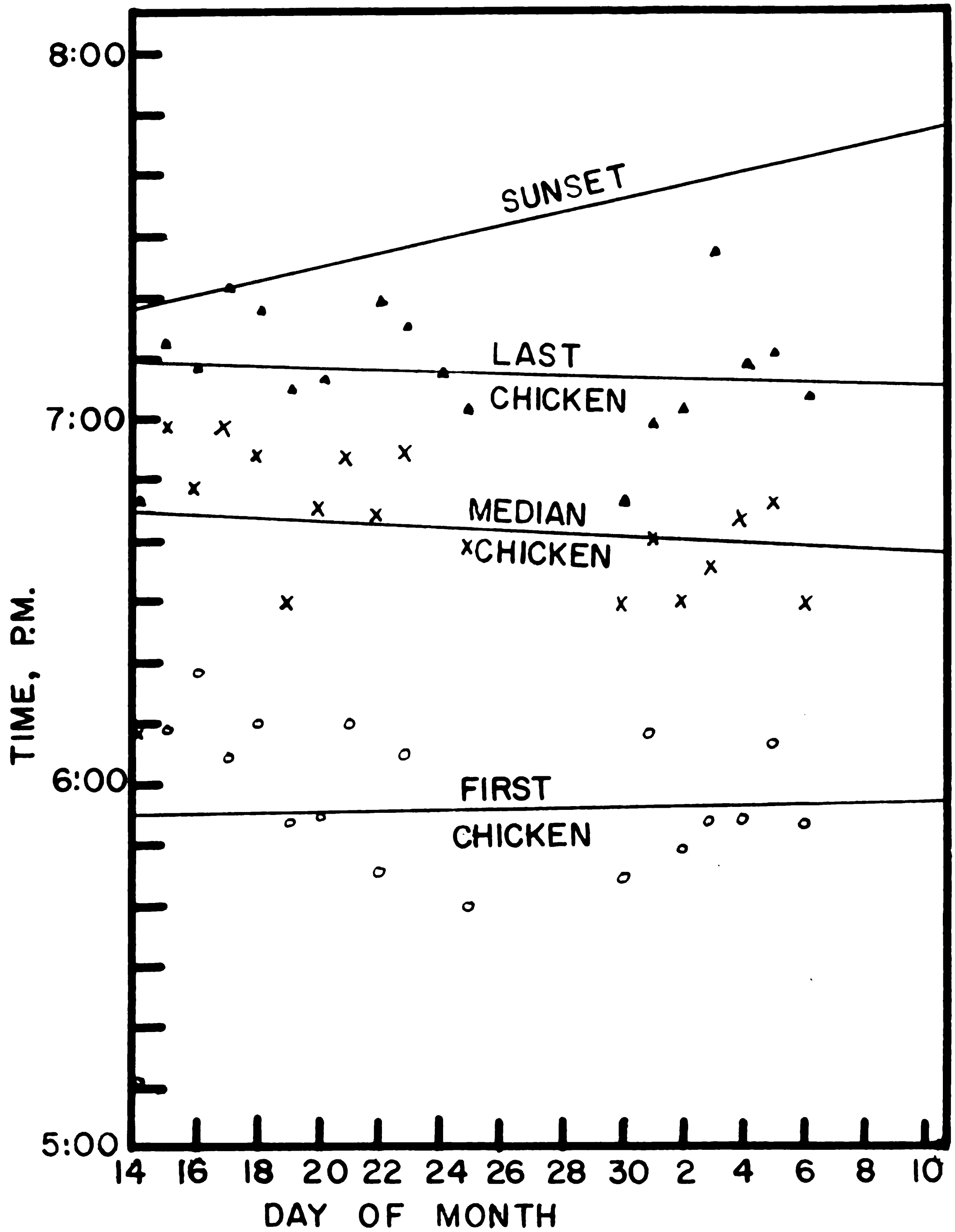

FIG. 5. ROOSTING TIME VERSUS DAY OF MONTH UNDER NATURAL LIGHT CONDITIONS FOR PERIODS FROM APRIL 14-25 AND APRIL 30-MAY 6.

$\Sigma X = 207$ $\bar{X} = 11.5$

$\Sigma X^2 = 3,357$ $\bar{Y} = 41.9$

$\Sigma Y = 754$

$\Sigma Y^2 = 34,209$

$\Sigma XY = 8,332$

$$b = \frac{\Sigma XY - \Sigma X \Sigma Y/N}{\Sigma X^2 - (\Sigma X)^2/N} = \frac{8,332 - 156,078/18}{3,357 - 42,849/18} = \frac{-339}{976} = -0.347$$

then:

$$\bar{Y}_x = \bar{Y} + b(X - \bar{X}) = 41.9 - 0.347(X - 11.5)$$

Two of the three slopes for roosting time vs day are negative. Only the slope of the first chicken on the roost is positive and that one is only slightly positive.

From this investigation it would appear that no correlation exists between time of roosting and sunset time. Therefore, the act of roosting must be the result of some other factor than time of day.

<u>Analysis of Roosting Light Intensity</u> Plots of light intensity and number of chickens on roost vs time of day are presented for two different days in Figs. 6 and 7. Figure 6 is for a clear day at roosting time and Fig. 7 is for an overcast day. The rate of change of light intensity is constant for the two days represented. Differences in light intensities during roosting exist between the two representative days.

The results of the preliminary investigation indicate that chickens roost at a different light intensity on a clear day as compared to an overcast day. The light intensity of roosting for clear days and for cloudy days is presented in Table VIII. This is an arbitrary division of clear and cloudy days with a considerable variation of light intensity present in each category. This investigation indicates only that a chicken roosts at a light intensity dependent upon the average light intensity to which he has become adapted during the day. However, it does not establish whether the act of roosting is the result of a rate of change of light intensity or the differential change in levels of illumination.

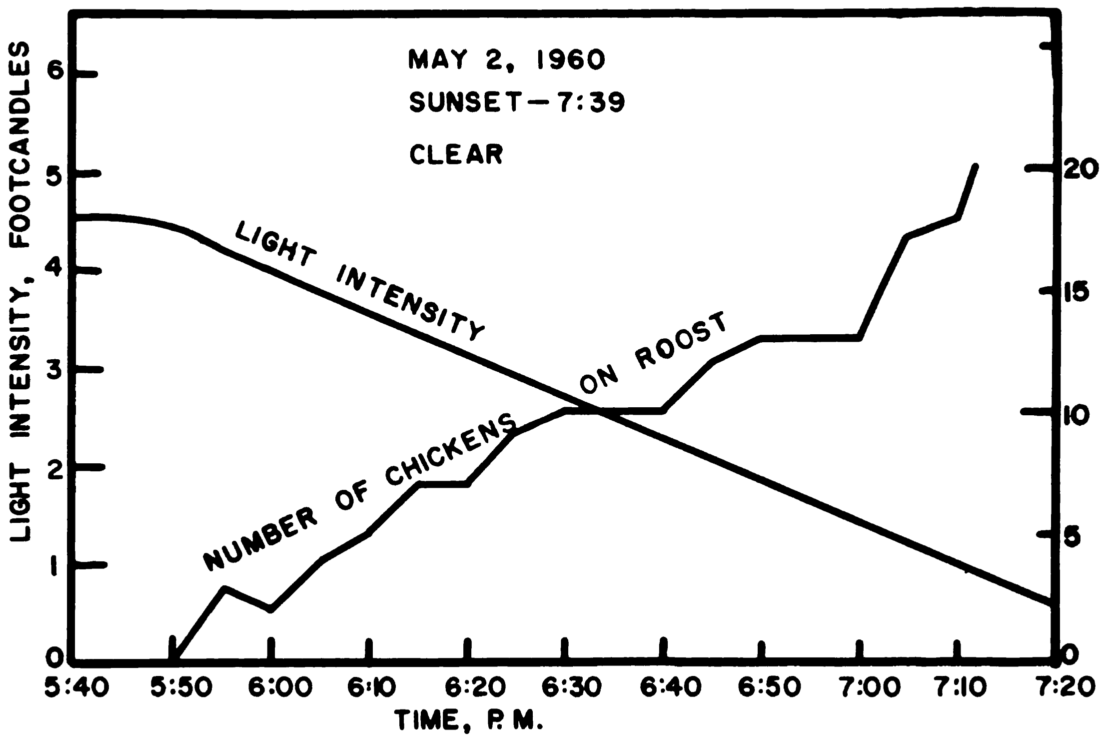

FIG. 6. LIGHT INTENSITY AND NUMBER OF CHICKENS ON ROOST DURING ROOSTING TIME FOR A CLEAR DAY

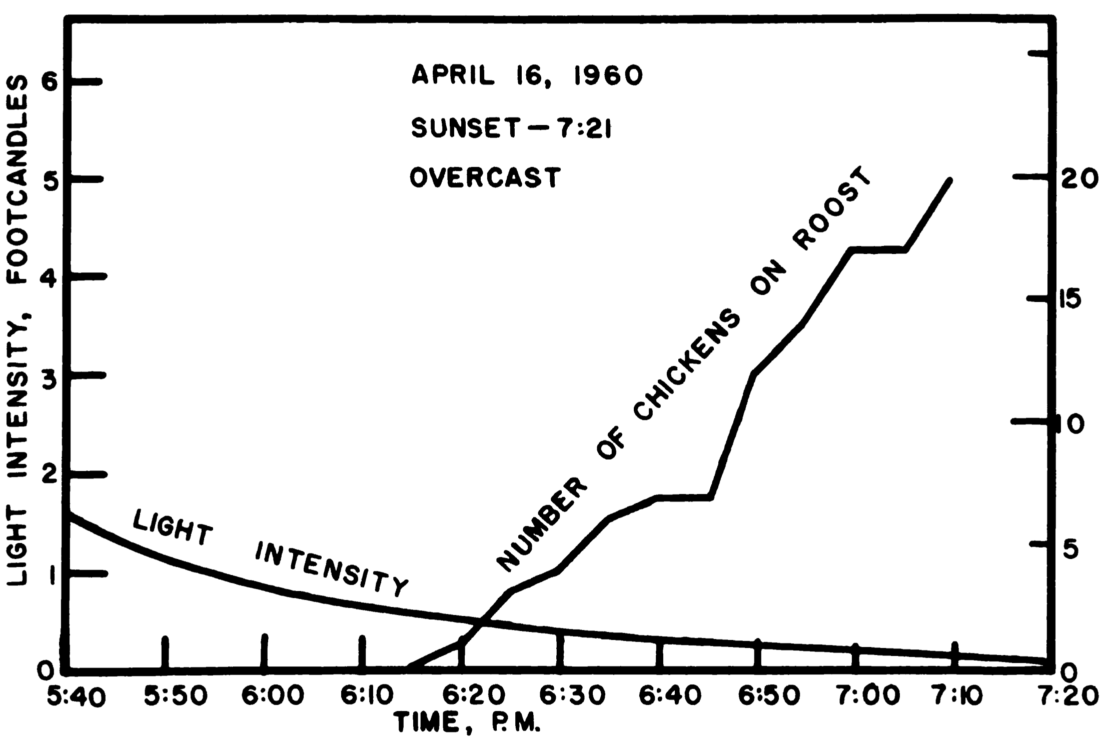

FIG. 7. LIGHT INTENSITY AND NUMBER OF CHICKENS ON ROOST DURING ROOSTING TIME FOR AN OVERCAST DAY

Table VIII Comparison of Roosting Light Intensities for Clear and Cloudy Days

Weather	Date	Median chicken on roost	First chicken on roost	Last chicken on roost
Clear	4-18	1.3 f.c.	3.4 f.c.	0.13 f.c.
	4-19	3.0	3.8	0.75
	4-20	1.0	2.7	0.35
	4-21	1.4	3.2	0.30
	4-22	2.2	3.6	0.20
	4-23	1.3	3.7	0.80
	5-1	2.4	4.2	1.40
	5-2	2.7	4.4	0.90
	5-3	2.7	4.5	0.60
	5-4	1.3	2.9	0.70
Average		1.9	3.6	0.61
Cloudy	4-14	0.80	1.05	0.25
	4-15	0.45	1.30	0.25
	4-16	0.25	0.55	0.15
	4-17	1.10	0.70	0.30
	4-25	0.40	2.60	0.20
	4-30	0.40	0.90	0.30
	5-5	0.80	1.80	0.30
	5-6	0.40	0.70	1.10
Average		0.58	1.20	0.36

Results of Rising Investigations

Investigation of the light intensity required by 20 White Rock hens to rise was conducted from April 15 to 23, 1960 and April 30 to May 6, 1960. Data for this investigation is presented in Table IX.

Analysis of Rising Time vs Sunrise Time A plot of sunrise time and rising time for the median chicken to roost vs day of month is presented in Fig. 8. The slope of the sunrise time vs day is -1.43 for this period of the year.

The slope of the time of the median chicken off the roost vs day is -1.33. This slope is 7 percent less than the sunrise slope of -1.43. Thus, the rising time of the median chicken correlates quite closely with the sunrise time. The calculation of the slope of the rising time was determined from the same relationships as the slope of the roosting time discussed previously.

One of the possible reasons for the high correlation between sunrise time and time of the median chicken to rise is that the light intensity during darkness is

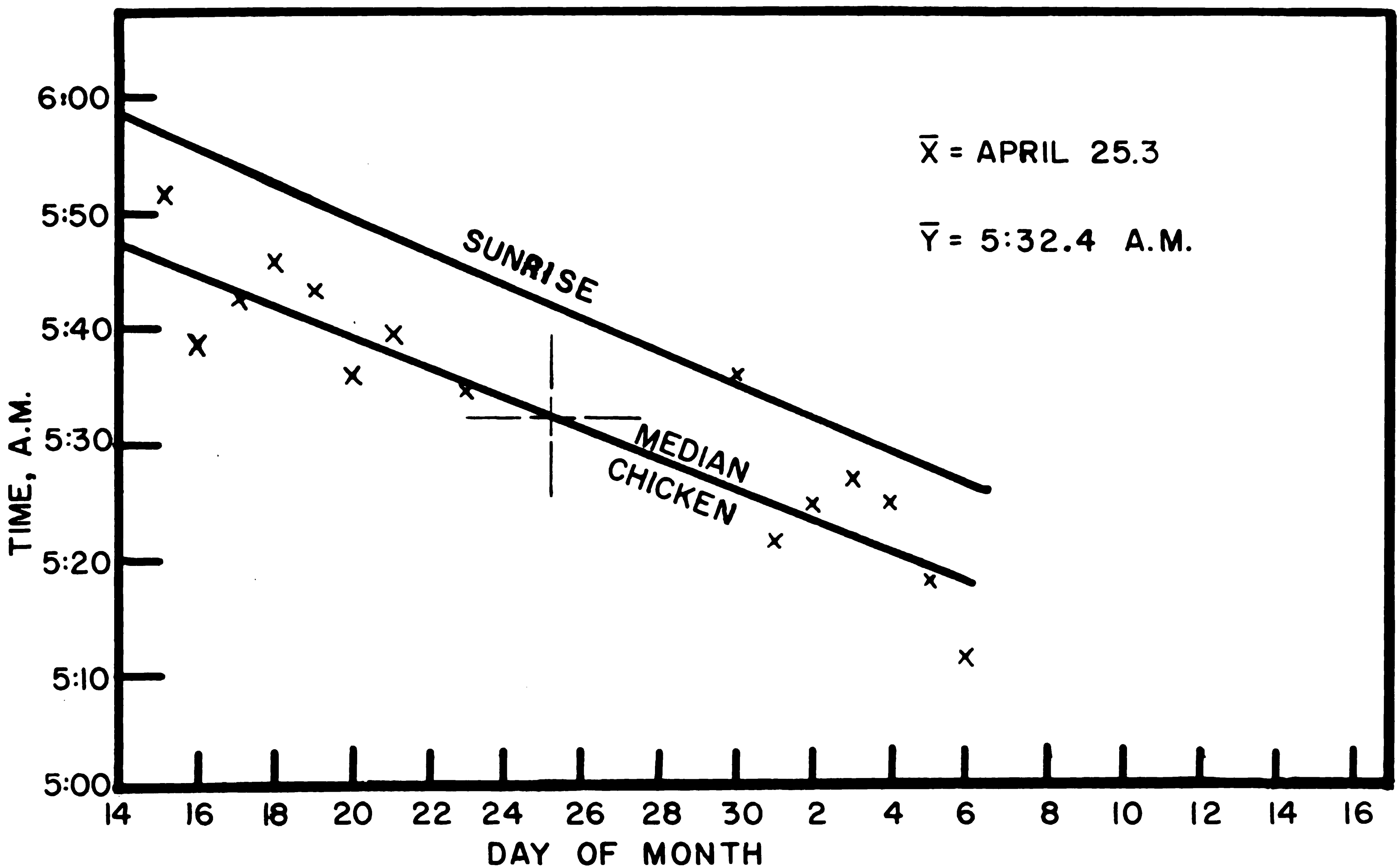

FIG. 8. RISING TIME OF MEDIAN CHICKEN VERSUS DAY OF MONTH UNDER NATURAL LIGHT CONDITIONS FOR PERIODS FROM APRIL 15-23 AND APRIL 30-MAY 6

Table IX Results of Rising Investigations With Natural Light

Date	Sunrise Time	Time median chicken off roost	Light Intensity in footcandles: Median chicken off roost	Light Intensity in footcandles: 1st chicken off roost	Light Intensity in footcandles: Last chicken off roost	Weather
4-15	5:57	5:51	0.050	0.05	0.15	overcast
4-16	5:56	5:38	.025	0.02	0.13	overcast
4-17	5:54	5:43	.050	.05	.08	cloudy
4-18	5:52	5:46	.050	.03	.075	cloudy
4-19	5:52	5:43	.160	.04	.55	clear
4-20	5:49	5:36	.050	.02	.15	overcast
4-21	5:48	5:39	.050	.02	.15	overcast
4-23	5:45	5:35	.050	.02	.10	overcast
4-30	5:35	5:36	.075	.05	.35	overcast
5-1	5:33	5:22	.100	.05	1.10	clear
5-2	5:32	5:25	.075	.05	0.40	cloudy, rainy
5-3	5:31	5:27	.125	.03	1.10	light cloud
5-4	5:29	5:25	.125	.03	1.70	mostly clear
5-5	5:28	5:18	.050	.04	1.00	overcast
5-6	5:27	5:12	.050	.04	0.30	overcast

fairly uniform regardless of the prevailing weather conditions. The chickens become adjusted to approximately the same level of light intensity each night and therefore rise at approximately the same light intensity every day. The rising light intensity for the first few chickens off the roost remains fairly constant. However, there is still a considerable difference in the rising light intensity for the last chicken off the roost. This appears to be an effect of the degree of cloudiness. Apparently, some chickens do not respond to a change in light intensity from low levels of illumination to high levels as quickly as other chickens.

Analysis of Rising Light Intensity Plots of the light intensity and number of chickens off the roost are presented for two different days. Figure 9 is for April 17, 1960 which was an overcast morning, and Fig. 10 is for May 4, 1960 which was a clear morning. There is only a slight difference in rising intensities for the first chicken off the roost for the two days, 0.05 footcandles on April 17 and 0.03 footcandles on May 5. There is considerably more difference in the light intensity for

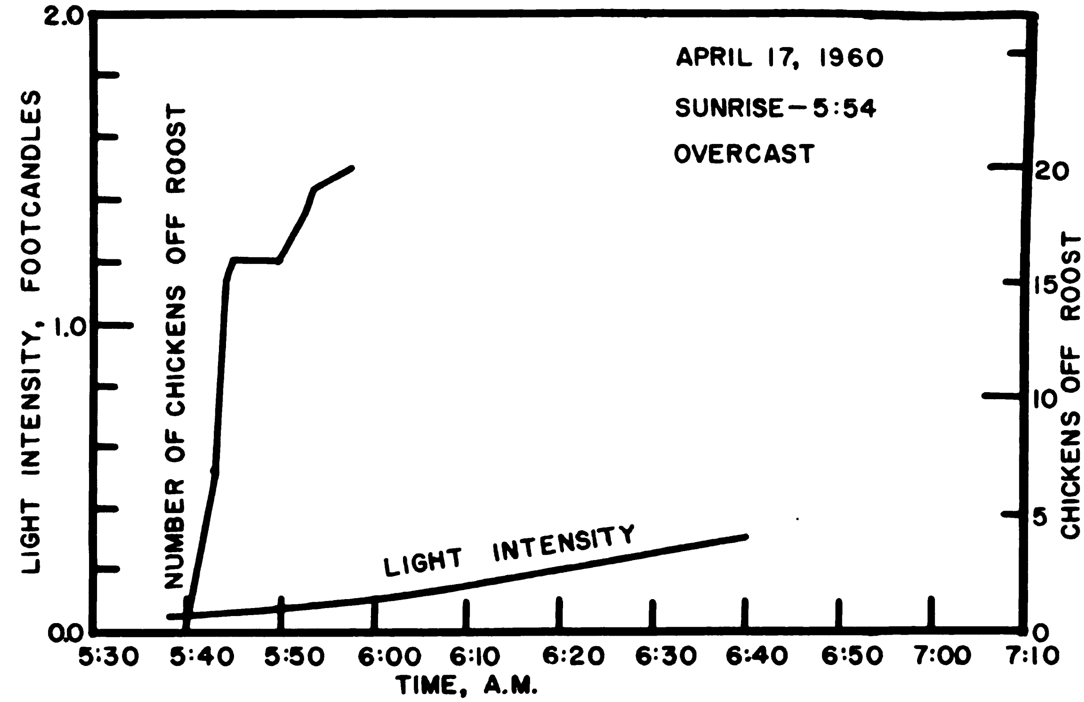

FIG. 9. LIGHT INTENSITY AND NUMBER OF CHICKENS OFF ROOST DURING RISING TIME FOR AN OVERCAST DAY

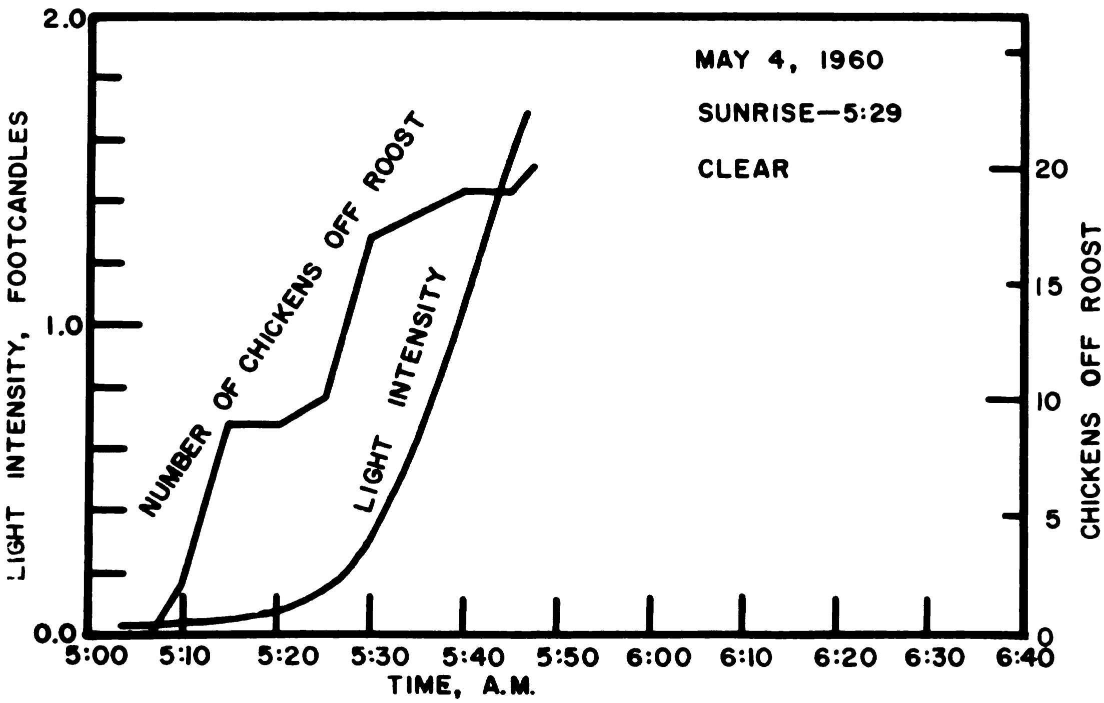

FIG. 10. LIGHT INTENSITY AND NUMBER OF CHICKENS OFF ROOST DURING RISING TIME FOR A CLEAR DAY

the median chicken off the roost, 0.05 footcandles on April 17 and 0.125 on May 4. On April 17 a reading of 0.08 footcandles was recorded for the last chicken off the roost as compared to 1.70 footcandles on May 4. Apparently the last chickens to rise are affected more by the degree of cloudiness than the earlier ones.

Comparison of Rising vs Roosting Intensity

There is a difference between roosting and rising light intensities for chickens. In general, chickens rise at a much lower light intensity than the light intensity at roosting. The lowest recorded light intensity for the median chicken roosting was 0.40 footcandles as compared to the highest rising light intensity of 0.16 footcandles. The lowest light intensity for the last chicken on the roost was 0.13 footcandles as compared to the highest for rising of 0.05 footcandles for the first chicken off the roost.

Variation of Light Intensity in Pen 205

A Weston footcandle meter was used to determine the light intensity in various parts of the pen shown in

Fig. 11 on a uniformly overcast day. The readings taken at the east window at 3:00 p.m. were much higher than the rest of the pen. The phototube detected an average light intensity of 3.0 footcandles for the pen. The visual angle of the tube did not include the darkest area of the pen (the nesting area). This area of the pen had less than 0.1 footcandle. The chickens tended to congregate in the areas of higher light intensity.

Conclusion

Apparently, chickens respond to a lower light intensity after becoming adapted to a low level of illumination than if they had become adapted to a higher level of illumination. This is evidenced by the difference between light intensities of rising and roosting. Also, the differences of roosting light intensities between overcast weather and clear weather tend to substantiate this hypothesis.

This investigation indicates that the act of roosting or rising is not directly correlated with the time of sunset or sunrise. The effects of changes in light intensity appear to be more important in determining when

when a chicken is activated to roost or rise.

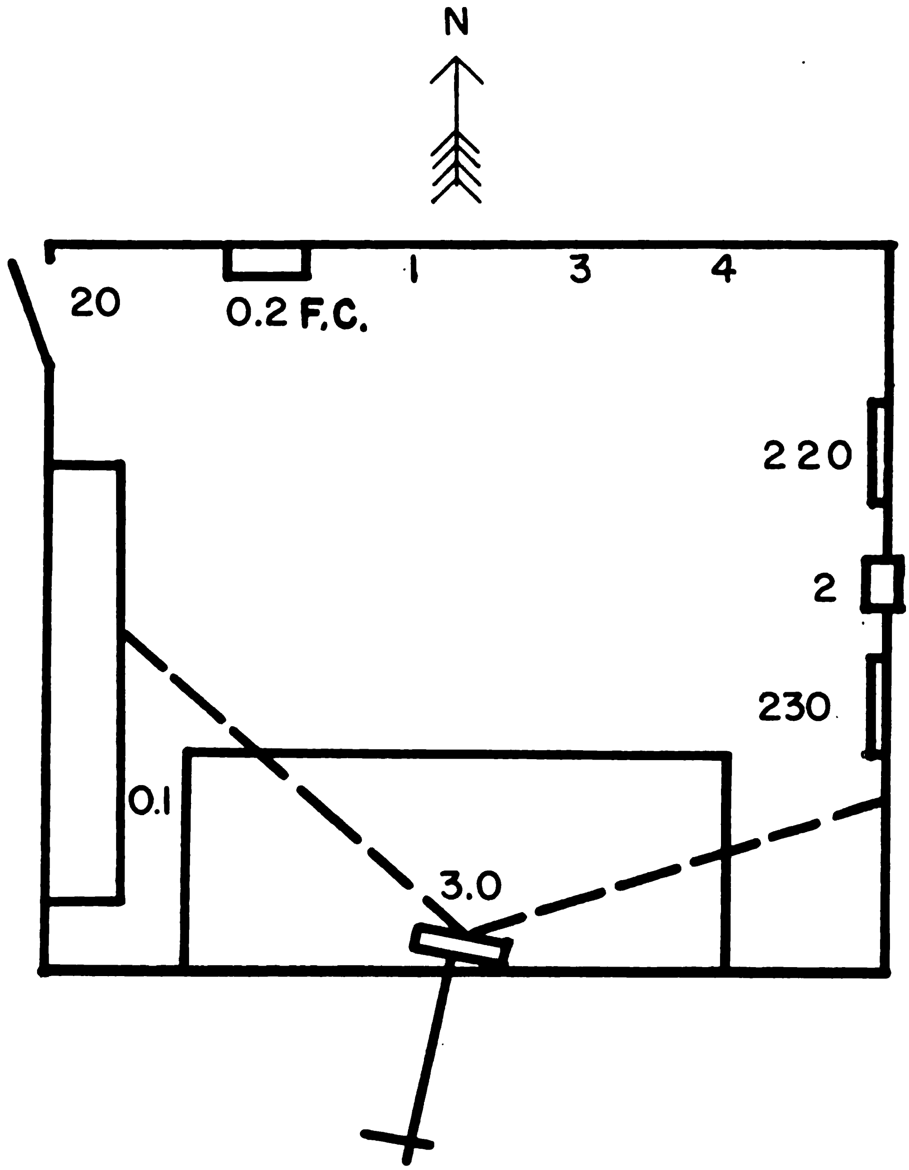

FIG. 11. VARIATION OF LIGHT INTENSITY IN PEN 205 FOR A UNIFORMLY OVERCAST DAY (APRIL 26, 1960) WITH THE PHOTOTUBE READING 3.0 FOOTCANDLES

INVESTIGATION OF RISING AND ROOSTING LIGHT INTENSITY

The results of preliminary tests indicated that there were differences in roosting light intensity between cloudy days and bright days under the natural daylight conditions existing at the commercial house. However, the light intensity varied considerably. The degree of cloudiness changed from day to day and hour to hour, thereby causing changes of light intensity in the pen. Also, the rate of change of light intensity at roosting time was dependent upon the degree of cloudiness.

A different experiment with more precisely controlled dependent variables was developed. The objective of this experiment was to test the hypothesis that a chicken roosts at a light intensity dependent upon the light intensity to which he has become adapted.

The requirements for this experiment were:

(1) Pens sealed from exterior sources of light,

(2) Pens where light intensities could be adjusted at any intensity between one and thirty foot-candles.

(3) Method of observing roosting and rising of chickens,

(4) Constant length of light period,

(5) Constant rate of change of light intensity at roosting and again at rising.

Design of the Experiment

Location The experiment was conducted in five pens of the Experimental House of the Poultry Science Department as shown in Fig. 12. Ten White Rock hens of the same strain as the ones used in the preliminary tests were used in each pen.

The Experimental House has a straw loft and windows facing south. Five pens were sealed from outside light by tacking roofing paper over the cracks. Two sheets of black plastic were placed over the windows to prevent outside light from reaching the pens. The plastic sheets were lapped so that observations could be made by pulling open one of the sheets.

Artificial Lights One hundred twenty volt incandescent filament lamps were used to provide artificial light for each of the five pens. Table X shows the wattage of lamp used in each pen during each three day test.

Table X Wattage of Lamp Used in Each Pen for Tests

Test	Pen 1	Pen 2	Pen 3	Pen 4	Pen 5
No.1	25 W	150 W	200 W	60 W	100 W
2	200	60	25	100	150
3	100	200	60	150	25
4	150	25	100	200	60
5	60	100	150	25	200

The duration of the full intensity light period was 13 hours per day, 8:30 a.m. to 9:30 p.m. At rising time the light intensity increased from 0.0 footcandles at 7:55 a.m. to full light intensity for each pen at 8:30 a.m. During roosting the light intensity changed from full intensity at 9:30 p.m. to 0.0 footcandles at 10:00 p.m.

Apparatus The light intensity in the pens was lowered by reducing the line voltage to the lamps by means of

FIG. 12. EXPERIMENTAL POULTRY HOUSE WITH BLACK PLASTIC OVER WINDOWS OF TEST PENS

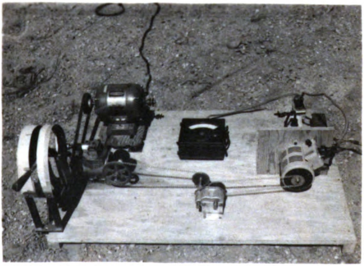

FIG. 13. VOLTAGE CONTROL APPARATUS USED AT ROOSTING AND RISING TIMES

a Variac. The rotor of the Variac was turned at a constant rate by a series of gears driven by an electric motor shown in Fig. 13. A Graham transmission was used to switch the direction of rotation of the rotor, and to control the rate of increase or decrease in voltage.

Footcandle readings were made with a Weston Footcandle Meter Model 614. Brightness measurements were made with a Spectra Brightness Spot Meter with readings in footlamberts.

Calibration of Light Intensity vs Volts

Footcandle readings were obtained in several areas of each pen for different voltages under the five treatments. In Fig. 14 are footcandle values measured at the height of a chicken directly under the lamp for each pen treatment.

Procedure

The standard procedure for each test period was:

(1) Start stop watch shortly before each test started (checked with Western Union time).

(2) Record line voltage and stop watch time.

(3) Record time at which motor was turned on.

(4) Record both number of chickens on or off roost and stop watch time for each pen.

(5) Repeat No. 2 and No. 4 until all chickens are on or off roost.

(6) Determine light intensity at which each chicken gets on or off roost from Fig. 14.

Daily Results

An example of the data for the hens roosting in Pen Number 2 with 150 watt lamps is presented in Table XI. First, the light intensity in footcandles for each time of change in number of chickens on the roost was

Table XI Sample of Daily Results for Chickens Roosting in Pen No. 2 With 150 Watt Lamps

Time, Min	Light Intensity, Footcandles	Number on Roost	Slope
T	I	N	b
15.1	3.6	3	
18.1	2.0	6	
21.5	1.1	8	
23.3	0.7	10	
Average	1.9	6.8	-0.436

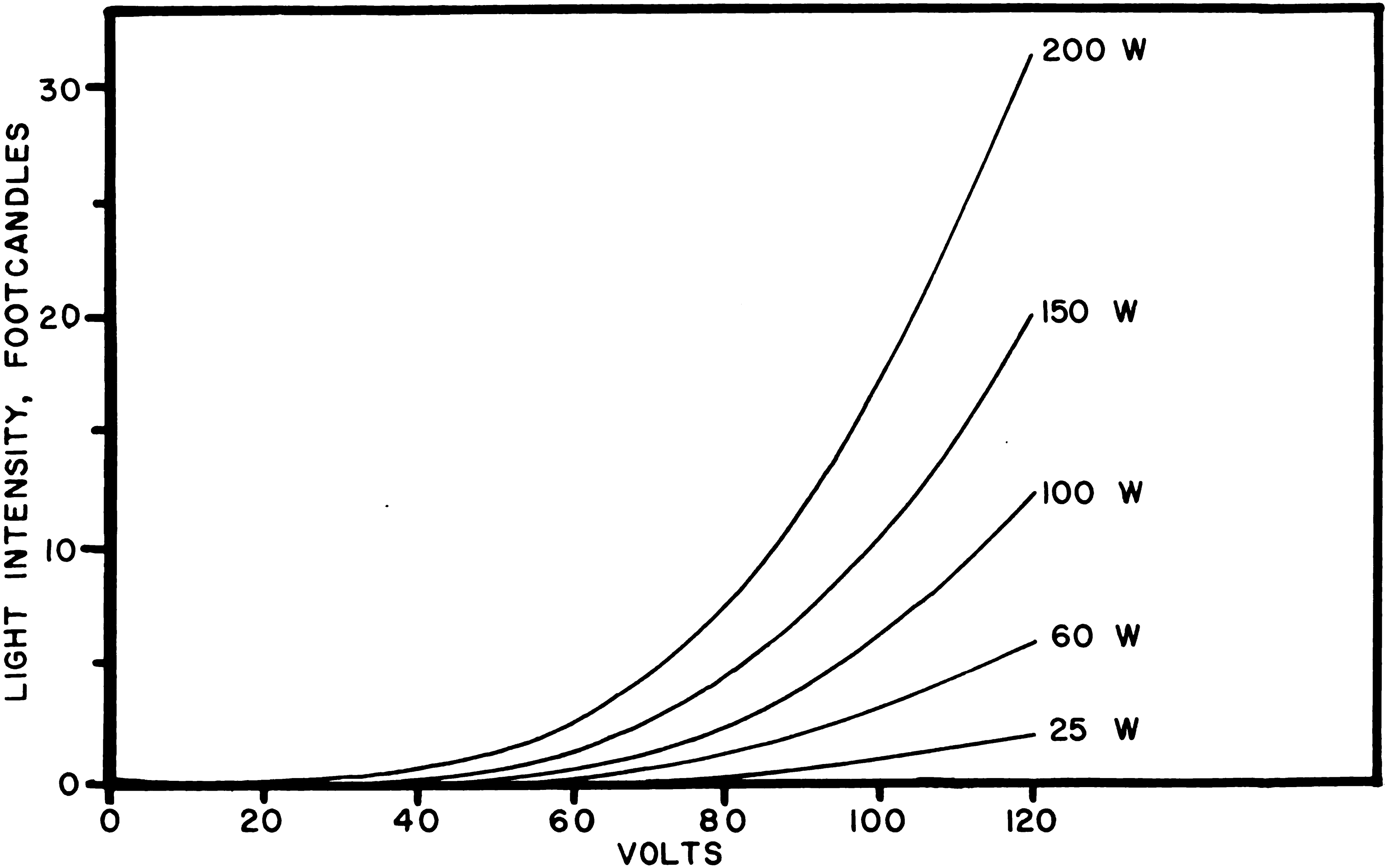

FIG. 14. CALIBRATION OF LIGHT INTENSITIES OF VARIOUS LAMP WATTAGES FOR PENS IN EXPERIMENTAL HOUSE VERSUS LINE VOLTAGES. FOOTCANDLE READINGS TAKEN 6 INCHES ABOVE FLOOR DIRECTLY UNDER LAMP.

obtained with the aid of the curves in Fig. 14. Second, the average light intensity at roosting was determined. Next, the average number of chickens on the roost (off the roost for rising) was determined. The slope of the number of chickens on the roost vs light intensity was determined from the same formula as used in the preliminary results.

Results

The results of the experiment for roosting are presented in Table XII. Average light intensity (in foot-candles), average number of chickens on the roost, and slope of roosting are represented for each day of the experiment.

An analysis of variance showed that there were significant differences at the 5 percent level between treatments for all three factors: light intensity, number on roost, and slope. No significant difference was found between pens. A summary of the significance between treatments is given in Fig. 15. The line over the values indicates no significant differences between treatments.

Table XII Results of Roosting Experiment with Artificial Light

Pen No.	25W - 2 f.c.			60W - 5.5 f.c.			100W - 12 f.c.			150W - 20 f.c.			200W - 30 f.c.		
	$\bar{I}$	$\bar{N}$	b	$\bar{I}$	$\bar{N}$	b	$\bar{I}$	$\bar{N}$	b	$\bar{I}$	$\bar{N}$	b	$\bar{I}$	$\bar{N}$	b
1	1.3	9.0	-0.165	2.7	8.5	-0.208	7.0	4.0	-0.859	10.5	8.5	-0.463	5.8	5.3	-0.643
	1.4	6.3	-6.061	3.2	8.7	-0.987	5.1	5.6	-0.812	7.7	6.5	-0.268	9.7	5.2	-0.363
	1.1	6.5	-3.537	3.0	6.0	-1.624	5.8	5.3	-0.818	8.6	5.4	-0.500	11.9	5.2	-0.474
2	1.7	9.0	-0.000	1.4	7.0	-1.851	3.9	5.0	-0.996	1.9	6.8	-0.436	1.8	7.3	-3.020
	0.9	7.5	-1.860	2.3	6.3	-1.359	3.4	5.4	-1.585	1.9	7.3	-1.206	5.6	5.5	-0.706
	1.3	7.7	-0.294	1.9	6.4	-2.361	2.4	6.2	-1.350	3.9	8.0	-0.740	13.7	6.2	-0.258
3	1.1	7.8	-4.000	3.0	7.6	-0.438	3.8	5.7	-1.036	3.7	6.9	-0.912	6.7	6.4	-0.265
	1.2	7.8	-2.200	2.3	8.3	-0.912	1.1	5.6	-0.032	7.9	4.5	-0.617	8.5	6.0	-0.316
	0.9	7.8	-3.333	2.4	7.8	-3.281	1.7	6.5	-3.173	2.9	6.4	-1.093	5.4	6.8	-0.735
4	1.2	8.7	-3.415	1.8	6.8	-1.410	3.9	6.8	-0.680	7.4	4.8	-1.013	7.8	6.8	-1.095
	1.7	9.5	-10.000	2.9	6.7	-2.144	4.8	5.5	-0.993	3.5	6.2	-1.172	7.3	6.6	-0.410
	1.1	8.3	-3.103	2.5	7.2	-1.306	1.9	8.3	-1.396	5.6	6.5	-0.587	5.1	5.4	-0.834
5	1.1	9.0	-2.195	1.8	8.0	-3.178	1.1	6.8	-1.994	2.0	8.0	-0.877	5.7	5.8	-0.815
	1.4	8.5	-0.458	1.5	7.8	-2.357	2.9	7.2	-1.420	6.0	6.4	-0.597	8.8	5.0	-0.460
	1.3	8.0	-3.773	1.2	6.5	-4.128	4.7	6.8	-1.232	5.3	7.0	-0.864	4.3	6.8	-1.180
Ave.	1.3	8.1	-2.960	2.3	7.3	-1.836	3.6	6.0	-1.223	5.3	6.5	-0.823	7.2	6.0	-0.772

$\bar{I}$ = Average Light Intensity (Footcandles)

$\bar{N}$ = Average Number of Chickens on Roost

b = Slope of Chickens on Roost vs Light Intensity

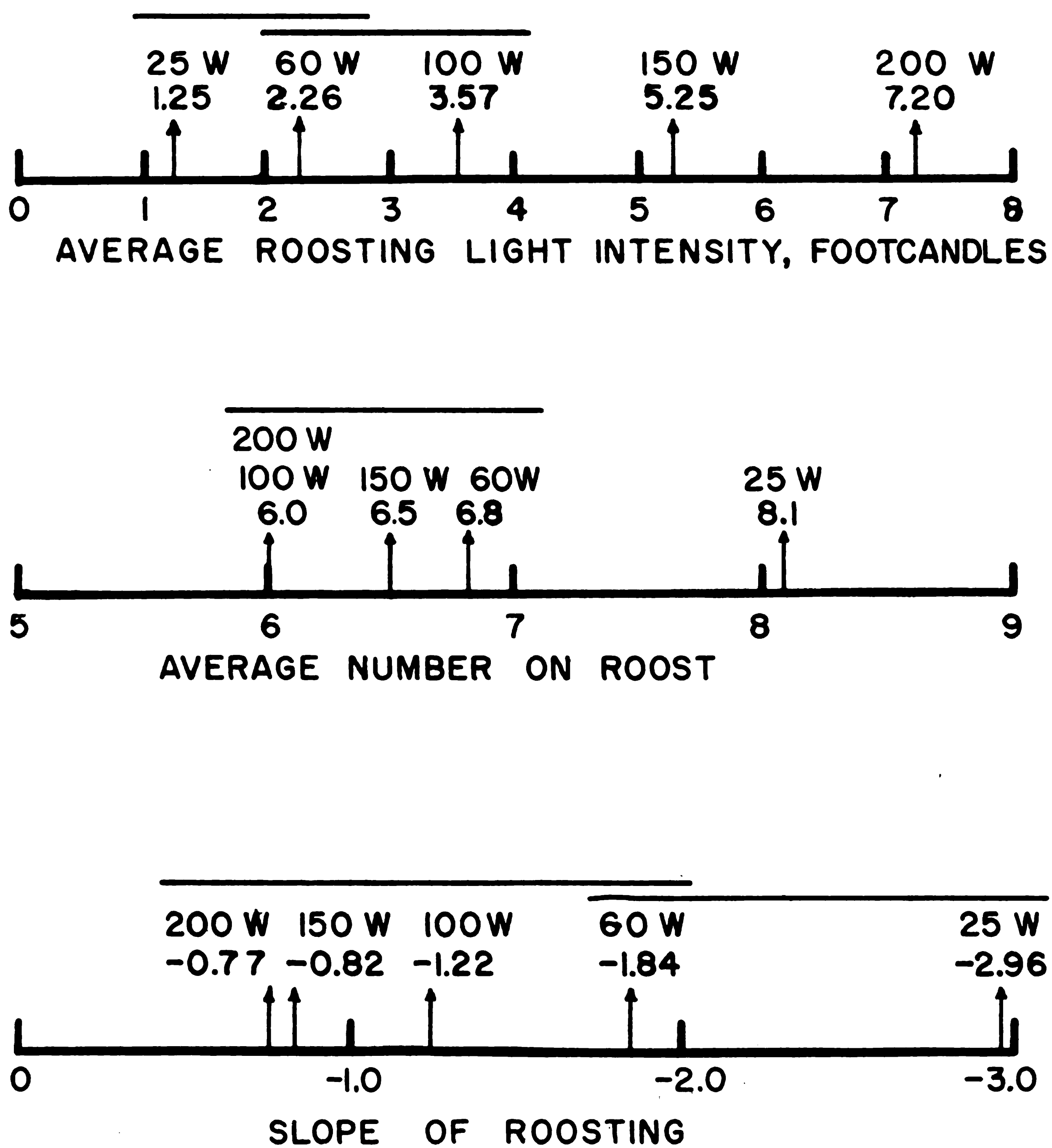

FIG. 15. SUMMARY OF SIGNIFICANT DIFFERENCES BETWEEN LIGHT TREATMENTS FOR ROOSTING. LINES OVER VALUES INDICATE NO SIGNIFICANT DIFFERENCES BETWEEN TREATMENTS.

For light intensity treatments, no significant difference was found between the 25 watt - 2 footcandle and 60 watt - 5.5 footcandle treatments and between the 60 watt - 5.5 footcandle and 100 watt - 12 footcandle treatments. There were significant differences between all other treatments.

For the average number of chickens on the roost, there are significant differences between the 25 watt - 2 footcandle treatment and the other four treatments. No significant differences exist between any of the four higher light intensity treatments.

The slope for the 25 watt - 2 footcandle treatment is significantly different than the 100 watt - 12 footcandle, 150 watt - 20 footcandle and 200 watt - 30 footcandle treatments, but not significantly different from the 60 watt - 5.5 footcandle treatment. There are no significant differences between the other treatments.

The results for the rising experiments are presented in Table XIII. No significant differences were found between any of the light treatments for either the average light intensity, average number off the roost, or average slope. Only pen number one was significantly different from other pens for number of chickens off the roost.

Discussion of Results

The results indicate that the following hypothesis is correct: A chicken roosts at a light intensity dependent upon the light intensity to which he has become adapted. The proof of this hypothesis comes from the fact that there is a significant difference between most of the light treatments.

The analysis of variance of average roosting light intensity showed that the 20 footcandle and 30 footcandle treatments were significantly different from all other treatments. Daily average light intensity for each treatment varies too much to be significantly different for the treatments at the lower light intensities of 2 and 5.5 footcandles and 5.5 and 12 footcandles. However, the means of the average light intensity for each treatment are distinctly different and indicate that chickens roosted at a light intensity dependent upon the light intensity treatment.

Table XIII Results of Rising Experiment with Artificial Light

Pen No.	25W - 2 f.c.			60W - 5.5 f.c.			100W - 12 f.c.			150W - 20 f.c.			200W - 30 f.c.		
	$\bar{I}$	$\bar{N}$	b	$\bar{I}$	$\bar{N}$	b	$\bar{I}$	$\bar{N}$	b	$\bar{I}$	$\bar{N}$	b	$\bar{I}$	$\bar{N}$	b
1	0.05	8.7	28.89	0.06	7.3	36.364	0.14	7.7	9.615	0.11	7.7	13.500	0.2	6.5	25.000
	0.05	7.5	32.50	0.05	7.3	43.902	0.06	8.0	21.951	0.12	7.3	23.121	0.4	8.5	25.000
	0.07	7.3	31.43	0.06	8.0	22.500	0.07	7.0	44.681	0.06	5.5	87.500	0.2	6.5	25.000
2	0.10	7.2	30.279	1.4	5.3	1.766	0.74	5.0	1.864	3.1	4.5	0.672	3.0	5.4	1.114
	0.72	6.8	71.642	6.6	5.0	5.283	0.13	5.5	42.857	1.1	6.0	2.282	2.0	5.9	1.479
	0.11	7.8	12.258	0.13	5.3	40.000	0.38	6.0	5.000	2.6	6.5	0.927	0.8	4.7	5.473
3	0.35	6.8	3.793	4.00	5.6	5.043	0.11	5.3	2.866	3.1	6.6	0.315	2.6	4.8	0.958
	0.01	10.0	0.000	0.28	5.3	8.750	0.18	5.6	8.800	1.1	5.7	1.847	2.3	5.7	0.701
	0.22	6.0	10.700	0.16	5.7	30.000	0.81	6.0	2.342	1.7	5.3	1.823	2.3	5.7	0.787
4	0.10	4.0	97.435	5.6	4.8	0.571	0.2	4.8	4.800	0.35	6.0	7.692	0.8	6.3	5.102
	0.09	6.8	158.620	0.16	5.0	4.000	0.06	9.5	10.345	0.23	5.3	20.000	0.9	5.8	6.286
	0.08	8.3	28.571	0.11	7.7	33.562	0.12	4.5	30.303	0.34	5.6	13.571	0.8	5.2	9.429
5	0.32	5.3	9.324	0.41	5.0	2.593	3.0	4.8	1.128	1.3	4.0	4.671	2.4	5.0	0.941
	0.14	5.1	37.143	0.25	6.0	9.60	1.3	4.4	2.464	1.4	6.6	2.505	4.1	6.0	0.398
	0.09	6.3	3.241	0.19	6.6	51.000	1.7	5.1	1.567	1.2	5.5	2.725	1.5	6.4	3.402
Ave.	0.17	6.9	37.06	1.30	6.0	19.67	0.67	6.0	12.70	1.19	5.9	12.21	1.6	5.9	7.41

$\bar{I}$ = Average Light Intensity (Footcandles)

$\bar{N}$ = Average Number of Chickens Off Roost

b = Slope of Chickens Off Roost vs Light Intensity

The analysis of variance for average number of chickens on the roost showed that only the 2 footcandle treatment was significantly different from the other treatments. No significant difference was found between the other treatments. Actually, several chickens in the 2 footcandle treatments were consistently on the roost before 9:30 p.m. when the light intensity started to change. This caused the average number on the roost to be higher for the 2 footcandle treatment than for the other treatments. The other treatments had only a few (zero, one, or two) chickens on the roost at 9:30 p.m. Apparently the chickens in the 2 footcandle treatment were anticipating the onset of darkness. At least they were tired of struggling in the dark environment. Observations of activity in the two footcandle treatment pens showed that the hens were sluggish as compared to the hens in the higher light intensity pens.

The results indicate that the slope of roosting is not affected significantly by the different light treatments. Only the 2 footcandle treatment is significant from the 12, 20, and 30 footcandle treatments. The averages of the slopes are distinctly different from each other. However, the variation of the slopes within the treatments is high, causing the average slopes of four of the five treatments to be not significantly different from each other. The above is probably an indication that a chicken acts as an individual and is not dependent entirely on the action of the group.

The results of the rising experiments showed no significant difference between any of the treatments for either average rising light intensity, average number off the roost, or average slope. For rising, the chickens reacted similarly, regardless of treatment, since each pen of chickens had been subjected to the same light intensity (total darkness). Apparently, the act of rising took place shortly after the time when the chickens first could distinguish other objects in the room, such as a feed trough or even another chicken off the roost.

COMPARISON OF INCIDENT LIGHT AND REFLECTED LIGHT

The footcandle meter is a common instrument for measuring light intensity in a chicken pen. This meter measures the incident light in footcandles. However, a chicken, or even a person, does not see the incident light, but the reflected light. Objects, such as feeders, nests, roosts, and other chickens, reflect the incident light. Objects vary in their ability to reflect light. Light colored objects reflect more incident light than the dark objects. Thus, a discrepancy exists between what a chicken sees and what is commonly measured in a poultry house with a footcandle meter.

The reflectance of the surroundings in a poultry house should be measured instead of the incident light. Some interesting results were obtained when reflectance readings in footlamberts were made. (See Table XV). A footlambert is a unit of reflected light equal to a footcandle. White chickens within a pen reflected more footlamberts than any other object in the room. The light sources are the brightest objects in the room ranging from 3,300 footlamberts for the 25 watt lamp to 24,000 footlamberts for the 200 watt lamp. The reflectance from the chickens at the center of the floor underneath the lamps was 1.4 footlamberts in the 25 watt pen and approximately 15 footlamberts in the 200 watt pen. Other objects in the room had low reflectances from 0.1 footlamberts to 0.6 footlamberts in the 25 watt pen, and from 1.3 footlamberts to 8.0 footlamberts in the 200 watt pen.

Table XIV gives the footcandle readings in the various pens as taken at the points shown in Fig. 16. The footcandle readings can be compared with the footlambert readings in Table XV. The footcandle readings are higher than the footlambert readings due to the low reflectance of the surroundings.

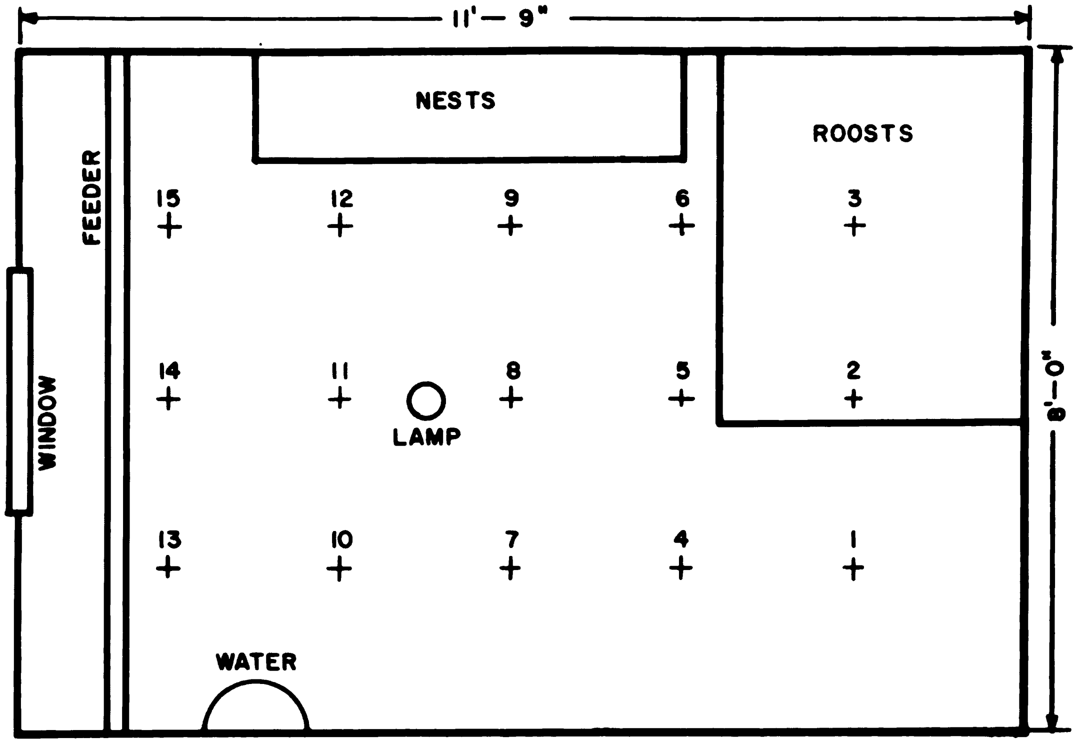

FIG. 16. LOCATION OF FOOTCANDLE READINGS IN PENS OF EXPERIMENTAL HOUSE

Table XIV Footcandle Readings at Locations Shown in Fig. 16 for the Various Lamp Wattages. Footcandle Meter Was Held Perpendicular to Light Source at Level of Litter and Equipment in Pen.

Lamp Wattages	Location of Readings 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
25	0.3	0.3	0.3	0.8	1.0	0.8	1.1	1.5	1.3	1.3	1.5	1.0	0.7	1.0	0.7
60	1.5	1.6	1.5	3.0	3.1	3.0	4.6	5.1	4.0	4.0	5.0	4.0	3.0	3.9	3.1
100	2.1	2.5	3.5	4.9	5.5	4.5	7.6	9.0	7.0	7.1	9.0	7.5	6.5	8.2	7.0
150	4.0	5.2	4.9	9.0	11.5	8.1	15.0	16.1	11.5	14.0	17.2	12.5	11.0	14.0	11.0
200	6.1	6.0	7.2	12.1	14.0	11.9	22.5	24.0	16.5	17.9	24.0	18.3	13.4	17.0	14.2

Table XV Footlambert Readings of Selected Objects in Test Pens of Experimental Poultry House

Object	Light Treatment					Natural Daylight[1]
	25 W	60 W	100 W	150 W	200 W	
Light Source	3,300	9,500	14,000	19,000	24,000	- - -
East Wall (middle)	0.2	1.3	1.7	1.5	2.0	13
West Wall (near roost)	0.1	0.6	0.8	1	1.5	2.7
North Wall	0.2	0.8	0.9	1.3	2.5	9
South Wall	0.2	0.9	1.6	5	5.5	7.5
Black plastic (windows)	0.1	0.7	0.9	1	1.3	- - -
Floor (under lamp)	0.2	1.1	1.8	4	5.0	11
Slats on Roost	0.1	0.7	0.6	1.3	1.7	3.1
Feed Trough (SW corner)	0.2	0.5	0.8	1	1.8	3
Center of Nests	0.6	1.9	3.3	5.5	8.0	17
Chicken (center floor)	1.4	3.7	7.8	17	16	6
Chicken (near feeder)	0.9	1.9	6.1	7	8.5	80
Chicken (on roost)	0.6	2.1	3.6	8.8	9.0	12
Sky (open window)	---	---	---	---	---	3,000
Grass (open window)	---	---	---	---	---	775
Feed Trough (center)	0.1	0.7	1.1	1.3	2.6	10

[1]Readings on July 11, 1960, 3:00 p.m., hazy - clear

CONCLUSIONS

As a result of the investigations of roosting and rising light intensities, the following conclusions can be made:

(1) Under natural light conditions roosting time does not correlate with sunset time for periods of less than one month.

(2) Chickens roost at a lower light intensity on a cloudy day than on a clear day.

(3) The rising light intensity is much lower than the roosting light intensity.

(4) A correlation exists between sunrise time and rising time under natural light conditions.

(5) The hypothesis is correct that chickens roost at a light intensity dependent upon a light intensity to which they have become adapted.

(6) The rising light intensity is not significantly different for the various treatments due to chickens becoming adapted to the same light intensity (absence of light) for each treatment.

(7) Measuring the surroundings in terms of reflected light (footlamberts) is a more realistic approach to studying poultry house lighting, than by measuring the surroundings in terms of incident light (footcandles).

FUTURE INVESTIGATIONS

More fundamental facts on the effects of light on chickens are needed. The underlying reasons of why and how chickens react to light need to be investigated.

Further investigations are needed on the effect of light intensities on the roosting of chickens.

(1) The effect of different rates of change of light intensity on the roosting of chickens should be investigated.

(2) The investigation of the effect of higher light intensities on the roosting light intensity of chickens, perhaps up to 10,000 footcandles, is needed. Also, the effect of higher light intensities on some of the performance factors such as egg production, feed conversion, and growth should be investigated.

(3) A study of certain responses to light of the different breeds of chickens is needed. The lighter breeds, such as White Leghorns, may respond to a light change differently than

the heavier breeds.

(4) The threshold light intensity for the cones in the retina is needed. Perhaps, this is the point, the transition between rod and cone vision, which causes chickens to rise. This same point may be higher for roosting and causes the chickens to roost at a higher light intensity than the light intensity at rising.

(5) The length of time for a chicken to adapt to an environmental change in light intensity should be investigated.

(6) Determine whether incident light or reflected light is the better criteria for measuring light intensity for poultry lighting.

REFERENCES

1. Baker, J. R. and R. M. Ranson (1932). Factors affecting the breeding of the field mouse. Proc. Roy. Soc. London. B110:313-22.

2. Bastian, J. W. and M. X. Zarrow (1955). A new hypothesis for the asynchronous ovulatory cycle of the domestic hen. Poultry Science. 34:776-788.

3. Bissonnette, T. H. (1932). Studies on the sexual cycle in birds. VI. Effects of white, green and red lights of equal luminous intensity on the testis activity of the European Starling (Sturnus Vulgaris). Science. 75:18-19.

4. Bissonnette, T. H. (1933). Does increased light absorption cause increased egg production in the fowl? Poultry Science. 12:396-99.

5. Byerly, T. C. (1957). Light and egg production. Poultry Science. 36:465-468.

6. Byerly, T. C. and O. K. Moore (1941). Clutch length in relation to period of illumination in the domestic fowl. Poultry Science. 20:387-390.

7. Callenbach, E. W., J. E. Nicholas, and R. R. Murphy (1943). Effect of light and availability of feed on egg production. Pa. Agr. Exp. Sta. Bul. 455.

8. Callenbach, E. W., J. E. Nicholas, and R. R. Murphy (1944). Influence of light on age at sexual maturity and ovulation rate of pullets. Pa. Agr. Exp. Sta. Bul. 461.

9. Carson, J. R., W. A. Junnila, and B. F. Bacon (1958). Sexual maturity and productivity in the chicken as affected by the quality of illumination during the growing period. Poultry Science. 37:102-112.

10. Coles, R. (1959). Autumn-hatched chicks. Jour. Ministry Agriculture. 66:236-239.

11. Curtis, G. M. (1920). Use of Artificial Light to Increase Winter Egg Production. Reliable Poultry Journal Publishing Co., Quincy, Ill.

12. Dakan, E. L. (1934). Light absorption, feed consumption, and the urge to lay. Abstract of a paper presented at annual meeting of Poul. Sci. Assoc. Poultry Science. 13:317-318.

13. Dobie, J. B., J. S. Carver and J. Roberts (1946). Poultry lighting for egg production. Wash. Agr. Exp. Sta. Bul. 471.

14. Dougherty, J. E. (1917). Artificial lighting of laying pens. Jour. of Amer. Assoc. of Inst. & Invest. in Poultry Husbandry. 3:71-72.

15. Fairbanks, F. L. and J. E. Rice (1924). Artificial illumination of poultry houses for winter egg production. Cornell Agr. Ext. Bul. 90.

16. Farm Journal (1959). How stimulight is working out. Article by Roy Dankinbring, Poultry Editor. Farm Journal Central Edition. December.

17. Fraps, R. M. (1954). Neural basis of diurnal periodicity in release of ovulation-inducing hormone in fowl. Proc. Nat'l. Acad. Sci. U.S. 40:348-356.

18. Goodale, H. D. (1923). The influence of certain methods of management on egg production. I. Their influence on winter egg production. Poultry Science. 3:173-79.

19. Hahn, Honigmann, and Blässer (1916, 1926). Mentioned in Wall's <u>The Vertebrate Eye</u>. 498 pp.

20. Hamilton, W. F. and T. B. Coleman (1933). Trichromatic vision in the pigeon as illustrated by the spectral discrimination curve. Jour. Comp. Psychol. 15:183-191.

21. Hammon, J. C. and H. W. Titus (1941). Effect of colored light and colored walls on the growth and mortality of chickens. Poultry Science. 20:507-513.

22. Hecht, S., S. Shlaer and M. H. Pirenne (1942). Energy, quanta, and vision. Jour. of Gen. Physiology. 25:819-840.

23. von Hess, Carl (1912). Vergleichende physiologie des gesichtssinnes. <u>Handbuch der Vergleichenden Physiologie</u>. (ed. Winterstein). Bd.4:1-290. Jena:Gustav Fischer.

24. Heywang, B. W. (1946). Growth of chickens fed only during the cooler part of the day. Poultry Science. 25:492-497.

25. Hutchinson, J. C. D. and W. W. Taylor (1957). Seasonal variation in the egg production of fowls; effect of temperature and change of day length. Jour. Agricultural Science. 49:419-434.

26. Hutt, F. B., W. F. Lamoreux and K. Goodwin (1955). Don't light growing pullets! The Kimberchik News. April.

27. Kable, G. (1926). Results from artificial lighting of laying houses. Agricultural Engineering. 7:304.

28. Kennard, D. C. (1929). All-night lights for winter layers. Bimonthly Bul. of the Ohio Agr. Exp. Sta., Wooster. 141:195-198.

29. King, D. F. (1959). Artificial light for growing and laying birds. Alabama Agr. Exp. Sta. Progress Report Series No. 72.

30. Krause (1863). Mentioned in Wall's The Vertebrate Eye. 192 pp.

31. Lashley, Karl S. (1916). The color vision of birds. I. The spectrum of the domestic fowl. Jour. Animal Behavior. 6:1-26.

32. Laurens, H. (1923). Studies on the relative physiological value of spectral lights. III. The pupillomotor effects of wavelengths of equal energy content. Amer. Jour. Physiol. 64:97-119.

33. Lewis, H. R., R. R. Hannas and E. H. Wene (1919). The first two years of the Vineland Contest. New Jersey Agr. Exp. Sta. Bul. 338. 103 pp.

34. McClary, C. F. (1960). Step-down step-up lighting plan. Poultry Tribune, Midwest edition. February. pp. 14-15, 36.

35. Moreng, R. E., R. L. Byrant and D. G. Gosslee (1956). Physiological reaction of chicks to limited light. Poultry Science. 35:977-983.

36. Mueller, C. D., T. B. Avery, H. D. Smith and R. E. Clegg (1951). Effects of controlled light and temperature for laying hens. Poultry Science. 30:679-86.

37. Newell, G. G. (1916). A Revolution in Egg Production. American Poultry Journal Publishing Company.

38. Nicholas, J. E., E. W. Callenbach and R. R. Murphy (1944). Light intensity as a factor in the artificial illumination of pullets. Pa. Agr. Exp. Sta. Bul. 462.

39. Nightall, E. W. (1955). Egg production and flash lighting. Jour. Ministry Agriculture. 62:421-424.

40. Penquite, R. and R. B. Thompson (1933). Influence of continuous light on leghorns. Poultry Science. 12:201-205.

41. Piper, Hans (1905). Untersuchungen über das elektromotorische Verhalten der Netzhaut bei Warmblütern. Arch.f Anat. U. Physiol., Physiol. Abt. (=Arch. f. Physiol.). Suppl. - Bd., pp. 133-192.

42. Platt, C. S. (1953). Maintaining winter egg production by the use of dim red light. Poultry Science. 32:143-145.

43. Polyak, S. (1941). The Retina. University of Chicago Press. Chicago, Ill.

44. Rowan, W. (1938). Light and seasonal reproduction in animals. Biol. Revs. 13:374-402.

45. Rider, P. L. (1938). The influence of light on growth and reproduction of the domestic fowl. Thesis for degree of M.S., Ohio State University. (unpublished).

46. Riley, G. M. and T. C. Byerly (1943). Influence of increased light on progress of molt and egg production in yearling Rhode Island Red hens. Poultry Science. 22:301-306.

47. Roberts, J. and Carver, J. S. (1941). Electric light for egg production. Agricultural Engineering. 22:357-360.

48. Ryan, F. A., E. P. Singsen, J. R. Carson, L. M. Potter and W. A. Junnila (1959). Fourteen hour day versus all-night lights in poultry laying houses. Abstract. Poultry Science. 38:1243.

49. Shoup, Mrs. G. P. (1918). Artificial lighting of poultry houses in Western Washington. Jour. of Amer. Assoc. of Inst. & Invest. in Poultry Husbandry. 4:44-45, 47.

50. Shutze, J. V., L. S. Jensen and W. E. Matson (1959). Effect of lighting regimes on growth and subsequent egg production of chickens. Poultry Science. 38:1246.

51. Staffe, A. (1950) Weitere. Untersuchungen über die Wirkung des lichtschocks auf die legeleistung. Der Geflügelhof. 13:446-49, 510-14.

52. Studnitz (1930). Mentioned in Wall's The Vertebrate Eye. 100 pp.

53. Sykes, A. H. (1956). Short day length and egg production in the fowl. Jour. Agricultural Science. 47:429-34.

54. Tomhave, A. E. (1954). Influence of artificial lights during rearing on the egg production of October hatched New Hampshires. Poultry Science. 33:725-29.

55. Vries, Hugo de (1943). The quantum character of light and its bearing on threshold of vision, differential sensitivity, and acuity of eye. Physica. 10:553-564.

56. Walls, G. L. (1942). The Vertebrate Eye. The Cranbrook Press, Bloomfield, Michigan.

57. Warren, D. C., R. Conrac, A. E. Schumacher and T. B. Avery (1950). Effects of fluctuating environment on laying hens. Kansas Agr. Exp. Sta. Tech. Bul. 68. 43 pp.

58. Watson, J. B. (1915). Studies on the spectral sensitivity of birds. Pap. Dept. Mar. Biol. Carn. Inst. Wash. 7:87-104.

59. Weber, W. A. (1951). Influence of light shock on the laying potential. Proc. 9th World's Poultry Congr., Paris. 2:99-101.

60. Weinmiller, von L. and K. Mantel (1940). Dauerbeleuchtung fur Lege-und Zuchthennen. Archif. f Kleentierzucht. 6:129-139.

61. Wetham, Elizabeth O. (1933). Factors modifying egg production with special reference to seasonal changes. Jour. Agricultural Science. 23:383-418.

62. Wilson, W. C. and Abplanalp, H. (1956). Intermittent light stimuli in egg production of chickens. Poultry Science. 35:532-538.

63. Wilson, W. O. and A. E. Woodward (1958). Egg production of chickens kept in darkness. Poultry Science. 37:1054-1057.

64. Withrow, R. B. (1959). Photoperiodism and related phenomena in plants and animals. No. 55 of the Am. Assoc. for the Adv. of Sci. Washington, D. C. pp. 767-785.

65. Young. Mentioned in Wall's <u>The Vertebrate Eye</u>. pp. 101.