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Effect of Varying Day-length on Time of Oviposition in Domestic Fowl

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SUMMARY

Forty-eight Single Comb White Leghorn pullets hatched January 21, 1956, were used to study the effect of varying day-length on the time of oviposition. The pullets were maintained in individual cages and housed in a windowless basement room. Artificial lighting under the control of an automatic timing device was used to provide day-lengths ranging from 21 to 42 hours. The experimental day-lengths consisted of alternating lighted and non-lighted periods of equal length.

From this experiment the following conclusions may be drawn:

1. Egg production and the length of clutch were progressively decreased when day-length was shortened from 24 to 21 hours.
2. The percentage of birds pausing 5 or more days increased as day-length decreased.
3. Day-lengths progressively greater than 24 hours were effective in increasing the length of clutch until sustained daily lay occurred for all birds.
4. The initial oviposition of longer sequences occurred earlier in the day while the terminal oviposition occurred later in the day.
5. The mean interval and mean lag between ovipositions decreased as the length of the sequence increased on a day-length of 24 hours.
6. The time of oviposition was restricted to the daylight hours on the 24-hour day. As day-length was decreased more eggs were laid during the dark period. Increasing the day-length to the 25-hour day also increased the percent of ovipositions occurring in the dark period. During the 27 through the 34-hour day-lengths the majority of the eggs were produced in the dark period.
7. Day-lengths greater than 24 hours progressively advanced the time of oviposition to an earlier hour of the day. On days shorter than 24 hours, oviposition occurred at a later time of the day.
8. The time of oviposition was delayed during the 26 through the 34-hour day-lengths. The amount of the delay or increased interval between ovipositions was equal to the number of hours that day-length was increased. The day-lengths of 36 through 42 hours did not delay ovipositions in all birds as many birds frequently laid two eggs per experimental day.
9. Hens demonstrated the ability to ovulate and lay eggs at a regular interval over an extended period of time. The phenomenon of laying in clutches results from the inhibiting effect of insufficient day-length (diurnal rhythm of light and dark periods).

Effect of Varying Day-length on Time of Oviposition in Domestic Fowl

INTRODUCTION

Laying hens exhibit certain seasonal trends in the production of eggs. Ordinarily maximum egg production is attained during the spring months. To-day, poultrymen know that the use of artificial lights during the fall and winter months will promote a more uniform distribution of egg production throughout the laying year. Recently, physiological processes by which the influence of light is exerted have received much attention. The earlier theory on this subject was that a longer day gave the hen an opportunity to consume more feed and digest and convert surplus food into eggs. Recent experimental work has shown, however, that the principal effect of light is its stimulating effect upon the pituitary gland which in turn stimulates the reproductive system to function.

Early experimental work indicated that the total yearly egg production was not increased by artificial light. However, the advent of windowless houses stimulated investigation of effects from complete control of light and recent results suggest the proper use of artificial lights can increase yearly production per hen.

The egg laying pattern of hens is not constant and exhibits characteristic cycles of lay or ovipositions. One of the most outstanding features of their reproductive cycles is their lay of eggs on successive days, each egg being laid at a successively later hour than the one preceding it (a sequence). Eventually, the hour occurs in the mid-afternoon, and an egg is not laid. The sequence is thus terminated. Sequences are usually separated by an interval of one day during which no egg is produced. The initial egg of the sequence is usually laid early in the morning, i.e. 7:00 to 9:00. The intra-sequence eggs are laid in the forenoon, while the terminal egg of the sequence is laid in the mid-afternoon. The length of the sequence may vary from one to more than a hundred eggs but the shorter lengths of 4 and 5-egg sequences are typical. Although sequence length may vary, sequences of the same length usually follow one another in any particular bird.

The interval between eggs laid on successive days ranges from 24 to 28 hours, depending on the length of the sequence. Hens tend to maintain a characteristic interval between successive eggs of a sequence, the birds with the longer intervals having the shorter sequences. Since the mean time for egg formation is approximately 26 hours, each successive oviposition within a sequence occurs, on the average, 2 hours later every day. Therefore, it was theorized that if a hen possessing an interval of 26 hours were subjected to a 26-hour day, the time required for egg formation would coincide with day-length. Hence, conditions would become such that the hen could produce an egg per day without interruption of the sequence.

While the length of day is very important to maintain a high rate of egg production, the day-night rhythm involved in egg production must not be overlooked. Light is known to exert a stimulus necessary for egg production. However, it is also known that light plus activity of the bird in some way inhibits the release of the ovulating-inducing hormone (OIH) which is responsible for ovulation of an egg. Delaying the onset of light by increasing the day-length should therefore result in increased clutch-length. Likewise, decreasing the day-length should cause the hen to produce eggs in smaller clutches.

Many hens exhibit the ability to lay at intervals of 24 hours, or an egg per day, for an extended period of time. Birds possessing the ability to lay at intervals of less than 24 hours are possibly controlled to a minimum of 24 hours by the diurnal rhythm of the natural 24-hour day. Therefore, the usual egg production records do not identify the birds possessing an interval of less than 24 hours between ovipositions. If the day-length were altered so that a 23-hour day would be provided, the birds laying at an interval less than 24 hours would become apparent. If such birds were used for breeding purposes (egg production), conceivably, the average time for egg formation could be greatly reduced, resulting in a greater number of eggs during the laying year.

The purpose of this experiment was to study the laying habits of birds when subjected to increased and decreased day-lengths. It was proposed that increased day-length should result in an increased clutch-length due to (a) providing the hen with a sufficient day-length that coincided with the time required to produce an egg and (b) by delaying the onset of the lighted period which has been reported to inhibit ovulation.

REVIEW OF LITERATURE

Effect of Artificial Light on Egg Production

According to Curtis (1920), the first report of the value of artificial light to promote winter egg production dates back to 1889. Since that time many people have experimented with the use of artificial light and in general obtained favorable results.

Light as a Physiological Stimulus. For many years, supplemental light was thought to stimulate egg production directly by providing the hen with a longer day to eat, exercise, digest and convert surplus food into eggs. Ample experimental work has shown, however, that the principal effect of light is its stimulating effect upon the pituitary. The pituitary then responds by secreting the hormones that control reproduction.

The first investigator to question the "feeding effect" of artificial lighting was Goodale (1924). Using trapnest records of several pens of pullets he found that there were some birds laying just as well in the unlighted pens as in the lighted pens. He also observed that all birds were laying in the lighted pens, whereas only a few individuals were laying in the unlighted pens. This led Goodale to suggest that artificial light operated directly to stimulate winter egg production rather than to stimulate greater feed consumption.

The investigations by Kable, Fox, and Lunn (1928) supported the suggestion of Goodale (1924). These workers found that when artificial light was applied to a flock, the response in egg production was immediate, regardless of the condition of the flock. During the months from October until February all the lighted flocks consistently maintained their production above that of the unlighted flocks. Since the amount of feed consumed was not governed by the number of hours of light in the day, these workers concluded that the increased production from lighting was apparently not entirely a result of providing a lengthened feeding time. These results were confirmed by Dakan (1934).

Whetham (1933) presented a new explanation of the results secured by the use of artificial illumination. She suggested that the action of light was probably connected with the activity of the anterior lobe of the pituitary. She advanced the theory that the increase in food consumption resulted from the extra egg production produced by the stimulus of light. Whetham noted that there was some evidence that the stimulus to the pituitary might be caused by the light ration rather than by the quantitative amount of light. Cole (1933), working with mourning doves, and Bissonnette (1933), working with starlings, ferrets, moles, and other animals, reported similar conclusions.

Burmester and Card (1939) subjected hens to various feeding periods ranging from a maximum of 14 hours daily to a minimum of 10 minutes every 12 hours. Artificial light was used to provide a 14-hour day. They found that hens lighted from 6:00 a.m. to 8:00 p.m. were able to maintain body weight and sustain production if fed an all-mash diet during at least 6 hours of total feeding time per day.

Even more recently, Callenbach *et al.* (1943) found that egg production of hens having limited access to feed was greater than that of comparable hens having feed available at all times. This work further confirmed the earlier studies of Goodale (1924), Kable *et al.* (1928), Dakan (1934), and Burmester and Card (1939).

The mechanism by which the reproductive system of the male and female may be influenced by environmental light changes has been studied by numerous investigators. Ample experimental evidence is now available demonstrating that the anterior pituitary gland plays a dominant role in the gonadal response to light (Marshall, 1937; Rowan, 1938). The manner in which light affects this gland is uncertain. The most widely supported theory is that light entering the eye, which acts as a receptor, starts nerve impulses or stimuli in the optic system. These impulses are then transmitted via the optic nerve to the brain which in turn sends impulses to the vicinity of the hypothalamus. The transmission to the pituitary is then completed by humoral relay involving the hypophysial-portal blood vessels. Following stimulation, the anterior pituitary secretes the gonadotrophic hormones which regulate the activity of the gonads (Bissonette, 1931a,b; Rowan, 1938; Benoit, 1935a,b and 1938; and Green and Harris, 1949).

The Effect of Light Intensity on Egg Production. Fairbanks (1924), on the basis of a 2-year study, established the minimum requirement for active feeding at 0.8 to 1.0 foot-candle of light.

Roberts and Carver (1941) studied the effect of light intensity in the artificial illumination of maturing White Leghorn chickens. Four groups of 20 birds were studied. The birds were housed in single-deck laying cages located in insulated pens which were provided with a relatively accurate control of temperature, light, and ventilation. These workers found that 13 hours of Mazda light, varying in intensities from 1 to 31.3 foot-candles, had no significant effect on egg production. From these results these researchers established the minimum requirement for egg production in the White Leghorn at approximately 1 foot-candle of light. Similar results were reported by Nicholas *et al.* (1944). They reported no effect on the degree of reproductive response when light intensities were varied from 0.5 to 38.0 foot-candles at a central point in the working area and from 0.0 to 27.0 foot candles at a central point in the roosting area.

Weber (1951) reported optimum results from the effect of "flash-lighting." Two 20-second flashes of high intensity light (1500 watts) in addition to natural daylight were used. The flashes were administered at 4:00 a.m. and 4:45 a.m. daily. Similar results were reported by Staffe (1951), Matthews (1957), and Fox and Morris (1958). In addition, the latter workers reported that flashes of lower intensity given at the proper time might also give maximum response.

Asmundson (1946) observed that light intensities of approximately 2 foot-candles provided the maximum response in the turkey. Low intensities of 0.3 to 1.0 foot-candle produced a much slower response. A light intensity of 0.1 foot-candle had no effect on egg production. When the turkeys were housed without artificial lights egg production was retarded.

The intensity of light may also affect sexual activity. Bissonnette (1931b), working with the European starling (Sturnus vulgaris), observed that the rate of sexual activity increased as each of the following intensities were studied: 10, 12, 25, 50, and 60 watts. In a later report Bissonnette and Wadlund (1933) found that a 200-watt bulb was more stimulating than a 1000-watt bulb at the same distance. Similar results were obtained by Burger (1939). In addition, Burger reported that gradual increases in the daily ration of light were only effective in inducing spermatogenesis when the day-length was longer than 9 hours. Birds kept on 10.25 hours of continuous light were not stimulated. From these results Burger pointed out that the length of daily exposure to light was the stimulating factor in sexual activation. However, there was a daily length of exposure beyond which further increases in length of day are not increasingly effective in stimulating spermatogenesis.

Effect of Hours of Light Per Day on Egg Production. One of the early recommendations on the optimum amount of light to be provided during the fall and winter months was made by Curtis (1920). He recommended 12 to 14 hours of light per day for maximum winter egg production. A similar recommendation was made by Fairbanks (1924). In addition, Fairbanks observed that one 40-watt lamp per 200 square feet of floor space gave maximum results.

Kennard and Chamberlin (1931) studied the effect of natural light plus all-night lighting on egg production. They observed that continuous light was more effective than either natural light or natural light plus morning lights beginning at 4:00 a.m. One 10 to 15-watt lamp per 400 square feet of floor space proved to be satisfactory. Penquite and Thompson (1933) also observed that natural light plus all-night lighting was effective in increasing egg production during the fall and winter months. They reported that hens under the influence of artificial light laid a greater number of eggs during the months of November, December, and January than did birds under natural light.

Although many early workers recommended a 12 to 14-hour light-day the first factual information concerning the effect of artificial light on egg production was provided by Dobie *et al.* (1946). Extensive studies on the optimum amount of light to be provided revealed that 13 hours of Mazda incandescent light were required to attain maximum production from high-producing hens. Any decrease in the hours of light per day resulted in decreased egg production. When artificial light was varied from 13 to 19 hours per day, egg production was not increased enough to warrant recommendations.

More recently, it has become apparent that "flash-lighting," consisting of the use of high wattage lamps for very short periods (a few seconds), may have the effect of several hours of continuous light. Staffe (1951) reported that the increase in winter egg production, induced by continuous light, could also be induced by "flash-lighting." He found that optimum results were secured when 2 flashes were used for a duration of 20 seconds at 4:00 a.m. and 4:45 a.m. daily. A 1500-watt lamp was used to provide the flashes. These results led Staffe to suggest that the total amount of light required could be less than 12 hours in 24. Weber (1951) reported similar results. Matthews (1957) found that 3 flashes of 20 seconds duration gave optimum results when given at 3:00 a.m., 4:00 a.m., and 5:00 a.m. Two 1500-watt lamps were used. An additional flash at 6:00 a.m. for 20 seconds did not increase egg production.

Fox and Morris (1958) reported that the time of the flash could be altered so that it was no longer an effective stimulus. He further observed that flash of relatively low intensity (300-watt bulb), given at the appropriate time, would give maximum results.

Intermittent lighting has recently given beneficial results in the stimulation of the gonads. Kirkpatrick and Leopold (1952) have shown with quail (colinus virginianus) that 9 hours of light with a 1-hour interruption during the dark period resulted in full sexual activity. Such a response was not obtainable when birds were subjected to the same amount of light given continuously.

Farner (1953), using white crowned sparrows (Zonotrichia leucophrys gambelii), found that the light-stimulated gonadotropic mechanism became active almost immediately after the photoperiod began. He further observed that after light-initiated activity, it continued for a time after the end of the photoperiod. This he called the "carry-over."

Dobie (1946) studied the effect of time of additional lighting (intermittent) on egg production. He noted that hens maintained on a base day of 8 hours (7:30 a.m.-3:30 p.m.) responded best to the 2-hour intermittent period when given from 11:30 p.m. to 1:30 a.m. When the birds were maintained on a base day of 11 hours (7:00 a.m. to 6:00 p.m.) egg production was not increased when a 2-hour intermittent period was given from 11:30 p.m. to 1:30 a.m. Dobie concluded that if 13 hours of light were provided, a dark period of 11 hours was not too long for maximum production.

Wilson and Abplanalp (1956) conducted an experiment to test the effect of intermittent versus continuous lighting. The intermittent group received 1 minute of light, and 3 hours and 59 minutes of darkness 6 times daily; thus the pullets received 6 minutes of light evenly spaced throughout the 24 hours. Egg production of the intermittent group was higher (69.8 percent) than that of comparable pullets on 24 hours of continuous light (66.9 percent) and slightly lower than that of pullets on 14 hours of light and 10 hours of darkness (70.0 percent). These workers concluded that intermittent lighting generally gave a higher egg production than the same amount of light given continuously.

Wilson and Woodard (1958) presented data showing that hens kept in continuous darkness for 5 weeks continued to lay eggs. These workers pointed out that some hens did cease egg production, while others previously pausing, started to lay. In 2 tests the production for birds pausing less than 5 days was 60.2 and 77.1 percent. It was their observation that hens losing the largest percentage body weight also had the greatest decline in production. They concluded that the hen does not need light for either ovulation or oviposition.

Moore and Mehrhof (1946), in an experiment using Light Sussex pullets, compared periodic increases in lighting to continuous light. Birds receiving all-night light laid 2.44 percent more eggs during the experiment than those receiving an increase of 2 hours every 14 days until continuous lighting was reached. After a slightly slower start, egg production tended to reach a peak faster in the periodically lighted group than in the continuously lighted group in 2 trials out of 3. In all 3 trials, however, the continuously lighted group sustained a higher rate of production than the periodic-light group. These workers concluded that a changing schedule of lighting resulted in the highest stimulatory effect. However, it also caused greater refractoriness to light stimulation than all-night lighting.

King (1958) reported on the "Stimulight" system of using light during the growing and egg-producing periods of the hen. In this system the chicks were restricted to 6 hours of artificial light each day from 0 to 5 months of age. During the laying year the light was increased 18 minutes each week. At the end of the experiment the hens were receiving 21 hours and 36 minutes of light each 24 hours. He found that the "stimulighted" group of pullets laid 270 eggs per pullet, compared with 215 eggs per pullet for those raised on 12 hours light for the first 5 months and 14 hours light per 24 hours during the laying year. The Doane Agriculture Service (1958) released data from a "Stimulight test" that was based on farm conditions. Using a large number of birds and the design of King (1958), they reported 209 eggs per hen for the controls and 236 for the "Stimulighted" flock. These findings are in agreement with the work of King (1958).

Effect of the Total Length of Light and Dark Periods on Egg Production. Little work on the total length of the light and dark period as it affects egg production has been reported. Byerly and Moore (1941) conducted an experiment to determine whether clutch-length could be increased by subjecting birds to alternate light and dark periods totaling 26 hours. It was their belief that if darkness was a limiting factor in terminating clutch-length in the usual 24-hour period, an increased day-length would permit the laying of longer clutches. Fourteen New Hampshire X Barred Plymouth Rock yearling hens were used. These hens were previously subjected to a 26-hour day. Five of these hens, which received 14 hours light and 12 hours darkness during the previous experiment, were placed on the 24-hour day (14 hours light, 10 hours darkness). The remaining 9 hens were placed on the 26-hour day consisting of 14 hours light and 12 hours darkness. During the interval between the experiments (one month) they were placed on 14 hours light and 10 hours darkness. Both groups had laid at approximately the same rate during the first experiment. The number of pullets used is not known. These workers showed that a 26-hour day, consisting of 14 hours light and 12 hours of darkness, increased the average clutch-length and hen-day egg production when calculated on a 24-hour basis. Using a test period of 8 weeks their results were as follows:

Yearling Hens	Average Clutch-Length	Percent Egg Production 24-hour basis
Natural daylight	2.10	44.6
14 hrs. light, 10 hr. darkness	1.83	43.5
14 hrs. light, 12 hrs. darkness	5.14	63.6
Pullets		
14 hrs. light, 10 hrs. darkness	2.04	64.8
14 hrs. light, 12 hrs. darkness	5.42	83.6

They suggested that clutches were lengthened by "assuring a lighted period of sufficient length to maintain pituitary and consequently ovarian activity shortly before ovulation." They further suggested that the rhythmic use of 14 hours light and 12 hours darkness permitted the birds adequate rest periods and thus delayed the onset of refractoriness.

Van Albada (1958), using 423 Brown Leghorn X White Leghorn pullets, studied the effect of the 26-hour day on egg production and egg-laying rhythm over a 12-month period. Fourteen hours of artificial light and 12 hours of darkness were given alternately. His data indicated that during the first half of the laying year the 26-hour group laid their eggs in longer clutches than either naturally lighted birds or birds maintained on 14 hours light and 10 hours darkness. During the spring months when the hours of light were increasing, the naturally lighted birds laid the longer clutches. Although clutch-length was increased by the 26-hour day, total egg production was increased very little. This was attributed to the fact that birds on the 26-hour period did not lay in less than 26-hour intervals. It was noted that birds on the 26-hour day had considerably thicker egg shells than birds maintained on the 24-hour day; therefore, he proposed that the 2-hour delay in the interval between eggs was a result of a delayed oviposition.

Effect of Light on Seasonal Distribution of Egg Production. In the chicken, rate of egg production is affected to a considerable extent by variations in light. Under natural conditions maximum egg production is ordinarily attained during the spring months with the lowest yield in production coming in the fall and winter months.

Lewis *et al.* (1919), working with the Vineland Egg Laying Contest, were the first to report the seasonal distribution of egg production. Dougherty (1922) reported that artificial lights in the early morning were effective in increasing the number of market eggs in the fall and winter months.

Kennard and Chamberlin (1931) showed that seasonal variation could be modified by the use of supplementary artificial light. These investigators observed that hens and pullets subjected to continuous light or morning lights beginning at 4:00 a.m. laid a greater number of winter eggs than those without light. These workers also presented data which indicated that continuous light was very valuable for bringing slow maturing or late-hatched pullets into production.

Penquite and Thompson (1933) also noted that the seasonal trends in egg production could be varied by using artificial light. Their work showed that continuous all-night lights changed the seasonal peak in egg production from the months of March and April to November and December. Observations also showed that continuous lights did not increase or decrease to a significant degree the total number of eggs produced.

Whetham (1933) made an extensive study of the factors modifying egg production, using egg-laying records for regions north and south of the equator at intervals of 5 degrees latitude. Latitudes 10°N and 20°S were considered equatorial. She observed that egg production curves from 10°N and 20°S were considerably different than those obtained from the more temperature latitudes of 55°N and 40°S. She also noted that egg production curves for the 6 most northerly latitudes were similar to the 3 most southerly latitudes, but reversed as to season, just like daylight curves. The highest yield in egg production was obtained some weeks before the longest days of the year. Likewise, the lowest yield was obtained prior to the shortest days of the year.

Using large numbers with 4 replications of each treatment, Gutteridge *et al.* (1944) reported an increase in fall and winter egg production when birds were lighted from October through April. Almost identical egg production between the lighted and non-lighted groups was observed at the end of the laying year.

The breeding season of the turkey can also be modified by artificial illumination. Supplemental light provided during the months of decreasing daylight is effective in initiating egg production prior to the month of March when naturally lighted birds are just coming into production (Albright and Thompson, 1933; Moore and Berridge, 1934; Marsden, 1936; Scott and Payne, 1937; and Wilcke, 1938).

Milby and Thompson (1941) reported that the number of eggs laid annually by the turkey can be almost doubled by continuous light. Davis (1948) noted that turkeys in lighted pens laid significantly more eggs than those in non-lighted pens.

Characteristics of the Oviposition Cycle

The Cycle and Rhythms at Which Oviposition Occurs. An obvious feature of the oviposition cycle in the domestic fowl is the lay of eggs on successive days (a sequence), followed by an interruption for one or more days before laying is resumed. Such behavior has been called a cycle of laying or clutch (Patterson, 1916; Atwood, 1929). Romanoff and Romanoff (1949), however, stated that only wild birds that incubate their eggs lay in clutches and the nonsitters lay in cycles. The frequency at which these sequences or cycles are repeated is called the laying rhythm (Goodale, 1915; Patterson, 1916; Warren, 1930).

Hays (1938) observed that many domesticated hens have a tendency to lay in rhythmic cycles. This regularity in laying is maintained during the pullet year and persists into the second year of production (Atwood, 1929).

Hens in regular production may vary in their laying sequences; however, many hens lay their eggs in a fairly characteristic pattern. Romanoff and Romanoff (1949) observed that the sequence and interruption in the sequence were not regular and constant.

Illustrations of some cycles and rhythms in the egg laying pattern of the domestic hen follows:

x-x-x-	One-egg cycle
xx-xx-xx-	Two-egg cycle
xxxxxx	Continuous cycle
xx-xxx--x	Irregular sequence; irregular rhythm
xx-xxx-x	Irregular sequence; regular rhythm
xx-xx--xx---	Regular sequence; irregular rhythm

The Interval Between Ovipositions. As is well known, hens tend to maintain a uniform interval between the successive eggs of a sequence, the females with the longer interval having the shorter sequences. The interval is usually longer than 24 hours; therefore, each oviposition beyond the first, except in lengthy sequences, takes place later in the day than did its predecessor (Atwood, 1929; Warren and Scott, 1935a; Hays, 1936; Fraps, 1955). Thus a female with a 26-hour interval lays the first egg of the sequence at 9:00 a.m. today, 11:00 a.m. tomorrow, 1:00 p.m. the next day, and 3:00 p.m. the following day. If laid on schedule, the fifth egg of the sequence would come at 5:00 p.m. the day following; however, hens usually do not lay so late in the day. The normal procedure is for the bird to miss a day and then start a new sequence of eggs at approximately 9:00 a.m. the following day.

The egg which would have been laid in the latter part of the afternoon was thought to be formed normally but, because of the onset of darkness, was held in the uterus overnight and released in the morning. However, Scott and Warren (1936) demonstrated that each succeeding egg in a sequence could be palpated in the oviduct approximately 5 hours after the oviposition of the preceding egg. The first egg of the sequence could not be detected until nearly 20 hours after the laying of the last egg of the previous sequence. This indicated that the break in the sequence in laying was due to a delay in ovulation and not to retarded egg formation.

Atwood (1929) reported a correlation between the number of eggs in a cycle and the length of the interval between the eggs. His results were:

Length of Cycle	*Mean Interval (Hours)*
2	28.033
3	26.844
4	25.927
5	25.484
8	24.571
11	24.700
26	24.160

Atwood also reported that in a single cycle, the interval shortens toward the middle of the cycle and lengthens toward the end. The interval between the last two eggs of a sequence was always the greatest. Heywang (1938) published extensive observations on interval length which confirmed the work of Atwood. Hays (1936) reported that the interval between eggs laid on successive days reached the lowest level during the spring months when egg production was highest. The longest interval occurred during the periods of lowest egg production.

Van Albada (1958) reported that birds maintained on a 26-hour day laid their eggs at a minimum interval of 26 hours.

Diurnal Periodicity. It is common knowledge that egg laying in the domestic fowl is restricted to the day light period. Although hens may lay at any time in the daylight hours, most of them lay during the forenoon (Turpin, 1918; Atwood, 1929; Hutt and Pilkey, 1930; Funk, 1934; Funk and Kempster, 1934; Warren and Scott, 1936; Heywang, 1938).

The data published by Turpin (1918), indicates that nearly 56 percent of all eggs are laid between the hours of 9:00 a.m. and 1:00 p.m. His results were as follows:

Time	*Hens Laying (Percent)*
7 a.m. to 9 a.m.	17.7
9 a.m. to 11 a.m.	28.5
11 a.m. to 1 p.m.	27.3
1 p.m. to 3 p.m.	19.5
3 p.m. to 5 p.m.	7.0

Among other species, turkey hens lay about 40 percent of their eggs before noon and 60 percent after noon in contrast to chicken hens, which lay more eggs in the morning (Stockton, 1950). Most pigeons lay in the early afternoon, whereas the domesticated duck lays very early in the morning (Riddle, 1923).

Heywang (1938) observed that the actual time of day when eggs are laid depends on the length of the sequence. Birds laying 1 egg in a sequence laid between the hours of 11 a.m. and 1:30 p.m. For birds with a 2-egg sequence, most of the ovipositions occurred between 9:00 a.m. and 10:30 a.m. Most of the eggs of the longer sequences were laid prior to 11:30 a.m.

Control of Oviposition

The Influence of Ovulation on Oviposition. In view of the close time relationship between ovulation and oviposition it was thought that perhaps oviposition was caused by ovulation. Fraps (1942) reported that when ovulation was experimentally induced some 3 to 6 hours before an expected oviposition, the egg was laid prematurely, and by about the same amount of time as the ovulation. Even though the ovulation and oviposition both occurred prematurely, the usual relationship between them continued to exist, e.g. oviposition occurring before ovulation.

The fact that 12 or more hours elapse between the laying of the last egg of a clutch and the ovulation of the first egg of the succeeding clutch, suggests that another mechanism may exist for regulating the time of lay.

Influence of the Ruptured and Unovulated Follicles on Oviposition. Rothchild and Fraps (1944a) demonstrated that the ruptured follicle influenced the time of oviposition. These workers removed the ruptured follicle at various times while the egg that had its origin in this follicle was in the oviduct. They observed that 17 out of 22 hens retained their eggs 9 hours to 3 days past their expected time of lay when the ruptured follicle was removed. Removal of the succeeding maturing follicle delayed lay for 3 and 5 hours for 2 hens. When both the most recently ruptured and the maturing follicle were removed simultaneously, 14 out of 15 hens retained their eggs from 1 to 7 days past normal expected lay.

These investigators also presented evidence that the maturing follicle, at or about the time of its ovulation, had some influence on the time of lay. Fourteen of the 31 birds that held their eggs laid them at the time of the first ovulation following removal of the ruptured follicle. The remaining 17, however, laid their retained eggs some time before and independently of ovulation. These results led the workers to suggest that the time of normal lay of hen eggs appears to be under the immediate control of the ruptured follicle from which the egg originated. However, some other agent must also be involved in the lay of retained eggs.

Rothchild and Fraps (1944b) subsequently undertook an experiment to test for this other agent. All ruptured follicles were removed from each of 48 hens. Twenty-one were then placed under normal lighting conditions (lights 6:00 a.m. to 8:00 p.m.), while the remaining 27 were subjected to reversed lighting conditions (lights 4:00 p.m. to 6:00 a.m.). Only 4 hens failed to retain the egg past the normal expected time of lay. The length of retention for the remaining 44 birds varied from 9 hours to 3 days. The majority of the birds in both groups laid their eggs during the lighted portion of the day. The largest number of ovipositions occurred 7 to 10 hours after the onset of light.

These workers also observed that of the 19 birds which received sham operations, 17 laid their eggs at approximately the normal expected hour on either standard or reverse lighting. Six were left under standard light and 13 were placed under reversed light. These workers concluded that some "extra ovarian" light-sensitive mechanism was involved in the process of oviposition.

Influence of Hormones on Oviposition. Apparently, Riddle (1921) was the first to study the effect of hormones on oviposition. Working with the dove, he found that the administration of whole posterior pituitary substances containing the pressor and oxytocic fractions would cause premature laying.

Morash and Gibbs (1929) reported that pituitrin caused uterine contraction in the opened bird, while McKenny, Essex and Mann (1932) observed the same results *in vitro.*

Burrows and Byerly (1942) reported that obstetrical pituitrin (containing mainly oxytocin) injected at the rate of 0.1 to 0.2 cc. intravenously was very effective in causing premature expulsion of hard-shelled eggs. Ovipositions occurred 3 to 4 minutes following injection. Similar results were reported by Burrows and Fraps (1942).

Influence of the Central Nervous System on Oviposition. Scott (1940) observed delayed oviposition in birds that were subjected to relatively mild disturbance such as handling of the bird or removing it to unfamiliar quarters. It was noted that the delayed egg was crowded into the uterus together with the succeeding egg. Ovulation occurred as normal. These results are in agreement with those of Warren (1930) who reported that disturbing birds with eggs in their oviduct caused an increase in the interval of time between the laying of eggs.

Weiss and Sturkie (1952) observed premature oviposition from hens when injected with acetylcholine and histamine. Injections of epinephrine resulted in delayed ovipositions ranging from 4 to 24 hours. In view of these results, the workers suggested that the uterus of the hen was innervated by both cholinergic and adrenergic fibres. Similar results were reported by Sykes (1955).

Sykes (1953a,b) studied the nervous reflexes involved in oviposition. He observed that when a loop of thread was placed in the uterus, a large number of eggs were laid prematurely. Ovulation apparently was affected very little. In the latter report, he demonstrated that birds could lay after spinal transection, although the ovipositions were delayed. Ovulation, however, was almost completely inhibited. Huston and Nalbandov (1953) reported that a thread placed in the oviduct of laying hens prevented ovulation without causing regressions of ovary, comb, and oviduct. When progesterone or gonadotrophins were injected into such birds, ovulation occurred, indicating that the endogenous LH secreted was not enough to cause ovulation, hence the thread blocked the ovulatory peaks of LH. These workers concluded that a neural mechanism was involved. Van Tienhoven (1953) reported similar results.

Polin and Sturkie (1955) studied the effect of ephedrine upon a hen that habitually laid soft-shelled eggs. They found that the hen held the egg normally and laid it with a normal shell after the ephedrine treatment.

Grau and Kamei (1949) observed a delay in oviposition in hens which were fed a purified diet. The delay ranged from a few hours to as long as 1 month. In one study involving 50 hens, observed for 21 days, 3 percent of the eggs were delayed and 22 percent of the hens were affected.

Influence of Light on Oviposition. The influence of light over time of oviposition in hens must be considered a proven fact. Results reported by Warren and Scott (1936) indicated that birds rarely laid between 5:00 p.m. and 6:00 a.m. under normal lighting conditions. When the day period was darkened, however, and artificial light provided at night, the birds laid mainly from 5:00 p.m. to 6:00 a.m. after about 4 days. In addition, these workers found that hens would lay and presumably ovulate at any hour of the day or night under continuous artificial light. It was noted that random lay over the day and night did not occur when continuous artificial light was supplemented by natural daylight. From results of this experiment the workers concluded that the onset of darkness was a determining factor in the termination of clutches, thus restricting egg laying to the lighted period. Their work indicated that approximately 60 hours were required for the hen to adjust to changes in lighting conditions.

McNally (1947), using 24 New Hampshire and Barred Rock pullets, reported that continuous illumination permitted the laying of eggs at any time of the day, approaching a normal distribution over the 24-hour day.

McNally also undertook studies to compare the effects of light and darkness with the effect of feeding on oviposition. All birds were kept in the dark from 8:00 a.m. to 4:00 p.m. Half of the birds were then feed from 4:00 p.m. to 11:00 p.m. while the other half were fed from 11:00 p.m. to 8:00 a.m. His results indicated that at the beginning of the experiment a few eggs were laid during the dark period. As the experiment progressed, however, most ovipositions occurred during the period the birds were fed.

Fraps *et al.* (1947), working with caged hens maintained on a 14-hour light-day for several months, did not observe random distribution in time of lay when the hens were subjected to continuous light. The reason for their failure to obtain random lay may possibly be found in their statement that a considerable difference in noise and disturbances existed between day and night.

These investigators also found that continuous light with feed from 8:00 a.m. through 4:00 p.m. caused most eggs to be laid between 6:00 a.m. and 6:00 p.m. When the hens were fed from 8:00 p.m. to 4:00 a.m. under continuous lighting, time of lay for most birds was during the hours of feeding. Body temperatures of 12 hens, taken at 2-hour intervals, was also highest during the feeding periods. These workers concluded that photoperiodicity was not a necessary factor in the regulation of time of lay and ovulation.

Wilson and Abplanalp (1956) observed the egg laying pattern of hens subjected to intermittent and continuous light. They reported that the intermittent group laid more eggs during the hours in which the light was given and the following hour than during the 2 subsequent hours of the 4-hour cycle. Eggs were laid throughout the 24 hours in the continuously lighted group with more eggs being laid in the afternoon and evening than during the morning hours.

Lanson and Sturkie (1958) studied the effect of the length of the light and dark periods on time of oviposition. They found that a minimum dark period of 2.5 hours was sufficient to alter the time of oviposition. Birds receiving 2.5 hours of darkness per 24 hours laid 14 hours from the start of the dark period. In contrast, pullets receiving 10 hours of darkness laid 16 hours from the start of the dark period. These workers also reported that when 10.5 hours of continuous light was supplemented with 7 one-half hour periods of light, the time of oviposition could be altered as much as 6 hours by the placement of these intermittent light periods. They also demonstrated that one-half hour periods of darkness separated by one-half hour periods of light did not have an accumulative effect in controlling the time of oviposition.

Characteristics of Ovulation Cycle

Warren and Scott (1935a) and Phillips and Warren (1937) conducted studies to determine the time interval between oviposition and succeeding ovulation. White Leghorn hens were celiotomized as soon as possible following oviposition to determine the time of ovulation. Warren and Scott found the interval to be 30.7 minutes (range 14 to 75 minutes) while the latter workers found the interval to be 32.2 minutes (range 7 to 14 minutes). A total of 51.8 percent of all ovulations occurred within 30 minutes following the time of lay. The earlier work of Warren and Scott was confirmed by McNally and Byerly (1936). These workers noted that 62.5 percent of the birds had ovulated when sacrificed 30 minutes following oviposition.

The ovulation of the first follicle of a sequence occurs early in the morning (Warren and Scott, 1935b; Fraps and Dury, 1943). The latter workers reported that the first ovulation in a sequence occurred between the hours of 4:00 a.m. and 7:00 a.m. when the birds were subjected to 14 hours of light (6:00 a.m. to 8:00 p.m.). Each succeeding ovulation in a sequence occurred at a later time of the day. Most of them, however, occurred in the forenoon.

Control of Ovulation

Influence of Oviposition on Ovulation. The time of ovulation is apparently not influenced by the time of oviposition. Warren and Scott (1935a) have shown that the time of the next ovulation is not changed when premature expulsion of the egg in the uterus is caused by manual crushing. These results were confirmed by Sturkie and Williams (1945). Weiss and Sturkie (1952) further confirmed the results of these earlier workers when they found that retarded laying, induced by ephedrine injections, had no effect upon the time of the subsequent ovulations.

Influence of Light on Ovulation. Bastian and Zarrow (1955) presented data showing that enforced wakefulness retarded ovulation of the initial follicle of the sequence. These workers pointed out that the delay in ovulation was approximately equal to the period of enforced wakefulness. Since the delay in ovulation could have been the result of either light and/or activity, 2 more experiments were conducted to determine their effects separately. Their data from these experiments indicated that activity alone had a significant retarding effect on ovulation. Light alone did not delay ovulation. These investigators concluded that both light and activity were necessary for the maximum retarding effect on time of ovulation. They further suggested that the inhibition caused by light and activity resulted in restriction of ovulation to the daylight hours.

Influence of Hormones on Release of Ovulation-Inducing Hormone. The fact that the pituitary releases ovulation-inducing hormone (OIH), presumably luteinizing hormone (LH), at a definite interval before actual ovulation is common knowledge. Evidence on the behavior of this hormone was supplied by the hypophysectomy experiments of Rothchild (1946) and Rothchild and Fraps (1948 and 1949). These investigators observed that all hens failed to ovulate when hypophysectomized 8 hours prior to expected time of ovulation. As the interval from hypophysectomy to expected ovulation was decreased from 8 to 2 hours the percentage of ovulating birds increased. From these results it was concluded that the pituitary was not required for ovulation after about 4 to 6 hours (average very close to 5 hours) before the ovulation occurs. From this they calculated that the probable time limits of the release of the OIH hormone occurred between 11:00 p.m. and 12:30 a.m. In addition, Rothchild and Fraps (1949) stated that OIH release could occur only during the hours of darkness.

Fraps *et al.* (1942) demonstrated that the injection of any of several gonadotrophins would cause premature ovulation. These workers reported that the average interval between the injection and resulting (premature) ovulation of the subsequent follicle was 7.5 hours (range 6.5-8.5 hours).

Fraps and Dury (1942) found that the first follicle of a sequence was much more sensitive to ovulation-inducing gonadotrophins than any of the subsequent follicles. They noted that intravenous injection of relatively small quantities of luteinizing preparations resulted in premature ovulation within 8 to 15 hours following injection. Fraps (1946) reported that the first follicle of a sequence was 20 times more sensitive to gonadotrophin injection than were subsequent follicles. A luteinizing preparation from either horse or male chicken pituitary was used.

Bastian and Zarrow (1955) also reported a higher degree of sensitivity for the initial follicle of the sequence; however, the difference was not nearly as great as that reported by Fraps (1946). Their results indicated that at 20 hours prior to expected ovulation the sensitivity of the first follicle was equivalent to 0.5 mg. of LH compared to 4 mg. for the succeeding follicle.

Fraps and Dury (1942) observed little difference in the interval between the gonadotrophin injection and the ovulation of the initial and subsequent follicles of a sequence. They concluded that this interval was approximately 8 hours. Rothchild and Fraps (1949), working with hypophysectomized birds, also noted that the interval between OIH release and ovulation was the same for all ovarian follicles of the sequence. Since this interval was the same these researchers stated that "the successive later hours at which ovulation occurs within a clutch are thus traceable to successively later releases of the ovulating hormone."

It is also known that the injection of progesterone may cause the anterior pituitary to release the OIH hormone. Fraps and Dury (1943) reported that progesterone injected either intravenously or subcutaneously forced ovulation of the initial follicle within 7 to 9 hours. The second follicle was ovulated between 8 and 11 hours following injection.

Recently, Fraps (1955) suggested that the time required for progesterone to induce initial follicle ovulation fell within very narrow limits. His results indicated that hens injected with 1 mg. of progesterone at/or near 4:00 p.m. ovulated within 7 to 8 hours following injection.

Van Tienhoven *et al.* (1954) investigated the action of Dibenamine to block LH release in the hen. They found that this drug blocked both spontaneous and progesterone-induced ovulation. They suggested that OIH, presumably LH, was released 8 to 14 hours before ovulation. This interval is in good accordance with observations by Fraps and Dury (1942 and 1943), Fraps *et al.* (1942), and Fraps (1955).

Hypotheses for the Ovulatory Cycle. Fraps (1954) proposed a hypothesis to explain the asynchronous ovulatory cycle of the domestic hen. The main point of this hypothesis is that the neural mechanism for the control of the release of the ovulation-inducing hormone exhibits diurnal periodicity in its threshold of response to excitation. The excitation for OIH release is thus restricted to a limited portion of the day.

In a 7-day hypothetical ovulation cycle, Fraps showed the relationship between excitation hormone concentrations and diurnally variable threshold requirements in the neural mechanism. The initial ovulation was assumed to occur at 6:00 p.m. Since 8 hours has been reported to elapse between excitation and ovulation, 0 hour and hour 24 of the cycle day correspond to approximately 10:00 p.m.

The first excitation occurs at a high threshold. Following this excitation (or the first OIH release), the second follicle initiates the secretion of the excitation hormone which reaches its threshold value on the second day of the cycle and hence causes the second excitation. The second excitation occurs later in the day than the first excitation, thus defining lag of ovulation. As the excitation hormone concentrations reach threshold values on successive days, excitation of the corresponding follicle takes place. On day 7 of the cycle, the threshold value is not reached, hence excitation does not occur, resulting in lapse or interval between sequences. As the period of lapse progresses, OIH concentration builds up. Usually with the onset of the following day, or at 0 hour, the threshold is reached and excitation occurs which results in the initial ovulation of the next sequence. In this particular cycle the excitation for OIH release was restricted between the hours of 10:00 p.m. and 6:00 a.m.

From the assumption that the ovulation-inducing hormone functions approximately 8 hours every night, Bastian and Zarrow (1955) have proposed a new hypothesis to account for the peculiar ovulatory cycle in the hen. The main point of this hypothesis is that two separate and independent cycles interact in such a way as to result in the peculiar ovulatory cycle of the hen. These two cycles are the 24-hour day-night rhythm and the rhythmic maturation of follicles.

EXPERIMENT TECHNIQUES

For the purpose of studying the effect of total length of day (both light and dark periods) on the time of oviposition a "light-proof" basement room was constructed with dimensions of 20 x 30 feet. The basement walls were of concrete and windowless. The experimental quarters were 250 feet away from other buildings. In this way irregular noises and disturbances were reduced to a minimum.

Forty-eight individual laying cages were located within the basement room. The dimensions of each cage were 10″ x 18″ x 15″ and each cage was located on a single level. Two units, each consisting of 24 cages suspended back-to-back were located parallel to each other within the basement. The feed trough was located at the front of the cages and birds had access to feed at all times. Water was given continuously in a V-type waterer.

Incandescent light was the source of illumination. Eight 40-watt bulbs were used. The lamps were mounted 24 inches above the center of each unit with a uniform spacing of 24 inches. The intensity of light varied from a maximum of 8 foot-candles at the water trough to a minimum of 4 foot-candles at the feed trough. Light intensity readings were taken with a Weston light meter. The desired variation in the length of the lighted and non-lighted periods was obtained by means of a "double" on and off cycle-timer. The timer, which was located in the artificial light circuit, provided a flexibility of 0 to 44 hours in either or both the lighted or non-lighted periods.

Controlled ventilation was provided by an exhaust fan and 2 air intakes, each equipped with a suitable light-trap. A suitable light-trap was provided at the entrance of the building; however, the care of the birds was performed only during the lighted period.

A record of time of oviposition was obtained by using an automatic recorder similar to the one used by Bastian and Zarrow (1954). In brief, it consisted of each cage being wired to an electrical circuit that was in turn routed through an electromagnet stylus that recorded on a smoked kymograph drum. Following oviposition the egg rolled to the front of the cage, closing the electrical circuit to that cage. Under the control of an electric clock, the recorder completed 1 revolution of the kymograph drum every 15 minutes. Once each day the recording was removed from the drum, coated with shellac, and analyzed. At this time the contact switches were reset and the recording machine was prepared to function during the following day. A typical record of the time of oviposition is shown in Figure 1. Each line represents a 15-minute interval. The first line on the left of the figure represents 4:30 p.m. on March 6, 1957, while the line on the extreme right represents 3:30 p.m. on March 7, 1957. The indentations in the tracings indicate the time of oviposition. The first egg was laid at 6:00 p.m. by Hen No. 20, the second at 10:30 p.m. by Hen. No. 11, the third at 11:15 p.m. by Hen No. 9, etc. Hens No. 1, 5, 13, 14, 17, and 22 failed to lay during the period shown in the tracing.

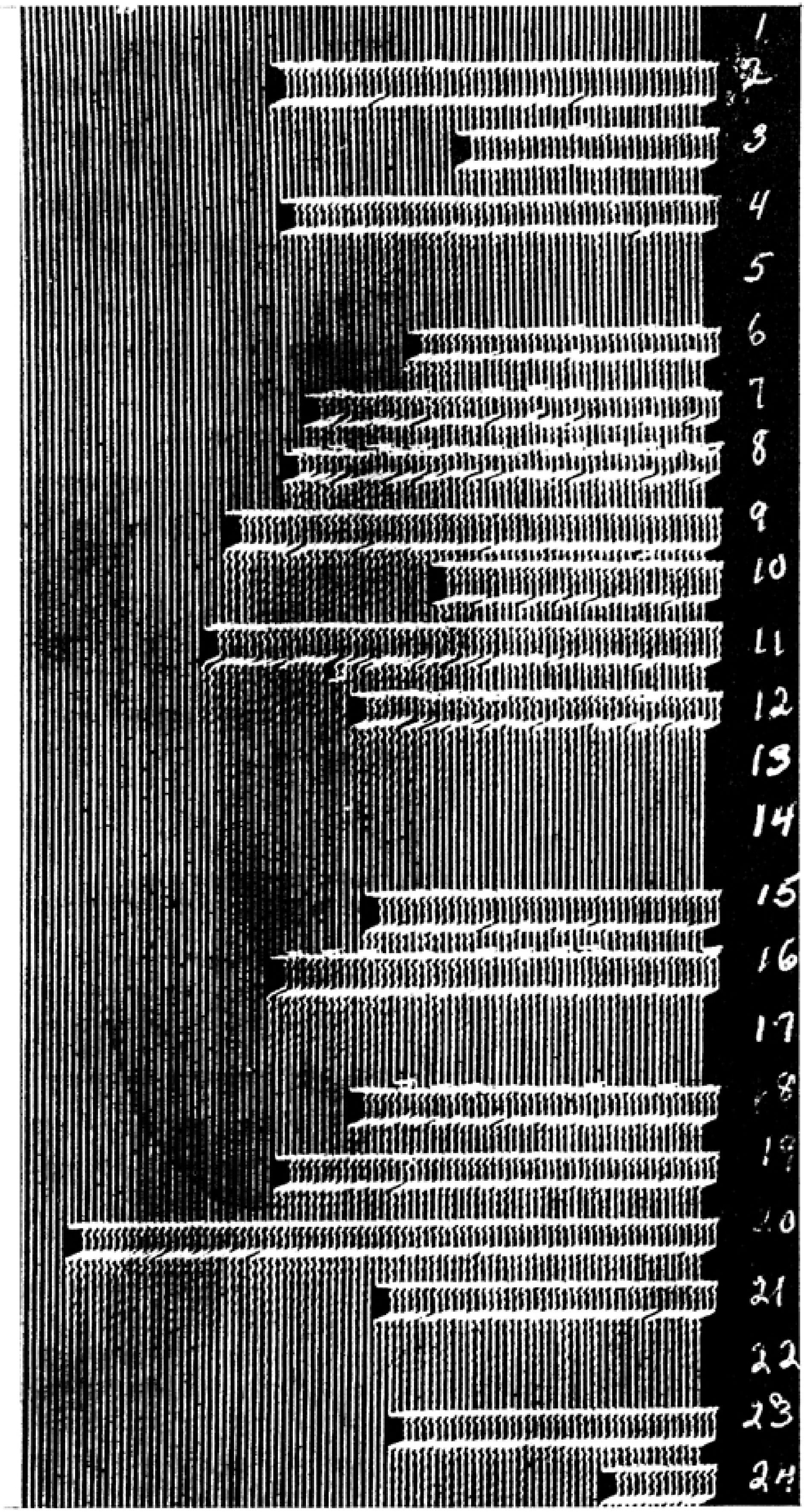

Figure 1. A typical record of the time of oviposition in a group of 24 hens.

The birds used in the experiment were 48 Single Comb White Leghorns, hatched January 21, 1956. The breeding of the pullets was considered good for egg production and consisted of the University of Missouri strain of purebred White Leghorns.

The pullets were brooded in a floor pen and raised in a confinement shelter. They received the same management and growing ration that was provided for all regular flock replacement young stock. At 6 months of age these pullets were transferred from the growing shelter to the laying cages located in the windowless basement. The pullets received natural light throughout the growing period.

Table 1 outlines experimental procedures followed to test various day-lengths. In all of the day-lengths that were studied the total amount of light and darkness was given in equal amounts. Each trial was scheduled to last for 14 experimental days. Occasional electrical or mechanical failures occurred, therefore some of the trials were extended for a longer period of time.

TABLE 1-DURATION OF THE EXPERIMENTAL PERIODS CONSISTING OF DIFFERENT DAY-LENGTHS

Date	Day-Length (Hours)	Number of Days: Experimental	Number of Days: 24-Hour (calculated)
July 26-Oct. 1 ('56)	24	67.00	67.00
Oct. 1-Oct. 16	23	15.50	14.85
Oct. 16-Nov. 7	22	24.50	22.46
Nov. 7-Nov. 28	21	24.25	21.22
Nov. 28-Dec. 17	24	18.75	18.75
Dec. 17-Jan. 1	25	14.50	15.10
Jan. 1-Jan. 16 ('57)	26	13.50	14.63
Jan. 16-Jan. 31	27	14.00	15.75
Jan. 31-Feb. 14	28	12.00	14.00
Feb. 14-Mar. 3	29	14.00	16.92
Mar. 3-Mar. 19	30	13.00	16.25
Mar. 19-Apr. 4	32	12.00	16.00
Apr. 4-Apr. 17	34	9.00	12.75
Apr. 17-May 8	36	14.00	21.00
May 8-May 29	38	13.50	21.38
May 29-June 25	40	16.00	26.67
June 25-July 26	42	17.50	30.63

Birds were brought into the basement to adapt to the new environment 54 days ahead of the scheduled experiment. During this time several birds suffered from "cage fatigue." The affected birds were removed and replaced with birds out of the same hatch. One bird, No. 27, died during the latter part of the experiment and was not replaced.

Experimental trials testing the effects of varying the length of light and dark cycles (day) were begun September 16, 1956. After the initial 24-hour day test period, the birds were subjected to decreasing day-lengths of 23, 22, and 21 hours. This was accomplished by taking one-half hour of light and one-half hour of darkness off the previous day-length. During the course of the 21-hour treatment period, it became apparent that egg production was severely affected. Decreasing of the day-length was halted because of the high incidence of birds pausing.

Following the 21-hour day, one and one-half hours of both light and dark were added to the respective period to give a total of 12 hours light and 12 hours darkness. After a period of 2 weeks at this particular day-length, days greater than 24 hours were tested for their effect on the time of oviposition. Beginning with the 25-hour day and continuing through the 30-hour day, one-half hour of light and one-half hour of darkness were added to the previous day-length to provide the increased day-length. After the completion of the 30-hour day, it was decided that faster progress should be made in testing the longer day-lengths. This was accomplished by adding 1 hour of both light and darkness to the respective period of the previous day-length. This plan of increasing the day-length was followed throughout the remainder of the experiment.

Daily temperature readings were taken at the time that the kymograph chart was changed. The average, maximum, and minimum temperatures for each day-length are recorded in Table 2. A complete all-mash laying ration containing 16 percent protein was used throughout the experiment (Table 3).

TABLE 2-THE MEAN, MAXIMUM, AND MINIMUM TEMPERATURE FOR EACH DAY-LENGTH

Day-Length (Hours)	Mean Temperature Degrees F	Maximum Temperature Degrees F	Minimum Temperature Degrees F
24	74.6	80	70
23	76.3	76	60
22	65.4	77	55
21	47.1	65	32
24	41.0	60	25
25	39.0	48	35
26	35.0	45	25
27	41.2	47	36
28	45.5	56	39
29	45.3	56	38
30	47.3	60	40
32	48.2	56	40
34	48.5	59	42
36	64.8	71	54
38	64.9	78	60
40	73.9	80	67
42	78.7	86	71

Effect of Day-Length on Hen-Day Egg Production. Table 4 summarizes the percent hen-day egg production obtained throughout the experimental trials. Total number of eggs and percent of 5-day pause for each day-length are also given. Total number of hen-days on both experimental and 24-hour basis are recorded. Hen-day egg production was calculated on the basis of both the experimental and 24-hour day which were defined as follows:

The experimental day egg production = daily egg number ÷ the number of females alive on that particular day.

The experimental day egg production computed on a 24-hour day basis was arrived at by dividing the number of hours in the experimental day by 24. The number of 24-hour periods in the experimental day was divided into the daily number of eggs laid. This product was then divided by the number of females alive on that particular day. The average annual egg production of the 36 birds that were in the cages throughout the entire experiment was 212 eggs.

TABLE 3-LAYING RATION #16

Ingredient	Pounds
Ground Yellow Corn	1090
Wheat Shorts	250
Soybean Oil Meal	150
Meat and Bone Scraps	150
Dehydrated Alfalfa Meal	50
Ground Oats	200
Limestone	60
Bone Meal	20
Fine Salt	10
	1980
New Values	
Ground Corn	10.5
Dry A and D Mix (1500A, 300D)	5.0
Vitamin Mix 58-C	2.0
Manganese Sulfate	0.5
Vitamin B_{12} (6.0 mg. lb.)	2.0
	20.0

Following a decline during the second 2-week period, egg production increased from 58.1 to 75.4 percent on the 24-hour day. As day-length was experimentally decreased, both experimental and 24-hour day production decreased. The experimental day and 24-hour day production on the 21-hour day was 42.6 and 48.7 percent, respectively. When the day-length was increased directly from 21 hours to 24 hours, production continued to decrease, reaching a low of 42.3 percent. When day-length was increased from 24 hours through 29 hours, both experimental and 24-hour day production showed a steady upward trend, peaking at 78.4 and 64.9 percent, respectively, on the 29-hour day. During the 30-hour day egg production declined. There was a tendency for production to level off during the 32-hour day, although a slight decline was noted. A possible explanation for the decrease in egg production during the experimental periods may be attributed to the fact that an infestation of Northern Fowl Mites was noticed March 25. Treatment consisted of dusting the birds with sulfur and spraying the droppings with lindane.

During the 34-hour day test period there was a slight increase in production on both the 34-hour and 24-hour day basis. Egg production continued to increase during the 36-hour period; however, production on a 24-hour basis decreased. A very sharp increase in both 24-hour and experimental day production was observed during the 38-hour experimental day period. Increasing the day-length to a 40-hour day resulted in an increased experimental day production but decreased 24-hour production. Both experimental and 24-hour day production decreased during the 42-hour day test period.

TABLE 4-THE PERCENT OF HEN-DAY EGG PRODUCTION AND BIRDS PAUSING FOR FIVE OR MORE DAYS FOR PERIODS OF VARYING DAY-LENGTHS

Length of Day (Hours)	Total Hen Days		Percent Hen-Day Production		Percent of Birds Pausing
	Experimental Day	24-Hour Day (Calculated)	Experimental Day	24-Hour Day (Calculated)	
24	623.00	623.00	58.1	58.1	27.1
24	613.00	613.00	56.9	56.9	29.2
24	624.00	624.00	60.9	60.9	25.0
24	624.00	624.00	67.0	67.0	16.7
24	720.00	720.00	75.4	75.4	4.2
23	744.00	712.80	68.5	71.5	8.3
22	1175.00	1077.16	53.5	58.4	20.8
21	1153.75	1009.59	42.6	48.7	35.4
24	897.25	897.25	42.3	42.3	45.8
25	696.00	724.80	53.4	51.3	35.4
26	648.00	702.24	58.6	54.1	27.1
27	672.00	756.00	70.2	62.4	22.9
28	576.00	672.00	75.7	64.9	14.6
29	672.00	812.16	78.4	64.9	18.8
30	620.00	775.00	74.4	59.5	22.9
32	564.00	752.00	71.6	53.7	21.3
34	423.00	599.25	78.0	55.1	17.2
36	658.00	987.00	79.0	52.7	23.4
38	634.50	1004.86	94.6	59.7	14.9
40	752.00	1253.49	98.9	59.4	10.6
42	822.50	1439.61	95.6	54.6	12.8

The apparent high egg production on the experimental day during the 36 through the 42-hour day was largely caused by the laying of 2 eggs per experimental day by many hens, in addition to consistent daily laying by all hens. Because of the many hours provided in these long days, production on a 24-hour basis was expected to decline. Figure 2 indicates that days shorter than 24 hours increased the percentage of birds pausing for 5 or more days. It is interesting to note that on the 24-hour day, following the 21-hour day, almost 50 percent of the birds were pausing. As day-length increased from a 24 to a 29-hour day, the percentage of birds pausing decreased from approximately 46 to 15 percent. During the remainder of the experiment the percentage of birds pausing fluctuated between 11 and 23 percent.

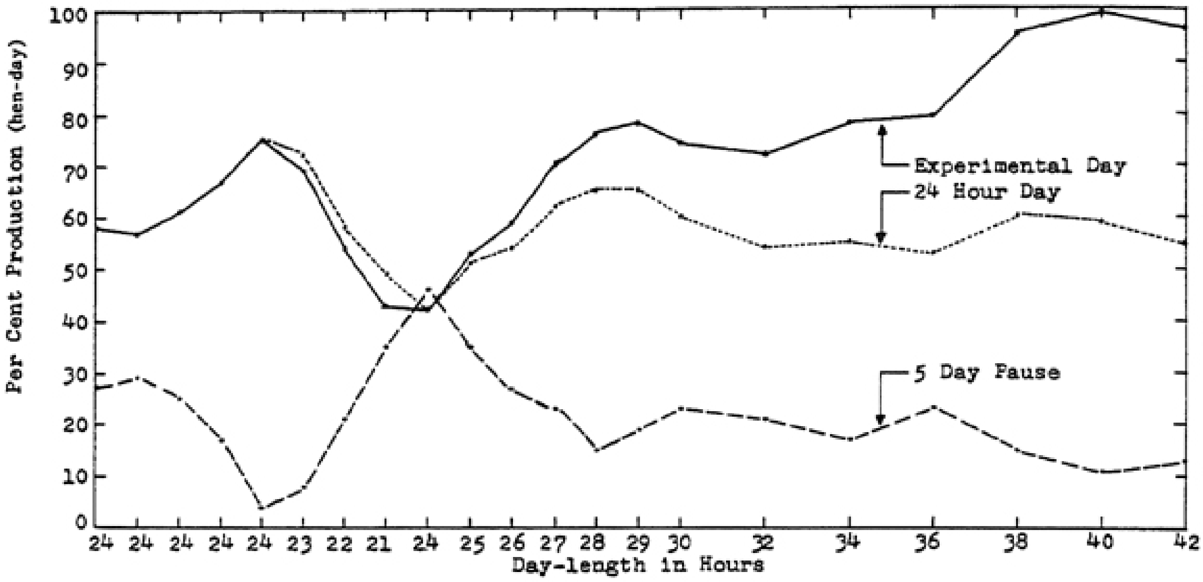

Figure 2. The effect of day-length on egg production.

Response of Clutch-Length to Change of Day-Length. Figures 3 and 4 graph the effect of varying day-length on the length of clutch. Clutch-length was calculated on an experimental day basis and may be defined as the number of eggs laid on successive treatment-days, separated from other clutches by one or more days during which no egg was laid. Figure 3 consists of birds just coming into production and those having relatively short clutches during the 24-hour day test period. Birds tending to have long clutches during the 24-hour day test period are plotted in Figure 4. Although the actual clutch-length cannot be determined readily from these graphs, a short black line denotes a short clutch. As clutches increase in length the black line also increases in length for each hen shown. The white portion between the black bars indicates a skip between ovipositions. As the length of interval between clutches increases, the white portion of each bar of the graph does likewise. The extra black plots above the black bars indicate that 2 eggs per experimental day were laid. The first 24-hour period shown in each figure was the pre-experimental adjustment or base period.

Obviously, clutch-length was progressively reduced when days shorter than 24 hours occurred. The majority of clutches on the 21 and 22-hour day consisted of 1 and 2 eggs, respectively. Both long and short-clutch birds were affected; however, the short-clutch birds were affected more. It is evident that the decreasing day-length also seriously affected the hens during the 24, 25, and 26-hour experimental day periods. Therefore, the rate of egg production and the increase in length of the clutches during these periods were not as great as was anticipated.

Days longer than 24 hours in length produced an increased clutch-length for all birds. Clutches varying from 40 to 50 eggs were common. Several clutches with at least 80 eggs occurred. The maximum clutch was 94 eggs, laid by Hen No. 25 from the 30 through the 42-hour day. During the 36 through the 42-hour day 2 eggs per experimental day occurred for a majority of the hens.

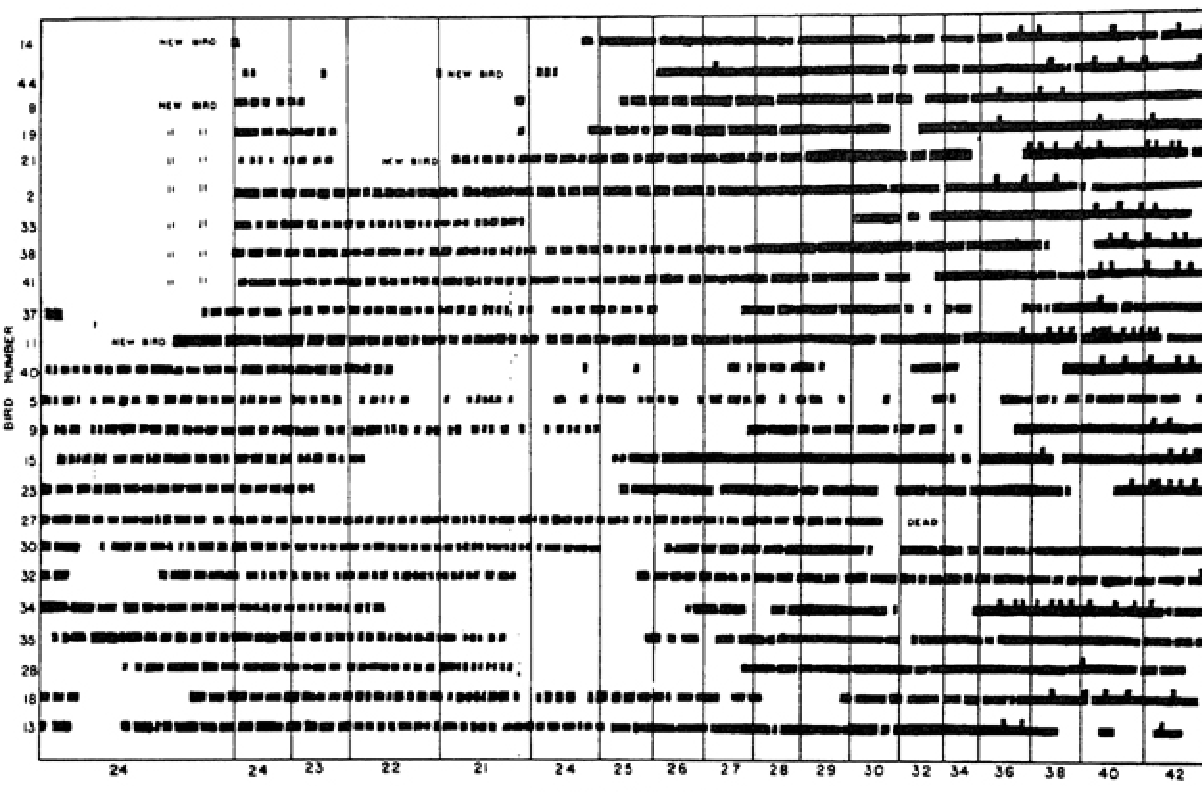

Figure 3. The effect of varying day-length on the length of clutch.

Time of Ovipositions and the Intervals Between Ovipositions in 24-Hour Day Sequences. The mean times of oviposition of eggs laid in sequences (clutches) of differing lengths are reported in Table 5. These data were computed from records of hens subjected to a 24-hour day (lights were on from 6:00 a.m. to 6:00 p.m. daily). The numbers of sequences on which the figures are based are given in the right hand column of the table. Only complete oviposition records were used; therefore, the number of a given sequence does not reflect the total number of sequences that were laid. It can be generally stated, however, that as the sequence length increases the incidence of such sequences decreases.

The military system of showing time of day was used to indicate the time of ovipositions. The "C_1" oviposition refers to the initial oviposition of a sequence. Successive ovipositions within the sequence are numbered with the respective subscript number in which they occur. The terminal oviposition is designated as "C_t".

Intervals between successive ovipositions in the sequences (Table 6) are calculated directly from time of ovipositions (Table 5). Mean intervals in hours for sequences of differing lengths are also reported. As the data indicates, both the individual intervals in the sequences and the mean lengths of intervals steadily decrease as the length of the sequence increases. It is evident that the interval between the last 2 eggs in a sequence is greater than any other interval within the sequence. These data are in agreement with those reported by Atwood (1929), Hays (1936), Heywang (1938), Berg (1945), Fraps (1955), and Van Albada (1958).

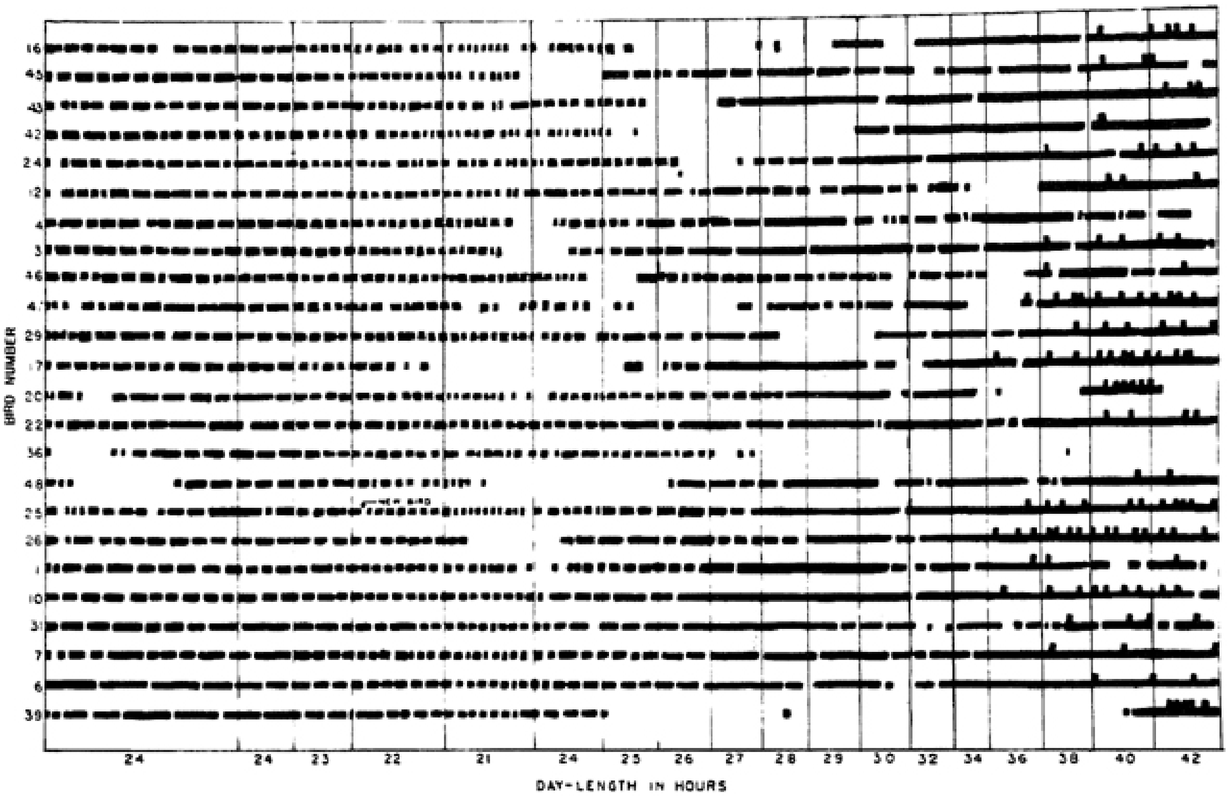

Figure 4. The effect of varying day-length on the length of clutch.

Lag at successive intervals between ovipositions, total lag, and mean lag for the same sequences used in Tables 5 and 6 are reported in Table 7. Individual lag at successive intervals between ovipositions was calculated by subtracting 24 hours from the appropriate interval as shown in Table 6. Total lag was the accumulative lag within the sequence. Mean lag was obtained by subtracting 24 hours from the mean interval in Table 6. These data indicate that as sequence length increases, mean lag and lag at successive intervals decrease.

The mean time interval and cumulative lag between the successive ovipositions for varying sequences are shown in Figure 5. The length of the sequence is indicated by the numerals below each set of bars. The black portion of each bar represents individual interval lag while the black portion plus the superimposed white portion represents the cumulative lag. A 2-egg sequence is represented by 1 bar, a 3-egg sequence by 2 bars, etc. A lag of 0 hours means an interval of 24 hours between eggs. When lag fell below 0 hours, it was indicated by a plot below the base line.

TABLE 5-THE TIME OF DAY OF SUCCESSIVE OVIPOSITIONS IN SEQUENCES OF DIFFERENT LENGTH PRODUCED DURING THE 24-HOUR DAY PERIOD

Sequence Length (No. of Eggs)	Ovipositions within Sequence													No. of Sequences
	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	
2	8:56	13:17												54
3	8:17	10:42	14:27											72
4	7:44	9:28	11:23	14:46										29
5	7:20	9:03	10:28	12:10	15:25									9
6	7:37	9:15	10:11	10:52	12;23	15:28								4
7	7:08	9:23	10:30	11:45	11:53	12:53	16:39							2
8	7:00	8:30	9:00	9:00	9:30	10:15	11:00	14:00						1
10	8:00	8:30	9:00	9:45	10:00	10:30	11:00	11:45	13:45	16:45				1
13	7:15	9:00	9:45	10:15	10:45	10:45	10:30	11:00	11:15	12:00	11:45	12:30	15:30	1

TABLE 6-THE INTERVAL BETWEEN SUCCESSIVE OVIPOSITIONS IN SEQUENCES OF DIFFERENT LENGTH PRODUCED DURING THE 24-HOUR DAY

Sequence Length (No. of Eggs)	Ovipositions within Sequence												Mean Interval (Hours)
	C_1- C_2	C_2- C_3	C_3- C_4	C_4- C_5	C_5- C_6	C_6- C_7	C_7- C_8	C_8- C_9	C_9- C_{10}	C_{10}- C_{11}	C_{11}- C_{12}	C_{12}- C_{13}	
2	28.21												28.21
3	26.25	27.45											27.05
4	25.84	25.95	27.23										26.05
5	25.72	25.42	25.69	27.22									26.01
6	25.78	24.96	24.41	25.71	27.05								25.58
7	26.25	25.13	25.25	24.13	25.00	27.75							25.58
8	25.50	24.50	24.00	24.50	24.75	24.75	27.00						25.00
10	24.50	24.50	24.75	24.25	24.50	24.50	24.75	26.00	27.00				24.97
13	25.75	24.75	24.50	24.50	24.00	23.75	24.50	24.25	24.75	23.75	24.75	27.00	24.69

TABLE 7-LAG IN OVIPOSITION SEQUENCES OF DIFFERENT LENGTH PRODUCED DURING THE 24-HOUR-DAY PERIOD

Sequence Length No. Eggs	Lag at Successive Intervals in Hours												Total Lag (Hours)	Mean Lag (Hours)
	L_2	L_3	L_4	L_5	L_6	L_7	L_8	L_9	L_{10}	L_{11}	L_{12}	L_{13}		
2	4.21												4.21	4.21
3	2.25	3.85											6.10	3.05
4	1.84	1.95	3.23										7.02	2.34
5	1.72	1.42	1.69	3.22									8.05	2.01
6	1.78	0.96	0.41	1.71	3.05								7.91	1.58
7	2.25	1.13	1.25	0.13	1.00	3.75							9.51	1.58
8	1.50	0.50	0.00	0.50	0.75	0.75	3.00						7.00	1.00
10	0.50	0.50	0.75	0.25	0.50	0.50	0.75	2.00	3.00				8.75	0.97
13	1.75	0.75	0.50	0.50	0.00	-0.25	0.50	0.25	0.75	-0.25	0.75	3.00	8.25	0.69

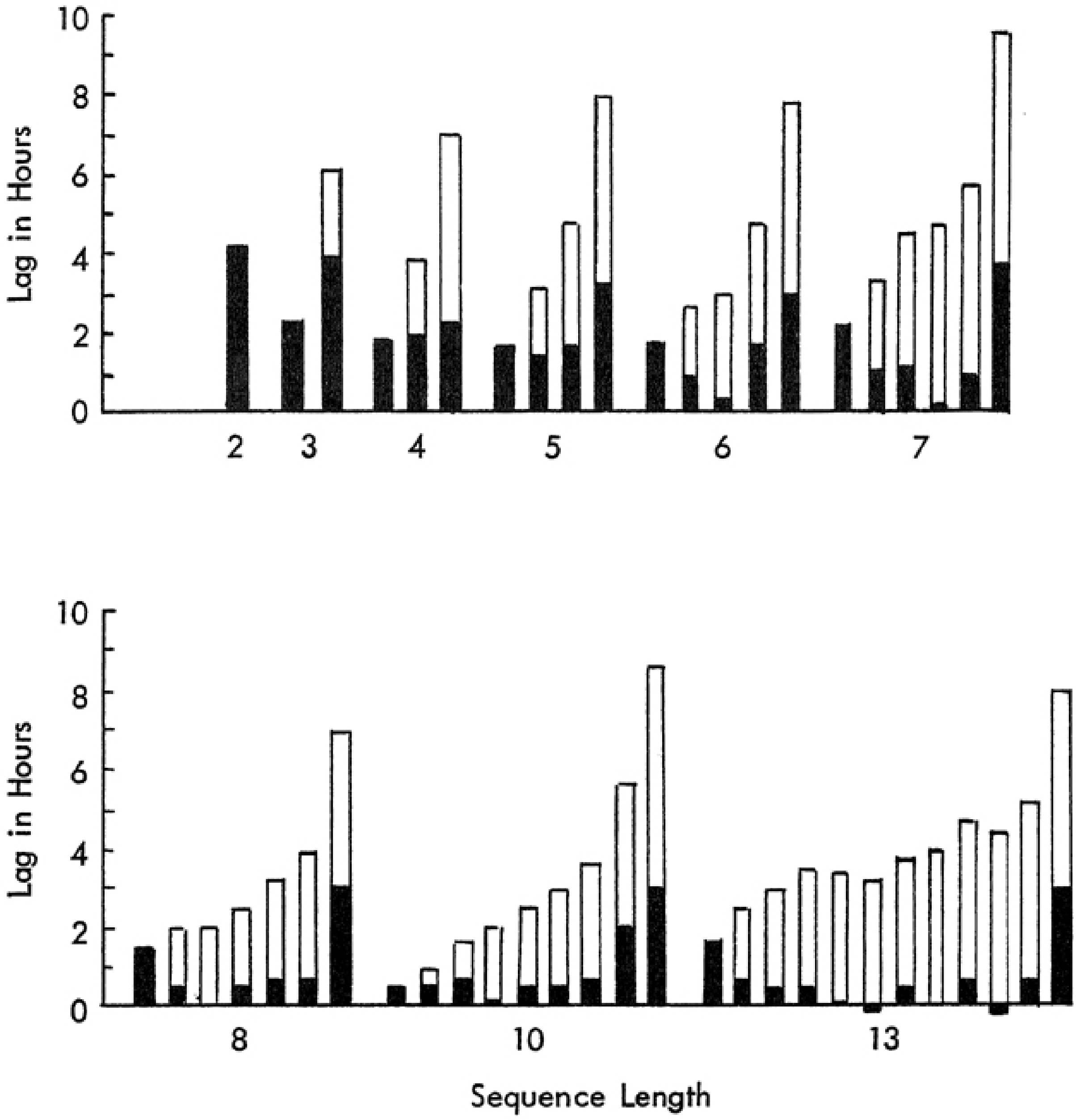

Figure 5. The lag in hours between the laying of successive eggs in a sequence.

This graph indicates that lag between the last egg and the preceding one was always the greatest, an observation that was noted earlier. Cumulative lag varied from 6.10 hours for the 3-egg sequence to 9.51 hours for the 7-egg sequence. These values are somewhat higher than Heywang's (1938) data indicate. However, Heywang used a large number of birds in contrast to the relatively small number used in this experiment. Probably the lighting conditions also differed some between the experiments.

Effect of Day-Length on Time of Oviposition. Figures 6 through 10 summarize the frequency distribution for time of ovipositions of various day-lengths. The number of eggs laid each 15-minute period within each hour is indicated by the height of the vertical columns. The distribution of eggs produced during the periods when the day-lengths were progressively decreased is graphed in Figure 6. The time of oviposition occurred at a later hour with each decrease in day-length. Two peaks in the time of ovipositions occurred on the 24, 23, and 22-

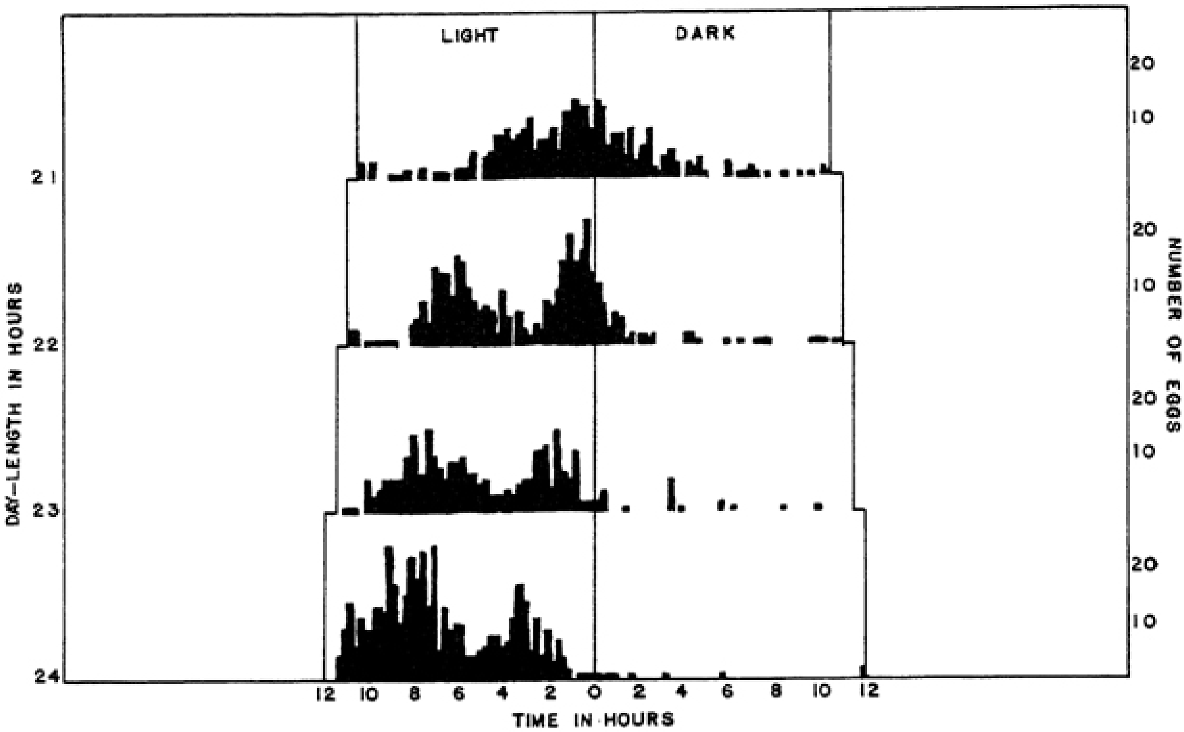

Figure 6. Frequency distribution of ovipositions in 15-minute intervals on the 21, 22, 23 and 24-hour day.

hour day. The first peak was generally around midday while the second peak occurred in mid-afternoon. During the 21-hour day these peaks merged into one so that a more-or-less normal distribution curve resulted (most of the hens were producing 1-egg clutches). Very few eggs were laid in the dark period during the 24-hour day. Each shorter day-length resulted in more of the eggs being produced in the dark portion of the day.

The effects of the 24 (following the 21-hour day period), 25, 26, and 27-hour days on distribution of ovipositions are shown in Figure 7. Ovipositions on the 25, 26, and 27-hour day-lengths advanced to an earlier hour of the day with each increase in day-length. The 24-hour day-length appearing in this graph again exhibited 2 peaks in time of oviposition. Only 1 peak occurred on the 25, 26, and 27-hour days. Most eggs were laid during the light period on the 24 through the 26-hour day. Oviposition occurred immediately after the onset of light on the 26-hour day and was closely grouped for all hens. On the 27-hour day most eggs were laid just prior to the beginning of the light period. Here again ovipositions were closely grouped for all birds.

Illustrations of the distribution of time of ovipositions during the 28 through the 30-hour days appear in Figure 8. The time of ovipositions continued to advance to an earlier time of the day as each of these day-lengths were tested. Few eggs were produced in the lighted period.

Observations of the distribution of time of ovipositions occurring during the 32, 34, and 36-hour days are presented in Figure 9. Eggs produced on the 32-hour day were laid over the entire dark period, oviposition starting approxi-

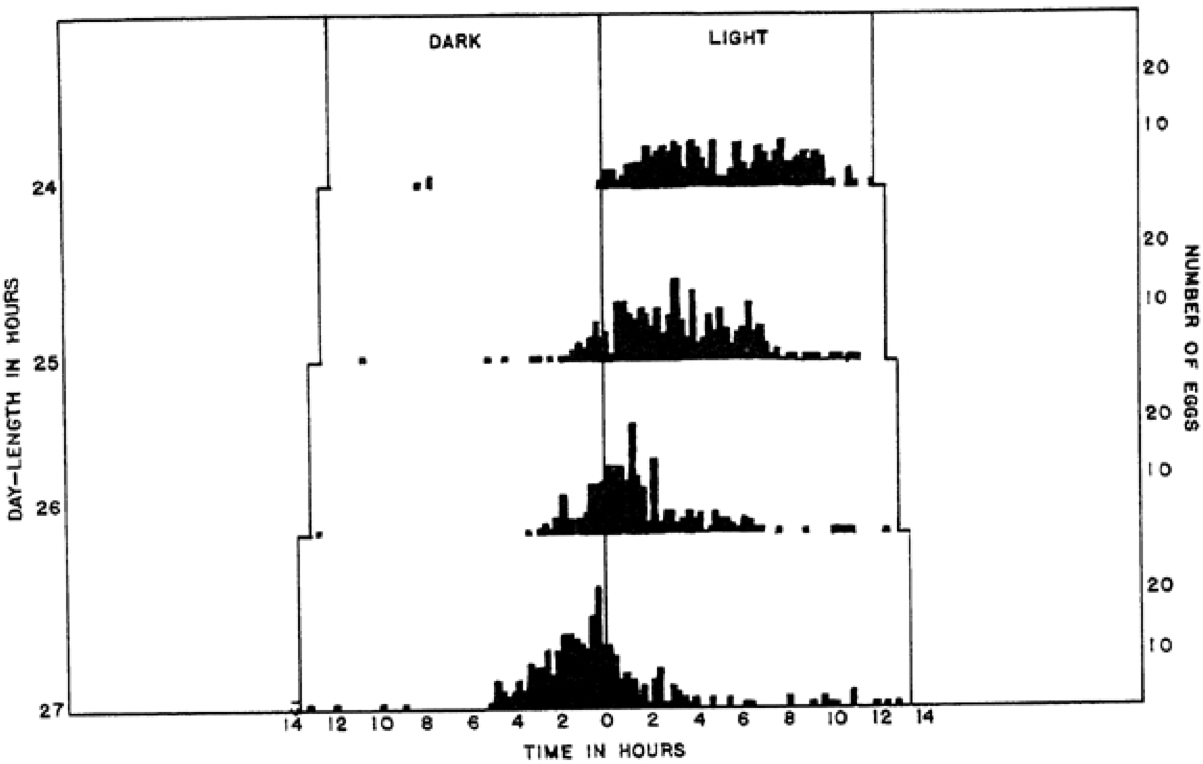

Figure 7. Frequency distribution of ovipositions in 15-minute intervals on the 24, 25, 26 and 27-hour day.

mately 2 hours before the onset of darkness. As day-length was advanced to 34 hours most of the ovipositions occurred in the lighted period, starting approximately 6 hours before the onset of darkness. Due to the short time that this period was tested (9 experimental days) the number of observations was reduced. During the 36-hour day-length most eggs were laid in the lighted period. However, several eggs were laid during the dark period, an effect resulting from the lay of 2 eggs per day.

It is very significant that throughout the experimental day-lengths of 25 to 34 hours, inclusive, ovipositions were delayed and all hens laid only a maximum of 1 egg per experimental day. The interval between eggs produced on these day-lengths coincided with the total number of hours provided in the experimental day in which the eggs were produced. The rhythm of the light and dark periods was a regulating factor in the time of oviposition.

The effects of the 38, 40, and 42-hour day-lengths on time of oviposition are presented in Figure 10. Peaking conditions were evident in all 3 day-lengths; however, many hens occasionally produced 2 eggs per experimental day. As a result, scatter occurred over the entire day and night period. The time of ovipositions was advanced to an earlier hour of the day with each increasing day-length.

Table 8 gives a numerical summary of the hourly distribution of ovipositions. The table consists of one full light and dark period and one partial light and dark period. The complete light and dark periods located on the left side of the table contain the summary. The partial light and dark periods appearing in the right-hand portion of the table are merely a replication of the light and dark

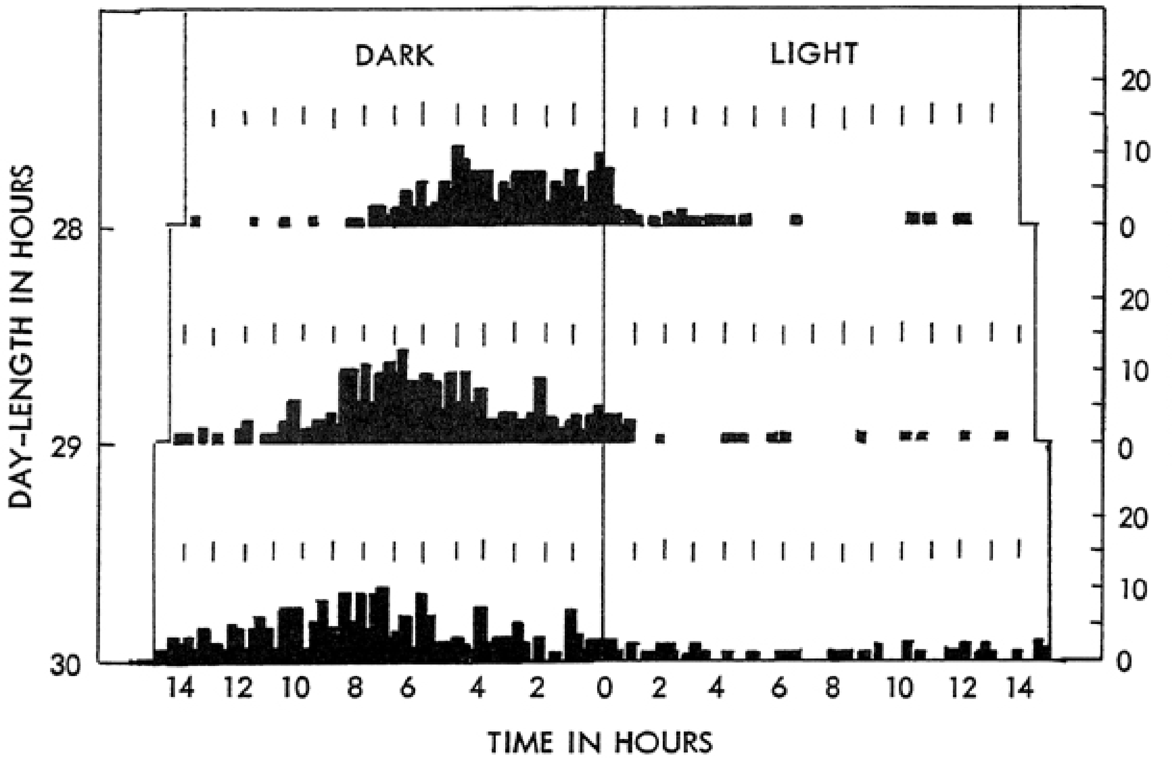

Figure 8. Frequency distribution of ovipositions in 15-minute intervals on the 28, 29 and 30-hour day.

periods on the left. The partial periods were placed in the table to illustrate the trend in time of lay throughout the various day-lengths.

As is evident from this table and as noted earlier, ovipositions occurred later in the day on days shorter than 24 hours and earlier in the day on days longer than 24 hours.

The percentages of eggs laid in the light and dark periods of each day-length are graphed in Figure 11. This graph indicates that over 98 percent of all eggs are laid during the lighted portion of the normal 24-hour day. As day-length was decreased, there was a steady decline in the percentage of eggs laid in the lighted portion of the day. When the 21-hour day was reached, 62 percent of the eggs were laid during the lighted period.

It was found that increasing the day-length also resulted in an increase in the number of the eggs laid in the dark period peaking at 91.2 percent on the 29-hour day-length (Table 9).

To further illustrate the effect of short day-length on time of oviposition, the daily lay of hen No. 2 was plotted in 15-minute intervals (Figure 12). Distribution of lay occurred throughout the lighted period of the 24-hour day-length. The first egg of the sequence was usually laid about one hour after the onset of light. This egg was followed with the lay of the second and third egg of the sequence in the morning hours. The terminal egg of the 4-egg sequence was laid in the mid-afternoon, approximately 3 hours before the onset of darkness.

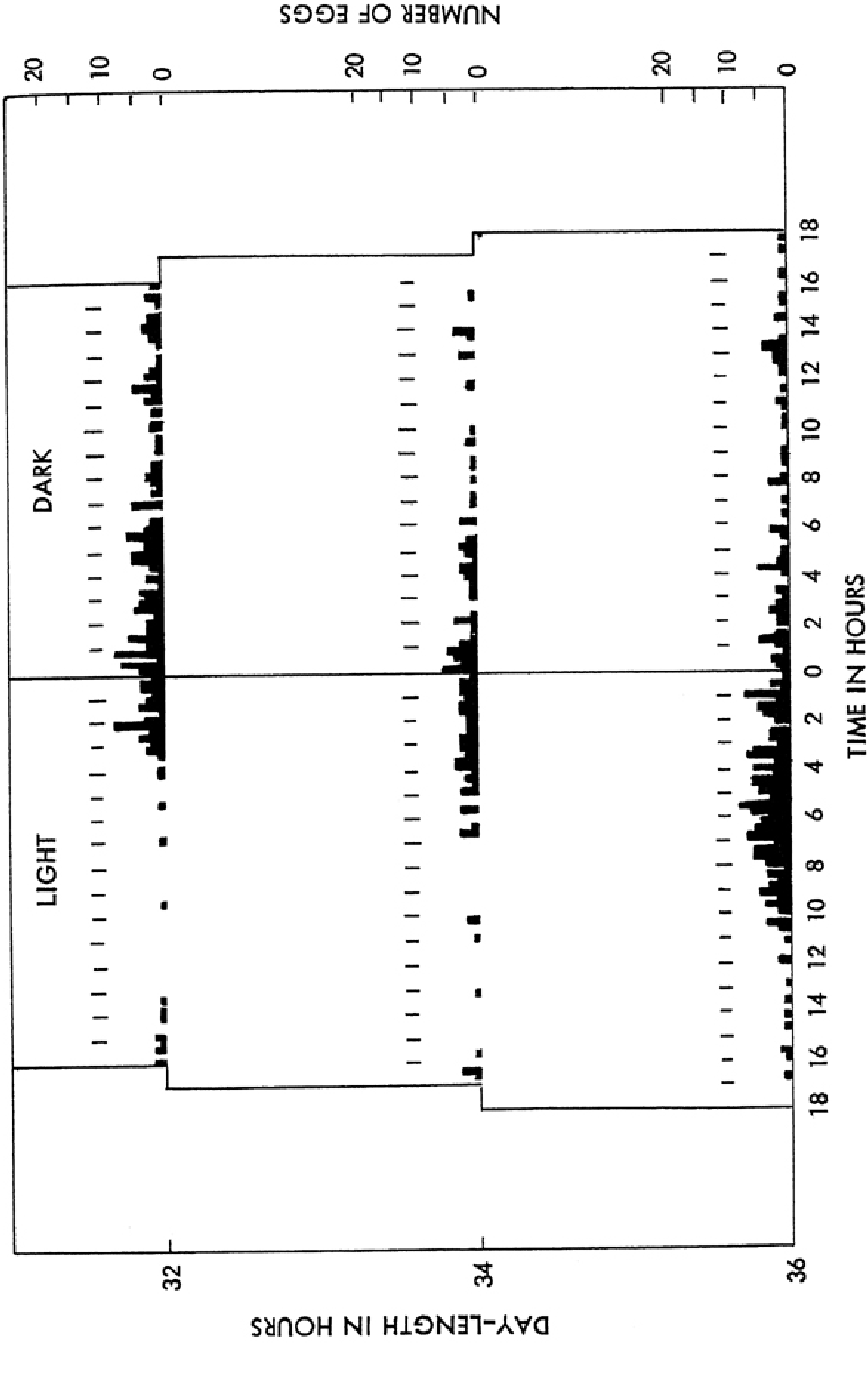

Figure 9. Frequency distribution of ovipositions in 15-minute intervals on the 32, 34 and 36-hour day.

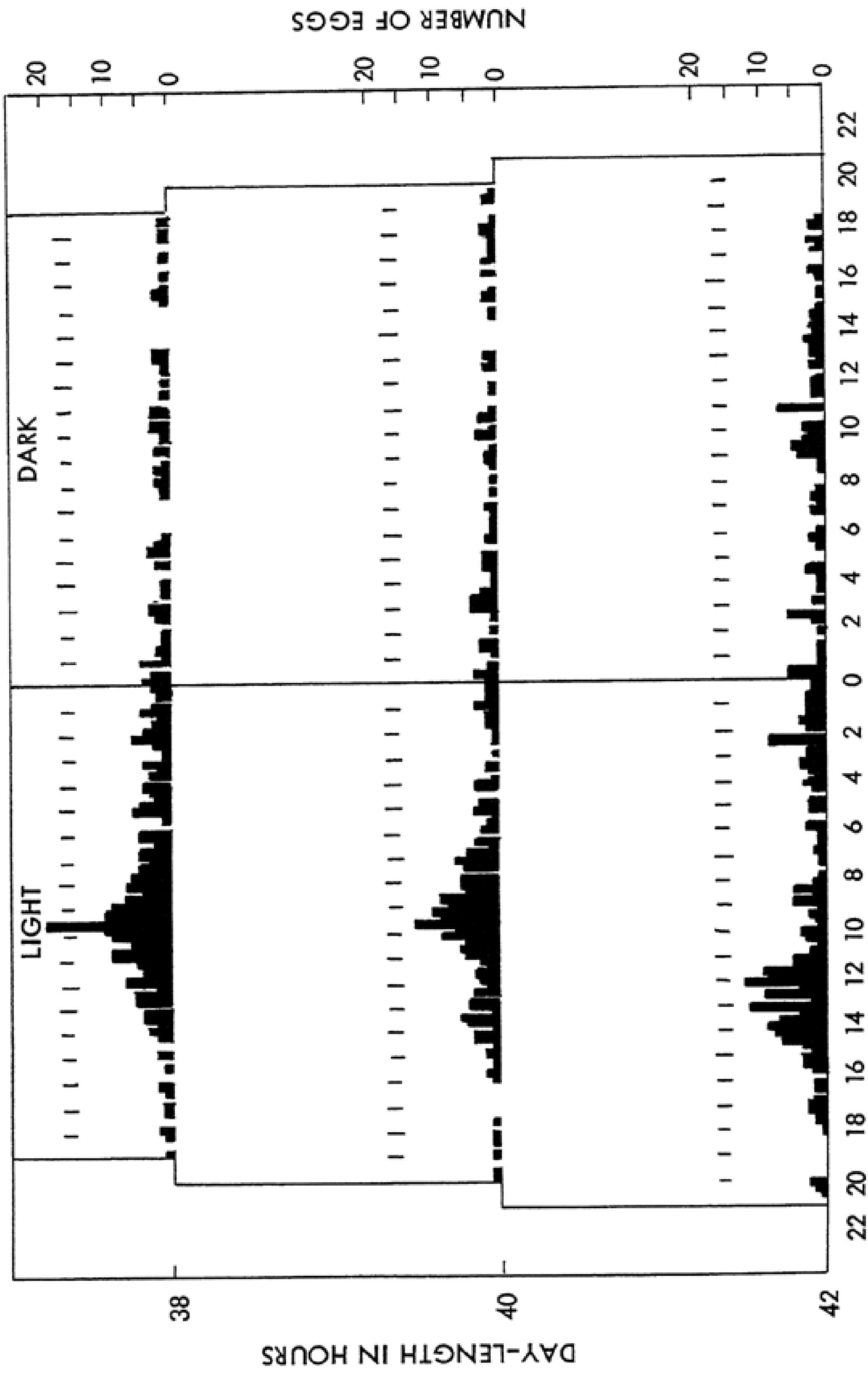

Figure 10. Frequency distribution of ovipositions in 15-minute intervals on the 38, 40 and 42-hour day.

TABLE 8-DISTRIBUTION OF OVIPOSITIONS OCCURRING AT INTERVALS OF ONE HOUR OBSERVED FOR EACH EXPERIMENTAL DAY-LENGTH

Light Dark Light Dark

Day-Length		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41
21	6	3	4	3	6	14	32	33	26	51	49	26	27	12	8	5	4	4	2	1	5	6	3	4	3	6	14	32	33	26	51	49	26	27	12	8	5	4	4	2	1	5
22	5	4	5	31	51	39	25	14	17	52	68	28	8	5	0	3	1	1	3	0	1	3	5	4	5	31	51	39	25	14	17	52	68	28	8	5	0	3	1	1	3	0
23	3	13	24	38	39	35	21	13	30	42	26	10	1	0	7	0	2	1	0	1	1	0	0	3	13	24	38	39	35	21	13	30	42	26	10	1	0	6	1	0	4	0
*24	13	40	59	64	78	37	23	28	48	29	15	3	4	1	0	0	0	1	0	0	0	0	0	2	13	40	59	64	78	37	23	38	48	29	15	3	4	1	0	0	0	1
25	26	32	28	37	20	23	27	6	5	2	3	1	0	0	1	0	0	0	0	1	1	1	2	7	15	26	32	28	37	20	23	27	6	5	2	3	1	0	0	1	0	0
26	42	39	23	12	9	9	7	1	1	0	4	0	1	1	0	0	0	0	0	0	0	0	1	7	16	31	42	39	23	12	9	9	7	1	1	0	4	0	1	1	0	0
27	31	12	17	8	2	2	2	0	2	4	4	1	2	1	0	1	0	1	1	0	0	1	13	23	33	49	56	31	12	17	8	2	2	2	0	2	4	4	1	2	1	0
28	12	2	6	3	2	0	1	0	0	0	2	1	1	0	1	0	1	1	1	2	7	15	18	34	21	28	22	25	12	2	6	3	2	0	1	0	0	0	2	1	1	0
29	13	1	0	0	3	1	1	0	1	0	2	0	1	1	1	3	3	5	10	12	27	36	38	31	28	14	17	11	14	13	1	0	0	3	1	1	0	1	0	2	0	1
30	6	4	4	3	2	1	2	2	2	2	4	4	4	1	5	7	9	12	14	22	18	27	16	20	12	13	11	10	8	7	6	4	4	3	2	1	2	2	2	2	4	4
32	5	3	2	0	0	0	0	0	0	1	1	1	5	16	11	12	20	15	14	11	13	15	9	5	7	3	4	10	7	5	7	6	5	3	2	0	0	0	0	0	0	1
34	4	1	0	1	0	0	3	0	0	0	4	3	7	13	10	10	10	18	6	5	5	7	5	4	2	2	3	0	2	3	5	0	1	0	4	1	0	1	0	0	3	0
36	0	1	3	2	1	2	2	8	14	11	21	18	21	16	18	9	14	7	11	6	8	6	4	4	2	4	3	1	4	1	6	5	3	1	1	2	0	2	2	2	2	2
38	2	3	4	1	4	13	12	20	30	48	27*	20	17	13	13	7	13	15	10	10	9	4	4	2	8	1	1	6	3	5	4	2	5	0	3	2	1	3	2	3	4	1
40	2	3	1	0	5	8	13	11	12	25	39	28	19	10	10	7	2	3	6	10	7	7	3	12	6	5	4	3	4	6	4	2	3	2	2	3	4	4	4	3	2	3
42	6	0	2	9	4	12	28	25	36	22	9	11	10	4	6	4	9	13	13	13	10	14	3	9	4	4	4	3	4	3	14	10	7	5	8	4	3	4	6	1	0	0

Hours

* Indicates 1st 24 hour test period.

As day-length was decreased to a 23-hour day the hen continued to lay one more 4-egg sequence. The ovipositions in this sequence, however, occurred at a later time of the day than those on the 24-hour day. Oviposition of the C_1 egg occurred 3 hours after the onset of light; C_2 was laid about midday, while the C_3, which was estimated ("x" within a circle), was plotted in the mid-afternoon at approximately the same time as the terminal egg of the previous sequence. The terminal egg of this sequence was laid in the dark, 15 minutes after the onset of the dark period. Following this 4-egg sequence, the hen started laying 3-egg sequences. The C_1 oviposition occurred approximately 3 hours after the onset of the lighted period. The C_2 oviposition occurred about midday while the C_3 occurred one hour before onset of the dark period.

As day-length was decreased to a 22-hour day, time of oviposition was confined to a smaller portion of the day. The first egg was laid approximately 5.5 hours after the onset of light; the terminal egg was laid near the onset of darkness.

Laying was again shifted toward the dark period on the 21-hour day. The terminal eggs of the 2-egg sequences were laid in the dark. During the latter part of the 21-hour period, the rate of lay was reduced to an egg every other day.

The intervals between ovipositions plotted in Figure 12 are recorded in Table 10. It is apparent that on the 24, 23, and 21-hour days, the mean interval was approximately 26.5 hours. On the 22-hour day this interval increased to approximately 27.25 hours.

The egg-laying pattern of hens subjected to the 38 and 42-hour day is presented in Figure 13. A study of this graph indicates that when 2 eggs are laid per day, one is laid early in the day while the other is laid late in the dark period. The following day an egg is usually laid at about the onset of the dark period.

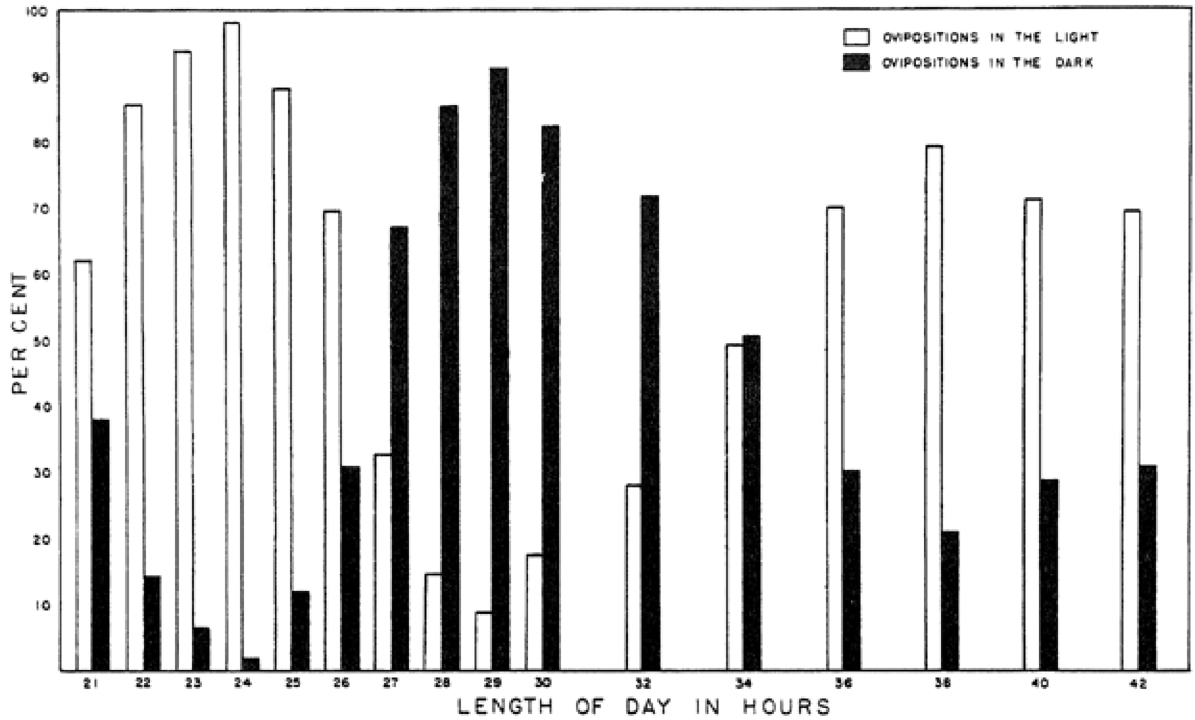

Figure 11. The percent of ovipositions in the light and dark period of the various day-lengths.

TABLE 9-THE PERCENT OF OVIPOSITIONS IN THE LIGHT AND DARK PERIOD OF THE VARIOUS DAY-LENGTHS

Day-Length (Hours)	Total Eggs	Light		Dark	
		Number of Eggs	Percent	Number of Eggs	Percent
21	321	200	62.3	121	37.7
22	364	311	85.4	53	14.6
23	307	288	93.8	19	6.2
24	445	437	98.2	8	1.8
25	238	210	88.2	28	11.8
26	204	148	72.5	56	27.5
27	266	87	32.7	179	67.3
28	206	30	14.6	176	85.4
29	274	24	8.8	250	91.2
30	262	46	17.6	216	82.4
32	208	57	27.4	151	72.6
34	134	66	49.3	68	50.7
36	241	169	70.1	72	29.9
38	345	272	78.8	73	21.2
40	302	215	71.2	87	28.8
42	356	246	69.1	110	30.9

From the time of ovipositions plotted in Figure 13 and the data in Table 11 it is obvious that oviposition and ovulation were occurring during both the light and dark periods of each day-length. Hen No. 42 is an exception as her ovipositions occurred only during the lighted portion of the day. Apparently

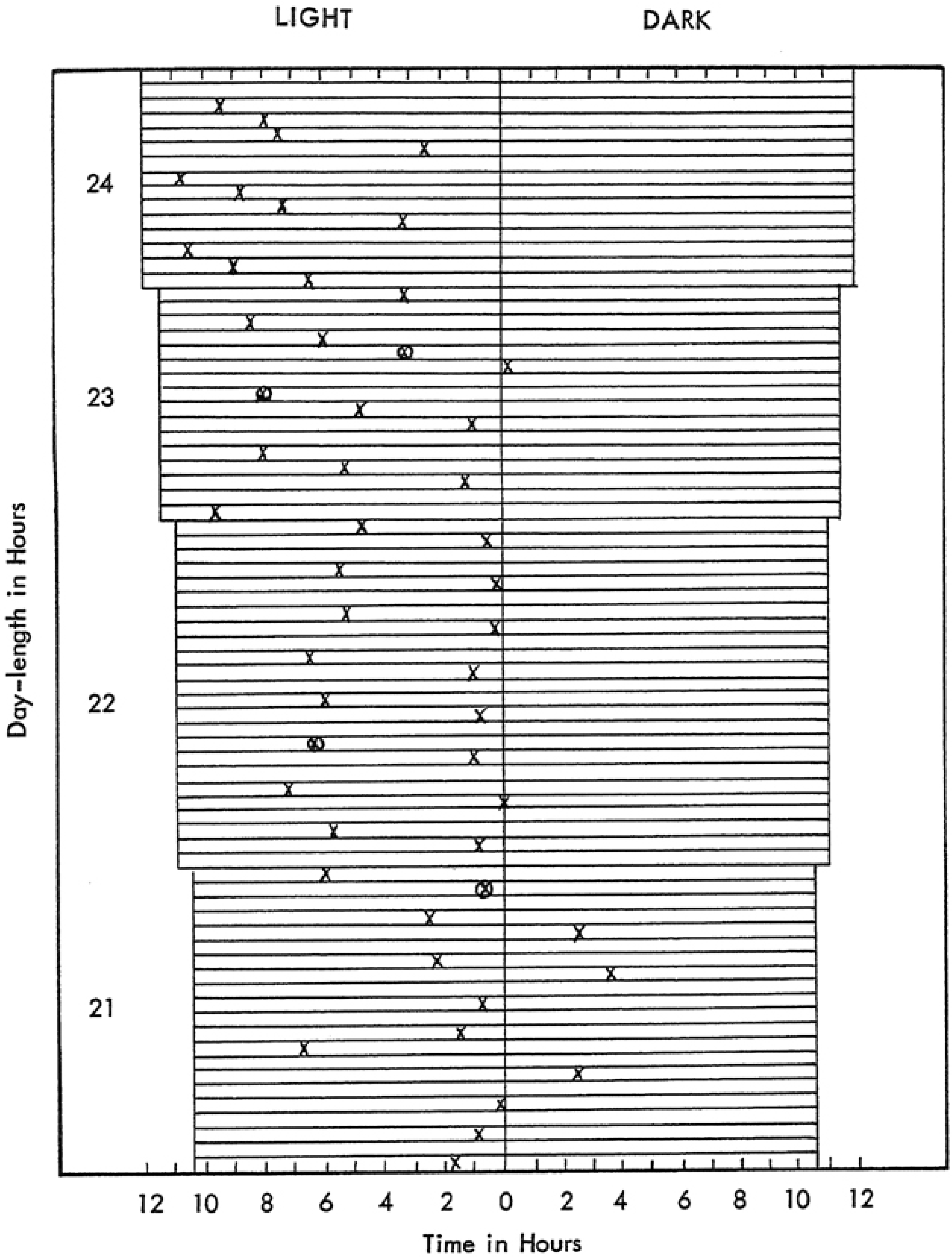

Figure 12. The effect of decreasing day-length on the time of oviposition for Hen No. 2.

the length of the experimental day continued to regulate the time of oviposition. This fact is clearly demonstrated by the mean interval between ovipositions of 37.9 hours on the 38-hour day-length and 48.03 hours on the 42-hour day-length.

TABLE 10-THE INTERVALS BETWEEN OVIPOSITIONS ON THE 24 THROUGH THE 21-HOUR DAY OF HEN NUMBER TWO

Day-Length (Hours)	Intervals in Hours			Mean Interval (Hours)
	C_1-C_2	C_2-C_3	C_3-C_4	
24	25.50	24.50	29.00	26.33
	26.00	25.50	28.00	26.50
	25.50	26.50	27.50	26.50
23	25.50	*26.00	26.50	26.00
	*25.25	27.75		26.50
	25.75	27.00		26.38
	25.50	26.25		25.88
22	27.25			27.25
	27.00			27.00
	27.50			27.50
	27.25			27.25
	*27.75			27.75
	29.25			29.25
	27.00			27.00
21	*26.50			26.50
	26.00			26.00
	26.75			26.75

* Estimated

Figure 14 demonstrates very clearly some characteristics of how a relatively long (No. 41) and short (No. 10) interval bird reacted to different day-lengths. Time of oviposition was plotted in 15-minute intervals. The "X" within the circle represents an estimated oviposition for Hen No. 10 who laid 281 eggs throughout the experiment compared to 204 eggs for hen No. 41. Hen No. 41, however, was a replacement and was placed in the cage during the initial 24-hour day test period.

Hen No. 10 laid 6, 4, and 5-egg clutches, respectively, on the 24-hour day contrasted to 4, 2, 3, and 3-egg clutches, respectively, for hen No. 41. Both hens laid the first egg of the sequence in the early morning while the last ovipositions appeared in mid-afternoon. When day-length was increased to 25 hours, hen No. 10 lengthened her sequence to 8 and 6 eggs. Here, again, as on the 24-hour day, the last or last 2 eggs of the sequence were laid just prior to the onset of light. These appear to be the first eggs of the following sequence; however, by the definition of sequence they are the last eggs of the preceding sequence. When day-length was increased to 26 hours, hen No. 10 started laying her sequence earlier in the morning than on previous day-lengths. During the latter part of the 26-hour day hen No. 10 was laying at a 26-hour interval, hence the day-length was matching her time required to produce an egg. It was a coincidence that as the interval between the last few eggs increased, day-length was advanced to a 27-hour day. This extra hour was enough to allow her to catch up with the lag within the sequence and as a result no day was missed. Eggs were now produced in the dark period at approximately a 27-hour interval. During the 28-hour day oviposition occurred every 28 hours.

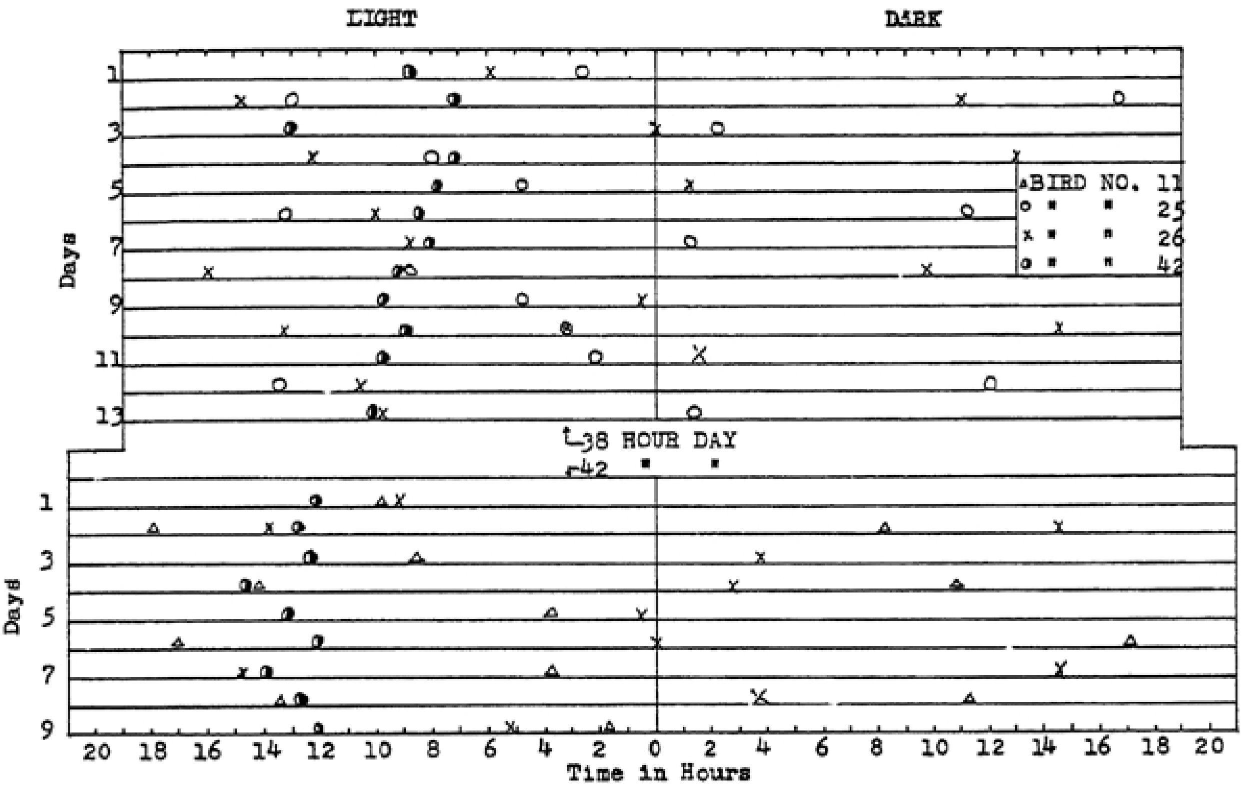

Figure 13. The egg-laying pattern of hens subjected to the 38 and 42-hour day.

Meanwhile hen No. 41 continued to produce eggs in short sequences during the 25, 26, and first part of the 27-hour day. During the latter part of the 27-hour day-length she increased her sequence to 6 eggs. This was followed with a 7-egg sequence on the 28-hour day. Even though sequence length was increased, she was still losing time as eggs were laid somewhat over 28 hours apart.

The approximate interval or time lag that occurs between the stimulus that initiates ovulation and the actual oviposition is shown in Figure 15. The mean time of oviposition, from the onset of the lighted period (L_0), is represented by the symbol "X." The symbols "L" and "D" represent the onset of the light (solid line) and dark (broken line) periods, respectively. The subscripts attached to the "L" and "D" indicate the number of light and dark periods prior to the mean time of lay.

In the data presented, it is apparent that lines "L_2" and "D_2" parallel line X to a closer extent than any other line. This indicates that the interval between the stimulus that initiates ovulation and the actual oviposition is between 40 and 60 hours. From the 21 through the 25-hour day it appears that the stimulus was occurring 40 hours prior to oviposition as lines D_2 and X were parallel. However, due to the skewing of the data by the intra-clutch and terminal ovipositions during this period, this section of the graph does not reflect an accurate measure of the interval. During the 26 through the 34-hour day most ovipositions occurred at the same time every day; therefore, this period reflects a relatively accurate interval between the stimulus of ovulation and the actual ovulation. Table 12 gives the data for this graph.

TABLE 11-THE INTERVAL BETWEEN SUCCESSIVE OVIPOSITIONS OF HENS SUBJECTED TO 38 AND 42-HOUR DAY-LENGTHS

Day-Lengths (Hours)	Bird No.	Interval in Hours								Mean Interval (Hours)
38	25	27.50	29.50	23.75	27.75	41.25	29.50	24.50	28.00	
		28.00	42.00	*38.75	38.75	27.75	25.50	27.50		30.67
	26	29.00	25.75	27.00	25.75	25.25	26.25	26.75	39.25	
		30.75	25.75	27.75	25.25	27.75	*25.00	26.00	38.75	28.25
	42	39.50	32.25	43.75	37.50	37.25	38.00	37.00	37.75	
		38.75	37.25							37.90
42	11	33.75	26.25	25.25	36.25	25.00	28.00	28.25	34.00	
		21.25	32.25	24.75	29.00					28.67
	26	37.25	28.50	31.25	41.00	38.75	42.50	27.25	29.25	
		31.25	32.25							33.93
	42	41.50	42.25	39.75	43.50	43.00	40.25	43.25	42.50	42.03

* Estimated.

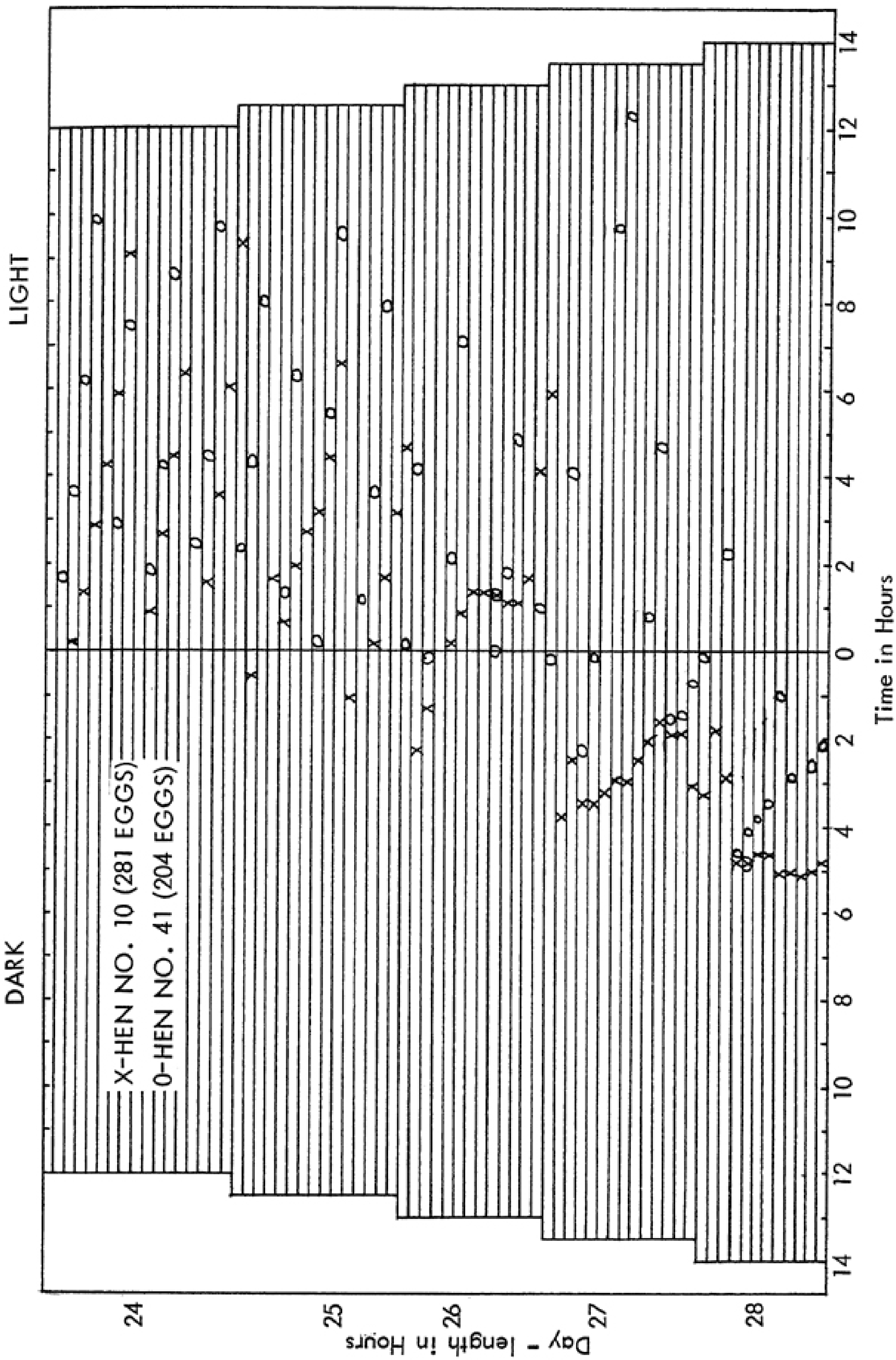

Figure 14. The effect of increasing day-length on the time of oviposition.

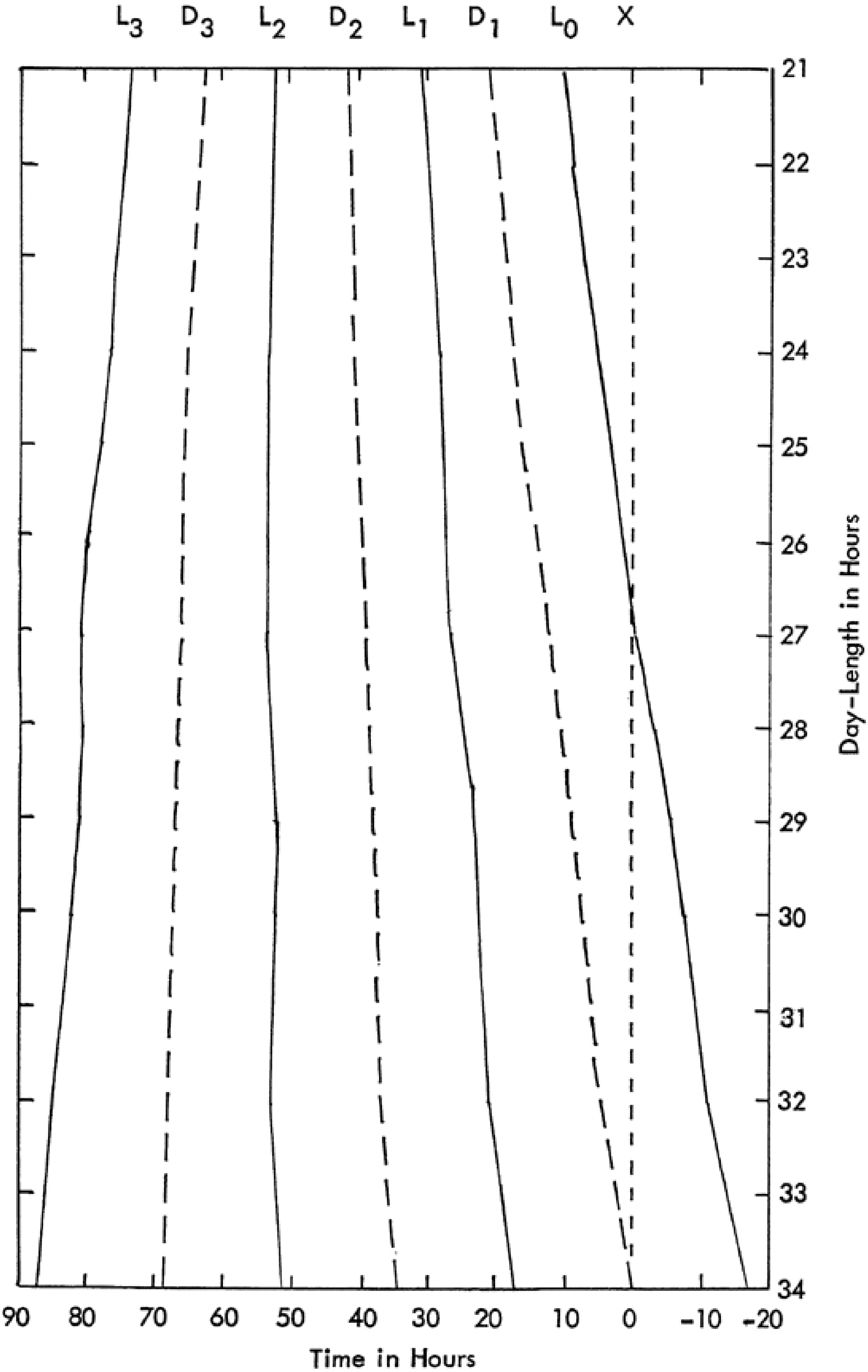

Figure 15. The time lag in hours between the onset of the previous light and dark periods and the mean time of oviposition.

TABLE 12-THE TIME LAG IN HOURS BETWEEN THE ONSET OF THE PREVIOUS LIGHT AND DARK PERIODS AND THE MEAN TIME OF OVIPOSITION

Day-Length (Hours)	Light and Dark Periods Occurring Prior to Ovipositions						Mean Time of Lay
	L_3	D_3	L_2	D_2	L_1	D_1	"L_0"
21	72.64	62.14	51.64	41.14	30.64	20.14	9.64
22	73.98	62.98	51.98	40.98	29.98	18.98	7.98
23	75.73	64.23	52.73	41.23	29.73	18.23	6.73
24	77.48	65.48	53.48	41.48	29.48	17.48	5.48
25	78.28	65.78	53.28	40.78	28.28	15.78	3.28
26	79.66	66.66	53.66	40.66	27.66	14.66	1.66
27	80.72	67.22	53.72	40.22	26.72	13.22	- 0.28
28	80.75	66.75	52.75	38.75	24.75	10.75	- 3.25
29	81.33	66.83	52.33	37.83	23.33	8.83	- 5.67
30	81.82	66.82	51.82	36.82	21.82	6.82	- 8.18
32	84.87	68.87	52.87	36.87	20.87	4.87	-11.13
34	87.34	68.34	51.34	34.34	17.34	0.34	-16.66

DISCUSSION

An interesting aspect of the data presented was that the time of oviposition could be controlled by varying the day-length. Although it was possible for the hens to lay during any of the daylight hours of a 24-hour day, most of them laid before noon. This is in agreement with earlier reports by Turpin (1918), Atwood (1929), Hutt and Pilkey (1930), Funk (1934), Funk and Kempster (1934), Warren and Scott (1936), and Heywang (1938). The fact that 2 peaks of oviposition occurred on the 24-hour day may be explained by the manner in which the various eggs within a sequence were laid. The first peak results from the lay of intra-clutch eggs; whereas, the second peak of lay is that of the terminal egg of the clutch which occurs during mid-afternoon. Decreasing the day-length to 22 hours resulted in a shifting of the peaks to a later time within each day-length. The very pronounced peaks of oviposition occurring on the 22-hour day (Figure 6) may be explained by the fact that only the initial and terminal ovipositions of a clutch were occurring; this resulted in the maximum interval that could be attained. As day-length was decreased to 21 hours, oviposition was restricted to a very limited portion of the day. This resulted in an egg being laid every other day, thus one peak in oviposition occurred.

Increasing periods of day-length progressively advanced the time of oviposition to an earlier hour of the day as each successive day-length was tested. As shown in Figures 7, 8, and 9 only one peak in oviposition occurred in all day-lengths from 26 through 34 hours. This reflects the absence of the tendency of the hen to lay eggs at a progressively later time of the day. This is in accordance with the proposed hypothesis that a day-length equal to the normal interval observed between ovipositions would permit the laying of eggs in longer sequences. Hens began laying daily eggs at regular intervals when the experimental day-length was equal to their respective times required for egg formation. Further increases in the length of day resulted in a corresponding delay in the time of oviposition. The data clearly demonstrates that hens maintained on insufficient day-lengths are subject to interruptions of clutches by unfavorable diurnal rhythm (see Figures 3 and 4).

Figure 11 clearly shows that successive decreases of day-lengths resulted in a greater percentage of the eggs being laid during the dark period. Likewise, successive increases of day-length up to 29 hours resulted in more eggs being laid during the dark period. These results indicate that ovulation and oviposition can occur at any time of the light and dark period. This supports the observation of Byerly and Moore (1941) that over 60 percent of the eggs were laid during the dark period when hens were maintained on a 26-hour day. Wilson and Woodard (1958) also reported that hens could lay and ovulate when kept in total darkness during a test period of 5 weeks duration.

The time of oviposition was shifted to a progressively earlier time of the experimental day with increased day-lengths, as previously stated. This can be attributed to the time lag that occurs between the stimulus that initiates ovulation and the actual oviposition. The lag was found to be approximately 40 to 60 hours, which spans the ovulation and oviposition of the previous egg. This is in agreement with results reported by Warren and Scott (1936) and Bastian and Zarrow (1955). The release mechanism is timed by the onset of the inactive periods which are shown as D_2 and D_3 in Figure 15. Therefore, the release mechanism was activated at a time of the experimental day approximately 2 hours earlier for each hour increase in day-length. Thus the actual oviposition occurred earlier relative to the total length of day.

The effects obtained on the length of clutch (Figures 3 and 4) from increasing and decreasing day-lengths were quite different. Decreasing the day-length obviously decreased the length of clutch. It should be pointed out, however, that the test period of each day-length was of short duration. It is likely that birds maintained on a given short day-length for a long period of time would adjust and therefore produce somewhat longer clutches than those reported in this paper. Another possibility is that the decreasing stimulus from light (light and dark periods were kept equal) affected egg production. It is very apparent that clutch-length increased with each increase in day-length until all birds were laying daily. Clutch-length did not increase as rapidly as was expected when day-length was progressively increased from the 24 through the 27-hour day. This may be attributed to the fact that an inadequate period of time was provided for the birds to recover from the ill effects of short day-length. It also appears that the infestation of Northern Fowl Mites, noticed during the 32-hour period, may have affected the birds and hence the time picture of clutch-length through the 30 and 32-hour day was not revealed. However, the data show conclusively that long day-lengths are effective in producing long sequences of lay as was previously suggested by the work of Byerly and Moore (1941), and Van Albada (1958), who reported an increase in the length of clutch for birds maintained on a 26-hour day.

As day-length was increased to a 25-hour day the interval between eggs remained approximately the same although sequence length began to increase. During the 26-hour day many hens began laying at 26-hour intervals. As day-length was increased to the 34-hour day the interval between eggs continued to be the same as the length of the experimental day. This would indicate that ovulation was "blocked" during the 26 through the 34-hour day; which resulted in a delay in ovipositions and prevented the birds from laying in inherent cycles. Both light and activity were observed by Bastian and Zarrow (1955) to influence ovulation of the immediate oviposition. These authors also reported that activity was decreased considerably during the hours of darkness. Since eggs were produced and presumably ovulated during the hours of darkness in a portion of this experiment, it would appear that activity would play a minor role in influencing ovulation of the immediate oviposition that occurs. The effect takes place prior to the ovulation of previous egg as shown in Figure 15. It is evident that the day-night rhythm and the rhythmic maturation of follicles were functioning together as an egg was produced every day. Since this was true, it is apparent that the OIH hormone must be released every night, a concept also proposed by Bastian and Zarrow.

The use of increased day-length demonstrated conclusively that the length of day exerts a blocking rhythm on the egg-laying ability of the chicken from the 24 through the 34-hour day. Because of this blocking rhythm it is conceivable that the high producing strains today would not show a consistent interval of less than 24 hours when subjected to a 24-hour day-length. There is no reason to doubt that a bird in peak production may, for a short period of time, produce an egg in an interval of less than 24 hours. If such birds were placed on a 23-hour day, it would be possible for the birds to lay at an interval less than 24 hours. By applying this method such birds could be identified and therefore used in genetic selection to decrease the interval in egg formation or increase the rate of lay. In the present experiment hens possessing intervals of less than 24 hours between ovipositions did not occur; however, the population was very small. Since many hens are able to lay eggs at intervals of 24 hours for long periods of time it is believed that birds possessing the ability to lay at intervals of 23 hours or less do exist.

Since the largest percentage of our present-day flocks lay at an average interval of 25 to 26 hours, apparently, the optimum day-length to obtain maximum production is approximately 25 hours instead of the usual 24 hours. Birds maintained on a 25-hour day-length would be subject to less inhibition of ovipositions than imposed by a 24-hour day-length. This would permit longer periods of continuous lay which in turn would place the bird in a more constant state of endocrine and physiological balance.

From the results of this experiment it is obvious that day-length plays a definite role in controlling the time of oviposition and rate of egg production. Therefore, it seems conceivable that if the effect of diurnal rhythm, that provides the blocking action, was eliminated the bird would be free to lay at the rate of her inherent rhythm. It is proposed that birds kept under continuous light would have an advantage in that they could lay at their own individual pace. Birds under the influence of continuous lighting lay at a very high rate for a short period of time (Poultry Tribune, 1959). Due to the refractoriness to constant light, this period of high production is usually followed by a gradual decline during the remainder of the laying year. From the assumption that an increase in intensity would produce a stimulus similar to that obtained by increasing the number of hours of light in the day, it is proposed that a high rate of egg production could be sustained with continuous lighting if a system of increasing light intensity were applied. Young growing pullets produced for such a lighting regime should be restricted to low levels of light intensity during the conditioning (growing) period. Throughout the laying year, increasing light intensity should maintain an increasing stimulus to the reproductive organs.

Day-lengths longer than 24 hours can be utilized effectively in experimental design to accomplish a controlled rate of egg production. A larger number of birds can be caused to lay at regular intervals and the time of oviposition readily predicted. Thus experimental variation due to rate of lay could be lessened considerably.

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