AN ABSTRACT OF THE THESIS OF

Chester Ervin Stotts for the Master of Science in Poultry Husbandry.

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Title: The Relation of Weight, Color, Specific Gravity and Time of Oviposition of Chicken Eggs To Their Hatchability.

Redacted for privacy

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During the period from May 8th to May 19, 1950, 2079 eggs from the Oregon State College flock of New Hampshires were classified according to weight, shell color, specific gravity and hour of lay. The following partial correlation coefficients were calculated between the measurements: color x specific gravity, .142; color x weight, .242; color x time of lay, .008; specific gravity x weight, -.058; specific gravity x time of lay, .066; and weight x time of lay, -.072. All are significant at the .01 level except between color and time of lay.

Hatchability data show that high specific gravity eggs hatched significantly better than low specific gravity eggs. The difference in hatchability between eggs above specific gravity 1.075 (critical point) and eggs below specific gravity 1.075 was greater in eggs laid by low producing hens and in light shell colored eggs. Eggs laid by low producing hens have the lowest average specific gravity scores as well as the highest percentage of their eggs below the "critical point". Egg shell color was related to hatchability in low specific gravity eggs, but not in medium and high specific gravity eggs. In the low specific gravity group medium and dark colored eggs hatched significantly better than either light or extremely dark colored eggs. Eggs weighing between 25 and 29.5 oz./doz. gave higher hatchability than eggs weighing from 22 to 25 or from 29.5 to 31 oz./doz. No relationship between hour of lay and hatchability could be detected in eggs from high producing hens (over 75 per cent production). Eggs laid before 9 A.M. by low producing hens hatched better than eggs laid later in the day. These differences could not be attributed to the length of time interval between eggs.

THE RELATION OF WEIGHT, COLOR, SPECIFIC GRAVITY AND TIME OF OVIPOSITION OF CHICKEN EGGS TO THEIR HATCHABILITY

by

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THE RELATION OF WEIGHT, COLOR, SPECIFIC GRAVITY AND TIME OF OVIPOSITION OF CHICKEN EGGS TO THEIR HATCHABILITY

INTRODUCTION

Because of the economic importance of the baby chick industry in the United States, numerous investigators have attempted, through their research, to find methods by which the number of chicks obtained from a given number of eggs could be increased. One line of approach to the problem has been the study of various egg traits and their influence upon hatchability. If it could be shown that the selection of eggs for one or more of their measurable physical traits would result in better hatchability, it might be a practical way for hatcheries to increase their efficiency. Breeders could intensify a program of breeding for eggs of a certain characteristic color or specific gravity and the whole industry should benefit from the increased hatchability.

Except for the recent work of Godfrey and Jaap (21, pp.874-889), all of the previous investigations on the effect of weight, color, specific gravity and time of lay upon hatchability of hens' eggs have dealt with only one of these factors at a time disregarding the influence that the others might have. The results reported, especially with respect to time of lay and color, have been conflicting. This has made it difficult to provide satisfactory explanations or to make positive recommendations to hatcherymen. In view of this it was thought desirable to study all of these factors in the same sample of eggs and also take into consideration the rate of lay, clutch position and time interval between eggs. By studying the relationships between these factors it was thought it might be possible to determine the cause of existing differences and make more specific recommendations possible.

REVIEW OF LITERATURE

Specific gravity.

Early work of Mussehl and Halbersleben (41, p.720) showed a correlation coefficient of .204 between specific gravity and per cent hatch of fertile eggs. Their data revealed that eggs below 1.08 in specific gravity hatched 16.0 per cent lower than eggs above this point, the respective percentages being 39.3 and 55.3 for the two groups.

Using the specific gravity test of Olsson (43, p.14), Munro (39, p.62) demonstrated a distinct curvilinear relationship between specific gravity and hatchability. Eggs below what he terms the "critical point" with regard to specific gravity (ie, 1.078 for Barred Rocks, 1.086 for Leghorns) averaged 32.4 per cent lower in hatchability of fertile eggs. An average of 22 per cent of the eggs fell below these points and by discarding these eggs before setting, the per cent hatch of total eggs was improved 8.3 per cent. Recent work by Godfrey and Jaap (21, p.888) also showed that specific gravity was a measure of hatching power and that this could be due to a smaller moisture loss during incubation in high specific gravity eggs.

Phillips and Williams (44, p.113) found no relationship between specific gravity and the hatchability of turkey eggs.

Employing direct means for determining shell thickness, Wilhelm (55, p.194) obtained a significant correlation coefficient of 0.164 ± 0.016 between egg shell thickness and hatchability. Previously, Hays and Sumbardo (28, p.200) did not find any relationship between these two factors in a strain of Rhode Island Reds selected for high egg production.

Of primary interest with regard to the specific gravity test is the physiological implications. Munro found that differences in specific gravity exist between eggs from different hens as well as between individual eggs from the same hen and that both of these differences are related to hatching power. Since this test measures percentage of shell, Munro was of the opinion it might be an indication of the physiological condition of the hen at the time the egg is laid.

Weight.

The relation between egg weight and hatchability has been studied by a number of investigators since the initial work of Benjamin (5, p.252) in 1920. He noted that large eggs hatched poorer than small eggs and that eggs of medium size hatched best. Halbersleben and Mussehl (22, p.144) also found that abnormally large eggs hatched less well than medium-sized ones.

Dunn (13, pp.108-110) made an extensive analysis of egg weight and its relation to hatchability. His data show no correlation between the mean egg weights of individual birds and the mean hatchability percentages for the same individuals, but it shows a difference in hatchability of 17.97 ± 3.97 per cent in favor of small eggs over large. He noted, however, that the deviation from the mean egg weight of the individual rather than the deviation from the flock mean was responsible for the effect on hatchability. This situation indicates that physiological factors connected with egg formation are responsible for the reduced hatching quality of eggs above or below the mean weight.

Godfrey (19, p.295) reported a significant curvilinear relationship between egg weight and hatchability. Maximum hatchability was obtained in the 50 to 58 gram egg weight range while above 58 and below 50 grams it declined sharply. Axelsson (4, p.31) also observed a curvilinear trend with small and large eggs hatching less well than medium sized eggs. Of the two extremes the small eggs hatched better than the large.

Scott and Warren (49, pp.76-77) presented data taken from one flock of White Leghorns in 1936 and another in 1939 which indicated that large egg size depressed hatchability. With regard to small egg size the evidence is conflicting; the group of females laying the smallest eggs gave the highest average hatchability in one year and the lowest in another. They observed that hens producing large eggs in relation to their body weight had lower hatching records than do individuals laying smaller eggs in relation to their body weight.

There is general agreement that extremely large egg size tends to depress the hatching power of the egg. Further evidence supporting this conclusion has been presented by Funk (14, p.21) and Warren

(52, p.3). The latter investigator presented correlation coefficients between hatchability and egg weight of -0.171 ± 0.044 and -0.264 ± 0.050 in White Leghorns and Rhode Island Reds, respectively. In this material hatchability decreased with increasing egg size however, it is generally accepted that the relationship is non-linear and the results, consequently, are of doubtful value. The same applies to the work of Wilhelm (55, p.194) who calculated a correlation coefficient of 0.259 ± 0.089 in White Leghorn material.

With regard to the hatchability of small eggs Jull and Haynes (33, p.694) presented data in which the smallest egg weight class hatched as well as the medium weight class. Hays and Sumbardo (28, p.200), using eggs from a Rhode Island Red family bred for high hatchability, failed to find any relationship between egg weight and hatchability. To what extent methods of analyses, experimental technique, etc. have contributed to these inconsistencies is not clear. In the material of some authors the smallest eggs had been excluded from their tests, and this may account for their failure to find a detrimental influence of small egg size upon hatchability.

Color.

The first inquiry relative to the effect of egg shell color upon hatchability was made by Benjamin at the Cornell Agricultural Experiment Station in 1920. He found that chalk-white, cream-tinted and brown-tinted eggs laid by White Leghorns gave similar hatching results (5, p.307). Since this early work, all investigations with regard to the effect of shell color upon hatchability have been made in the brown egg laying breeds.

Godfrey (20, pp.383-386) found that in New Hampshires and White Plymouth Rocks there was a trend for extremely light colored eggs to hatch poorly in comparison with the medium and dark brown eggs. In one of the two flocks of New Hampshires studied, he found a difference of 13.7 and in the other 16.1 in percentage hatch of total eggs between light and dark colored eggs. In White Plymouth Rocks, the difference in hatchability between the light and dark colored eggs was 9.9 per cent while in a flock of Barred Plymouth Rocks there was a difference of only 6.8 per cent in favor of dark colored eggs. His results were based on the total number of eggs set as no attempt was made to distinguish between fertile and infertile eggs. Later work by Godfrey and Jaap (21, p.888) gave the same results in both the Ohio and Oklahoma strains of New Hampshires. They obtained evidence that dark colored eggs lost less weight during incubation and that this could account for the differences in hatchability.

In a recent study by Funk and Forward (17, p.578) a difference of 19.1 per cent in hatchability was found between dark and light colored eggs. Embryonic mortality during the first 18 days of incubation and also during the hatching period was greater in light brown eggs.

Evidence that color has little effect in hatchability of eggs from meat-type strains of New Hampshires has been presented by Skoglund (50, p.6). He observed a slight tendency for dark brown and medium brown eggs to hatch better than light brown eggs, but these differences were not statistically significant.

Time of Lay.

Most of the results reported relative to the influence of time of lay on hatchability are conflicting. The initial work on the problem was made by Hutt and Pilkey (30, p.202) in 1920. They found that afternoon eggs had higher embryonic mortality than eggs laid before 9 A.M. The differences were greatest in March and not found after the middle of April. Results very similar to those of Hutt and Pilkey have been reported by Pritsker (45, quoted from 36, p.105). Among eggs laid during March and April, those laid before noon hatched 5.9 per cent better than those laid between noon and 4 P.M. No comparable difference could be found among eggs laid during August.

Detailed observations related to this problem were made by Funk (14, p.22) (15, p.187). His data, taken during 1931, 1932 and 1933, show that afternoon eggs hatched significantly better than morning eggs. He also noted that cold weather resulted in a non-significant decrease in hatchability of eggs laid before 9 A.M. All night lights resulted in non-significant differences in hatchability for eggs laid at different periods of the day. McNally and Byerly (38, p.283) obtained results similar to those of Funk. In their data afternoon eggs showed a slight improvement in hatchability over eggs laid in the morning.

Hays (25, p.89) reported that in the Massachusetts State College flock of Rhode Island Reds embryonic mortality and hour of lay were not related.

Nicolaides (42, p.276) and Bernier (6, p.62) found that greatest embryonic mortality occurred in eggs laid from 7 to 9 A.M. and eggs laid after 2 P.M. Bernier's differences were statistically significant when the analysis was made on eggs of all clutch positions, or those laid subsequent to the first egg of each clutch.

From the material presented, it can be seen that flock differences exist with regard to the influence of time of lay on hatchability. Conflicting results might be expected since any effect that time of lay might have upon hatchability is the total effect of clutch position, time interval between eggs, intensity of production and perhaps other factors.

The possible influence of intensity of production is indicated by the work of Funk (16, p.353) and Lamoreux (35, p.205) in which they found that eggs belonging to multiple egg clutches hatch better than eggs laid in one or two egg clutches. In general, those hens laying at a rapid rate lay most of their eggs early in the day with only those eggs near the end of the clutch cycle being laid in the afternoon.

There is general agreement that early morning eggs contain embryos in a more advanced state when development is arrested. McNally and Byerly (38, p.281), Scott and Warren (48, p.389) and Bernier (6, p.99). This may be due to a slight prolongation of the period of formation of the first egg of the clutch (48, p.389). The degree of development after a short period of incubation, and presumably at the time of laying, is also influenced by the time interval between successive eggs, McNally and Byerly (38, p.281), Hays (24, p.637), Scott and Warren (48, p.389) and Bernier (6, p.99). This may have an important bearing upon the relationship between time of lay and hatchability since the majority of eggs laid after short time intervals are laid in the mornings.

That the degree of embryonic development at the time of lay exerts an influence on subsequent development has been shown by McNally and Byerly (38, p.283), Bernier (6, p.148), Nicolaides (42, p.276) and Hays and Nicolaides (27, p.79). In general their results show a curvilinear relationship between blastoderm size at time of lay and hatchability. Taylor and Gunns (51, p.294), on the other hand, were unable to detect a correlation between embryo size in newly-laid eggs and hatchability of other eggs from the same hens, but found that the amount of overgrowth in the peripheral part of the area opaca of the blastoderm was significantly greater in embryos from high-hatching hens than in embryos from medium hatching hens.

PROCEDURE

Eggs used in this study were secured from the Oregon Agricultural Experiment Station flock of 320 New Hampshire pullets which had been laying for approximately nine months. Eggs were saved from May 8th to May 21st and set May 15th and May 22nd. The pullets were laying about 55 per cent during this period.

During the holding period the eggs were kept in a farm-type insulated egg room similar to that described in Station Circular 138

(8, p.12), except for a short period following the day of lay when they were graded for color, specific gravity and weight. The time of lay, as well as the hen number, were recorded on the egg at the time the hens were removed from the traps. The other measurements were marked on the egg at the time they were taken. Before being placed in the incubator the eggs were sorted out by hen numbers and recorded. Infertile eggs were detected by breaking out all clear eggs after ten days incubation.

The eggs were graded for color using six color classes which roughly correspond to the following classification found in Robert Ridgway's book entitled, "Color Standards and Nomenclature" (46, pp.1-43). The major differences between the two classifications are that in these experiments the eggs with pinkish casts were placed in classes corresponding to their underlying shade of brown. This was done to facilitate a more equal distribution between classes.

Ridgway's nomenclature	Our classification
-------------	Very light brown
Pinkish buff	Light brown
Light pinkish cinnamon	Medium brown
Pinkish cinnamon	Medium dark brown
Cinnamon	Dark brown
Orange cinnamon	Very dark brown

To measure the specific gravity of the eggs, a series of six salt solutions varying in density from 1.0725 to 1.0825, with a class interval of .0025, was set up. The specific gravity of each egg was regarded as that corresponding to the interval between the two solutions where in one it would float and the other sink. Those eggs that floated in the lowest specific gravity solution were put in the class 'below 1.0725' and those sinking in the highest specific gravity were put in the class 'above 1.0825'. The class interval and number of solutions were established by determining the specific gravity of 100 eggs laid by the same hens just previous to this experiment.

The egg weight classes ranged from 21.5 to 31 ounces per dozen with an individual class interval of 1.5 ounces. Each egg was weighed on a hanging type Zenith egg scales which was checked for accuracy before and after each weighing. Fortunately great variability in egg sizes existed so that a relatively even distribution among classes was obtained.

EXPERIMENTAL

I. Variation in Eggs

Correlation between measurements.

The degree of association of the egg measurements used in this study was determined to ascertain the degree to which hatchability could be influenced by other characters other than the one being tested. Partial correlation is particularly appropriate for this type of study in which the measurements are made simultaneously and where there is no definite independent variable. The partial correlation coefficient measures the degree of association between two characters with the remaining characters under consideration held constant. Thus a more reliable index of the relationship between two characters is obtained. Lines of regression were also calculated.

These show the average change in one egg character throughout the range of another.

Table 1 -- Simple and partial correlation coefficients showing the relation between color, specific gravity, weight and time of lay in 2079 eggs.

Characters	Simple correlation	Partial correlation
Color x specific gravity	.126	.142
Color x weight	.232	.242
Color x time of lay	.006	.008
Specific gravity x weight	-.055	-.058
Specific gravity x time of lay	.072	.066
Weight x time of lay	-.074	-.072

It can be seen by comparing the simple and partial correlation coefficients in Table 1 that the relation between any two characters is not influenced to any large degree by the other two. Except for the relationships between color and size (r = .242) and between color and specific gravity (r = .142) the other coefficients are small and indicate little association. Except for the relationship between color and time of lay all coefficients are significant at the .01 level.

The relation between color and egg weight accounts for 5.4 per cent of the total variations in egg shell color and egg weight. Similarly, 1.6 per cent of the total variation in color and specific gravity can be attributed to the relationship between them.

Relation between color and weight.

Fig. 1 shows that the relationship between mean egg shell color and egg weight is of a linear nature except for a rather sharp decline in color in the lowest egg weight class. The line of regression which is the line of best fit shows that eggs weighing from 29.5 - 31 oz./dozen are over one and one-half color grades darker than eggs weighing from 22 - 23.5 oz./dozen. The opposite regression of egg weight on egg shell color indicates that dark brown eggs are an average 1.3 oz./dozen heavier than the extremely light colored eggs. The mean weight of eggs of different color shades is shown in Table 2.

Table 2 -- Mean weight of eggs classified according to egg shell color.

Color	No. eggs	Mean weight (oz./dozen)
Very light brown	273	25.8
Light brown	314	26.5
Medium brown	339	26.7
Medium dark brown	362	26.9
Dark brown	376	26.7
Very dark brown	415	27.4

It is impossible to ascertain from these data how much of this association is due to heredity and how much is due to environment. Since both egg size and egg shell color are determined by multiple genes there is a possibility that some of the genes affecting these characteristics are located on the same chromosome and are therefore linked. A simple physiological explanation is possible if we can assume that both egg shell color and egg weight bear an inverse relationship to intensity and persistency of production. There is fair agreement in the literature to the effect that more prolific layers tend to lay smaller eggs, Marble (37, p.265), Jull (31, p.218) Hays (26, p.12); and that the intensity of egg shell color declines with continuous production, Kopec (34, p.285), Axelsson (4, p.161) and Hall (23, p.263). It is thus conceivable that the association between color and size is of a physiological nature involving simultaneous increases or decreases of body reserves of pigment and egg-forming materials. Further evidence supporting this hypothesis is found in the common observation that both egg size and intensity of color decrease in the late spring and early summer after long periods of continuous production. Controlled experiments showing these relationships have been conducted by Kopec (34, p.285), Axelsson (4, p.161) and Hall (23, p.263) with regard to shell color; and by Bennion and Warren (7, p.367) and Warren (52, p.3) and others, with regard to egg size.

Relation between specific gravity and weight.

Fig. 2 shows that the mean specific gravity of eggs changes very little in eggs of different weights. The regression line compares very favorably with that presented by Olsson (43, p.14) in his original work with salt solutions and provides additional evidence that the inverse relationship between the amount of shell material and egg size has little influence upon the specific gravity test as a measure of shell thickness.

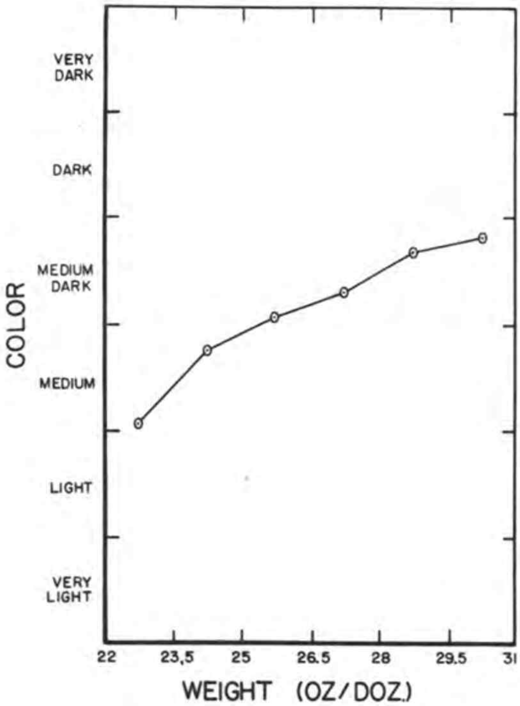

Fig. 1--Relation of mean shell color to egg weight.

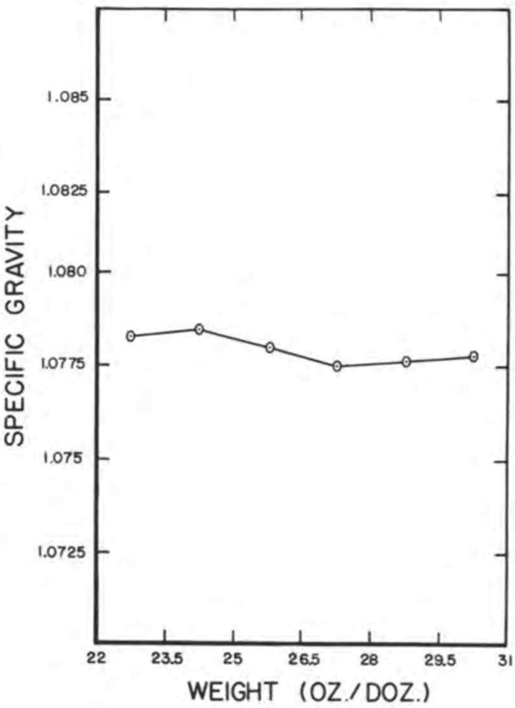

Fig. 2--Relation of mean specific gravity to egg weight.

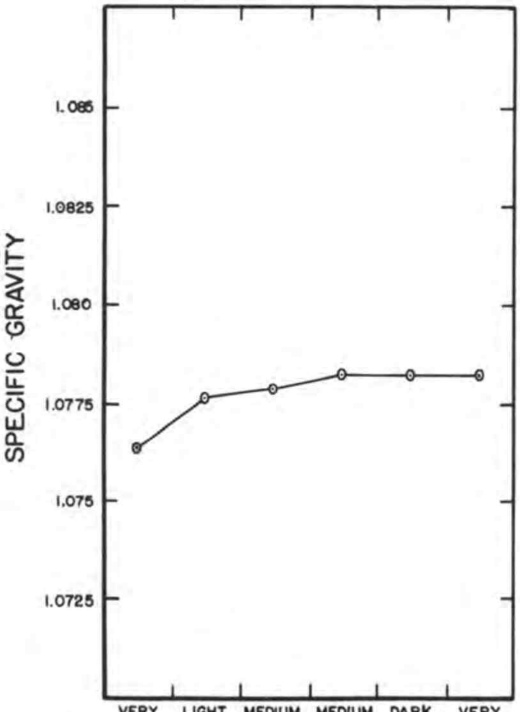

Fig. 3--Relation of mean specific gravity to egg shell color.

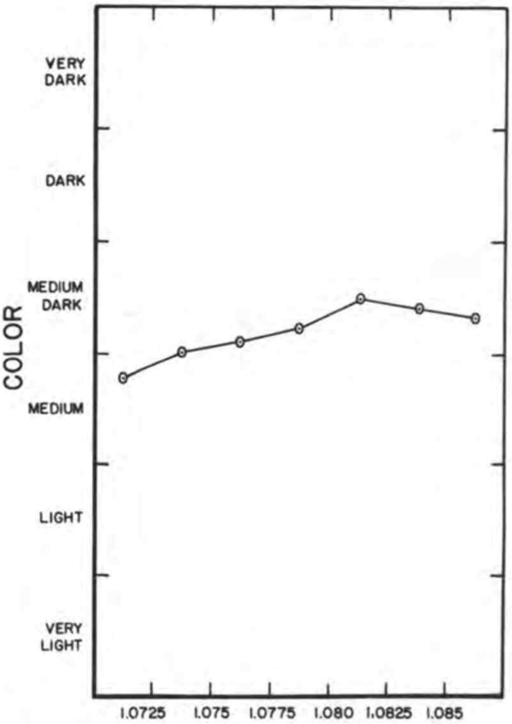

Fig. 4--Relation of mean shell color to specific gravity.

Relation between color and specific gravity.

Fig. 3 shows that the relationship between shell color and specific gravity is curvilinear in nature and indicates that there is a high degree of association between low specific gravity and light shell colored eggs, and little, if any, association between high specific gravity and dark shell colored eggs.

There is a somewhat greater tendency for light colored eggs to be low in specific gravity than for low specific gravity eggs to be light in color. Of 587 eggs in the two lightest color groups, 42.6 per cent have specific gravity scores less than 1.075, while of 690 eggs below specific gravity 1.075 only 36.2 per cent are in the two lightest color classes. The relationship is more striking when considering only those eggs extremely light in color and with the lowest specific gravity scores (less than 1.0725). In this case 50.9 per cent of the extremely light colored eggs have specific gravity scores less than 1.075 while only 38.5 per cent of the eggs below specific gravity 1.0725 are in the two lightest color classes.

Detailed examination of the data reveals that eggs laid by the same hen possess a somewhat similar specific gravity and a relatively uniform shell color. However, as has been shown, there is little tendency for the two to be associated except in those hens whose eggs are both light in color and low in specific gravity. In view of the fact that Godfrey (21, p.888) has shown that both low specific gravity and light shell color are indices of poor shell quality, as determined by breaking strength and weight loss during incubation, we may regard both as manifestations of low physiological efficiency of the individual hen's shell secreting glands and pigment secreting mechanisms. Presumably the body reserves of pigments and shell-producing substance might also be low in such individuals. This low physiological condition might then be reflected in the form of higher embryonic mortality during incubation.

The work of Godfrey in which he showed that both egg shell color and specific gravity are indications of breaking strength of eggs and also of weight loss during incubation poses the question as to the nature of this relationship. It does not appear to be wholly a matter of shell thickness because of the comparatively low correlation between them. A comparison of Fig. 1 in which color increased with increasing egg weight and Fig. 2 in which specific gravity decreased slightly with increasing egg weight is interesting in this regard and indicates that perhaps they are wholly different factors. Except for the data presented by Godfrey, no work has been done on shell color with regard to thickness of shell, texture, porosity, etc. It would seem very desirable if future research would be directed down this line.

Variation in color, specific gravity and egg weight with hour of lay.

The mean specific gravity, weight and color of eggs laid at different hours of the day are presented in Fig. 5. It can be seen that the relationship between specific gravity and time of lay is curvilinear. Egg shell color does not change in eggs laid at different hours of the day.

Eggs laid before 9 A.M. are the largest of the day while those laid after this hour show a consistent decline so that eggs laid after 1:30 P.M. are 2 grams smaller than those laid before 9 A.M. This curve is almost an exact replica of that presented by Funk and Kempster (18, p.8); both deviating only slightly from earlier data presented by Atwood (1, p.109).

The question arises whether the early morning eggs are biggest because they contain a higher proportion of eggs that are first in the cycle to which they belong. First eggs are larger than eggs laid later in the cycle as shown by results of Curtis (12, quoted from 29, p.357), Atwood (1, p.29), Bennion and Warren (7, pp.363-364) and Funk and Kempster (18, p.9). Eggs laid in the afternoon are likely to include a high proportion of eggs that terminate cycles which could account for them being smaller than those laid earlier in the day.

The curve of specific gravity as related to time of lay shows that eggs laid before 9 A.M. and after 12 P.M. have thicker shells than eggs laid from 9 A.M. to noon. If we can again assume that early morning eggs contain a high proportion of initial eggs of a clutch and afternoon eggs include a high proportion of eggs which terminate cycles, the data are in agreement with Berg (9, p.563) and Wilhelm (55, p.249). They have shown that, in cycles containing 3 eggs or more, those occupying first and last positions have thicker

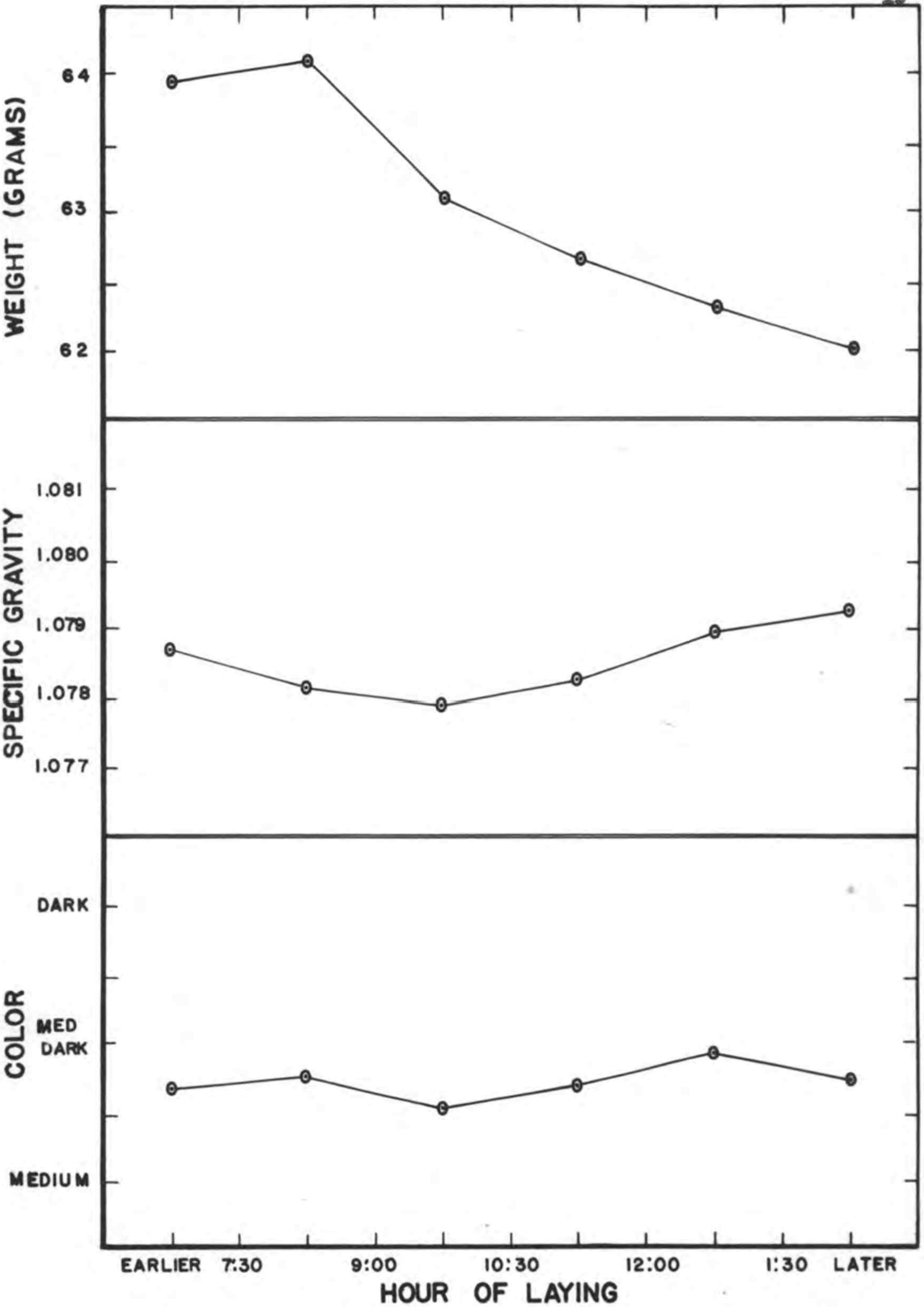

Fig. 5--Relation of weight, specific gravity and egg shell color to hour of day.

shells than those intervening. The reason is that the interval of time between the laying of the last egg and its predecessor is longer than the interval between any other two eggs of a clutch. Atwood (1, p.11). Since the egg is in the uterus for a longer time and shell formation goes on continuously during this period, Burmester (10, p.101), it is thus conceivable that they should have thicker shells.

II. VARIATION IN HATCHABILITY

Specific Gravity.

Hatching results obtained with eggs classified according to specific gravity are given in Table 1 and illustrated in Fig. 6. It can be seen that there is a distinct tendency for hatchability to fall off

Table 1 -- Specific gravity of eggs as related to fertility and hatchability.

Specific gravity classes	Eggs set	Fertility	Hatch of fertile eggs	Hatch of all eggs
	No.	%	%	%
Less than 1.0725	342	89.5	67.0	59.9
1.0725 - 1.075	348	91.6	71.8	65.8
1.075 - 1.0775	332	91.9	80.6	74.1
1.0775 - 1.080	306	89.5	82.5	73.8
1.080 - 1.0825	308	88.6	85.3	75.6
1.0825 - 1.085	224	88.4	84.3	74.6
1.085 - and over	219	92.2	86.1	79.5

in the lower specific gravity classes of eggs. This is true when considering either the percentage hatch of all eggs or the percentage

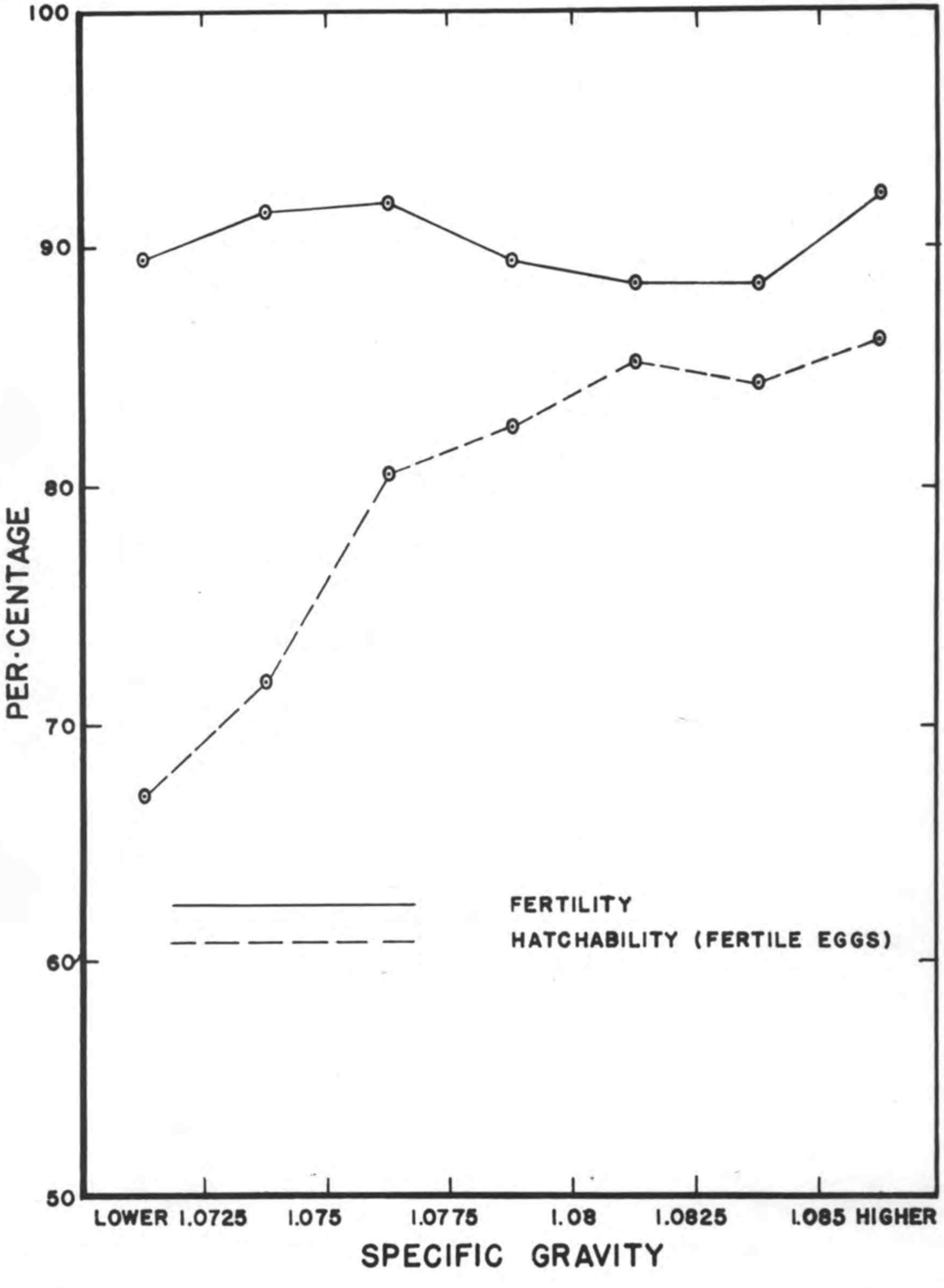

Fig. 6--Relation of specific gravity of eggs to hatchability and fertility.

hatch of those classified as fertile. The chi square test for independence based on hatch of fertile eggs shows that these differences are significant at the .01 per cent error point. (Chi square value, 6 d.f., 55.024). There is no apparent relationship between specific gravity and fertility.

Examination of the data indicates that there is a large drop in hatchability below a specific gravity classification of 1.075 and only a slight improvement above this point. This compares well with the "critical point" of 1.078 obtained by Munro (39, p.62) with Barred Plymouth Rock eggs and 1.074 obtained by Godfrey (21, p.878) with New Hampshire eggs. In this experiment 33.2 per cent of the total number of eggs were below the "critical point" as compared to 22 per cent found by Munro. By eliminating eggs below 1.075 in specific gravity from the hatching data the per cent hatch of fertile eggs would be improved 4.7 per cent and per cent hatch of all eggs would be improved 4.1 per cent.

Fig. 7 shows that the "critical point" based upon hatchability within a specific gravity range is influenced by egg shell color. The hatchability of light brown eggs drops considerably when their specific gravity falls below 1.0775, medium brown eggs below 1.075 and dark brown eggs below 1.0725. Above these points specific gravity has little effect upon hatchability. Since both egg shell color and specific gravity are highly correlated with egg shell quality and weight-loss during incubation (21, p.888), it would be desirable to know the extent to which the decrease in hatchability

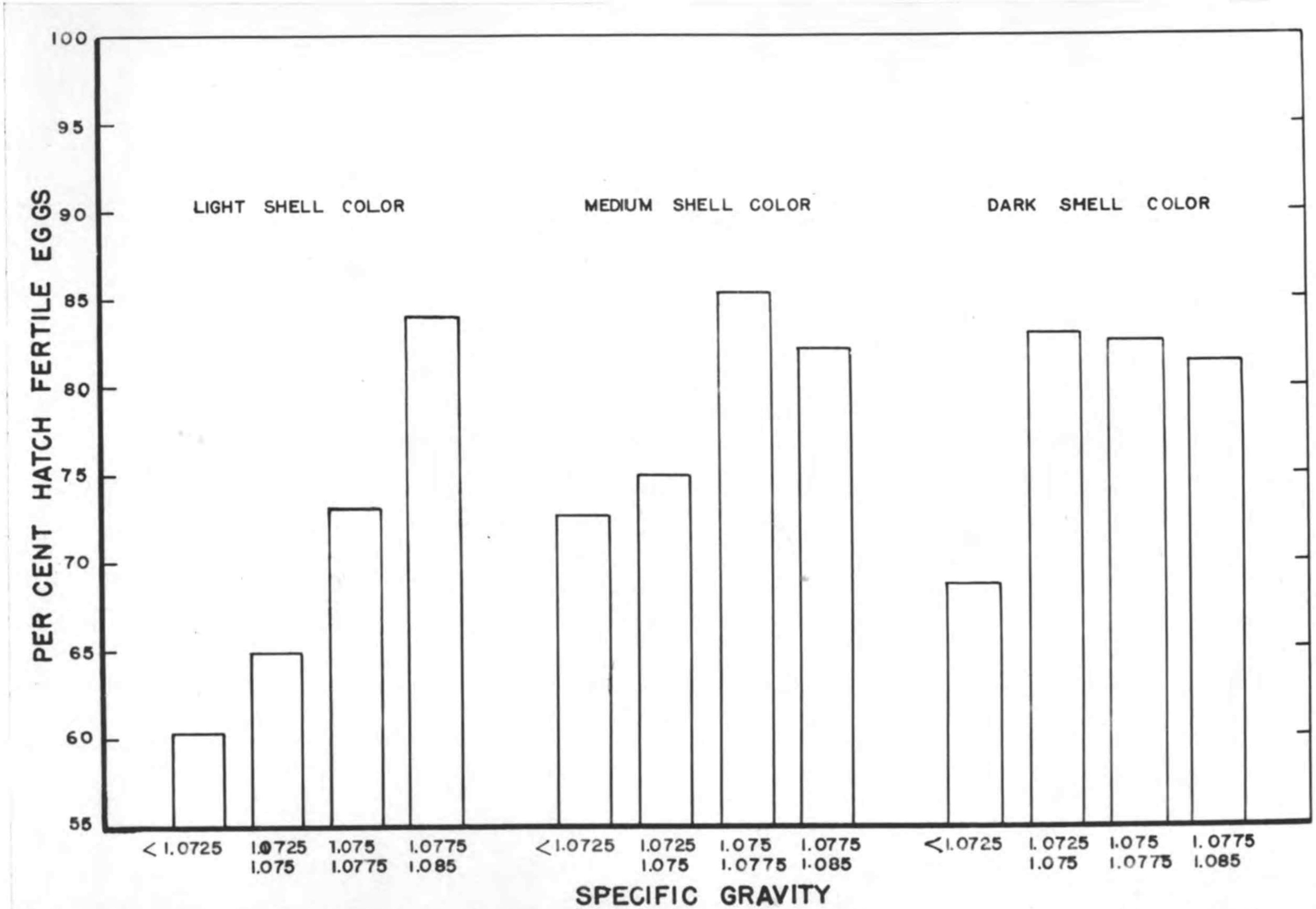

Fig.7-Relation of specific gravity to hatchability in eggs of dark, medium and light egg shell color

of eggs below the "critical point" is due to moisture-loss during incubation. It is unfortunate that weight-loss of eggs during incubation was not included in this study. As pointed out above, data in Fig. 7 show that there is interaction between egg shell color and specific gravity with regard to their effect upon hatchability, but they do not shed light upon the question of what part egg weight-loss may play upon hatchability.

The relationship between rate of lay, based upon the number of eggs laid throughout the 12-day hatching period, and the average specific gravity of eggs is shown in Table 2. Except for a drop in specific gravity in eggs of very high producing hens (over 83.3 per cent production), there is a positive correlation between intensity of egg production and specific gravity. Eggs from low producing hens are characterized by having the lowest average specific gravity, while eggs from hens laying at a rate between 75.1 to 83.3 per cent production have the highest average specific gravity. The smallest percentage of their eggs below the critical point (below 1.075) are also produced by hens in 75.1 to 83.3 per cent production.

Table 2 also shows that the difference in hatchability between eggs above the "critical point" and eggs below the "critical point" is influenced by rate of lay. In eggs from hens laying less than 33.3 per cent the high specific gravity eggs hatched 23.6 per cent better than the low specific gravity eggs whereas in eggs from hens laying better than 83.3 per cent the high specific gravity eggs hatched only 9.9 per cent better. This is primarily due to the fact that low specific gravity eggs from high intensity hens gave higher hatchability than low specific gravity eggs from low intensity hens. These results indicate that rate of lay will influence the improvement that one can expect to attain in hatchability through the selection of eggs based upon their specific gravity.

Table 2 -- Specific gravity of eggs as related to rate of lay.

Per cent production	No. eggs	Mean sp. gr.	Per cent eggs below sp. gr. 1.075*	Per cent hatch fertile eggs Below sp. gr. 1.075	Above sp. gr. 1.075	Diff.**
under 33.3	80	1.0744	36.2	51.4	75.0	23.6
33.4-50.0	138	1.0751	37.1	55.9	82.5	26.6
50.1-58.4	350	1.0761	34.0	69.2	85.0	15.8
58.5-66.7	416	1.0765	29.6	64.5	83.1	18.6
66.8-75.0	477	1.0772	27.3	74.2	84.5	10.3
75.1-83.3	460	1.0774	24.3	73.7	84.0	10.3
over 83.3	329	1.0763	33.4	73.2	83.1	9.9

*Per cent of total number of eggs laid by all hens at any production level.
**Difference in hatchability between egg above the "critical point" and below the "critical point".

<u>Weight.</u>

The relationship between egg weight and hatchability is shown in Table 3 and Fig. 8. Inspection of the data indicates that those eggs weighing close to the mean or flock average (26.72 oz./doz.) hatch better than those which deviate greatly from the mean. The chi square

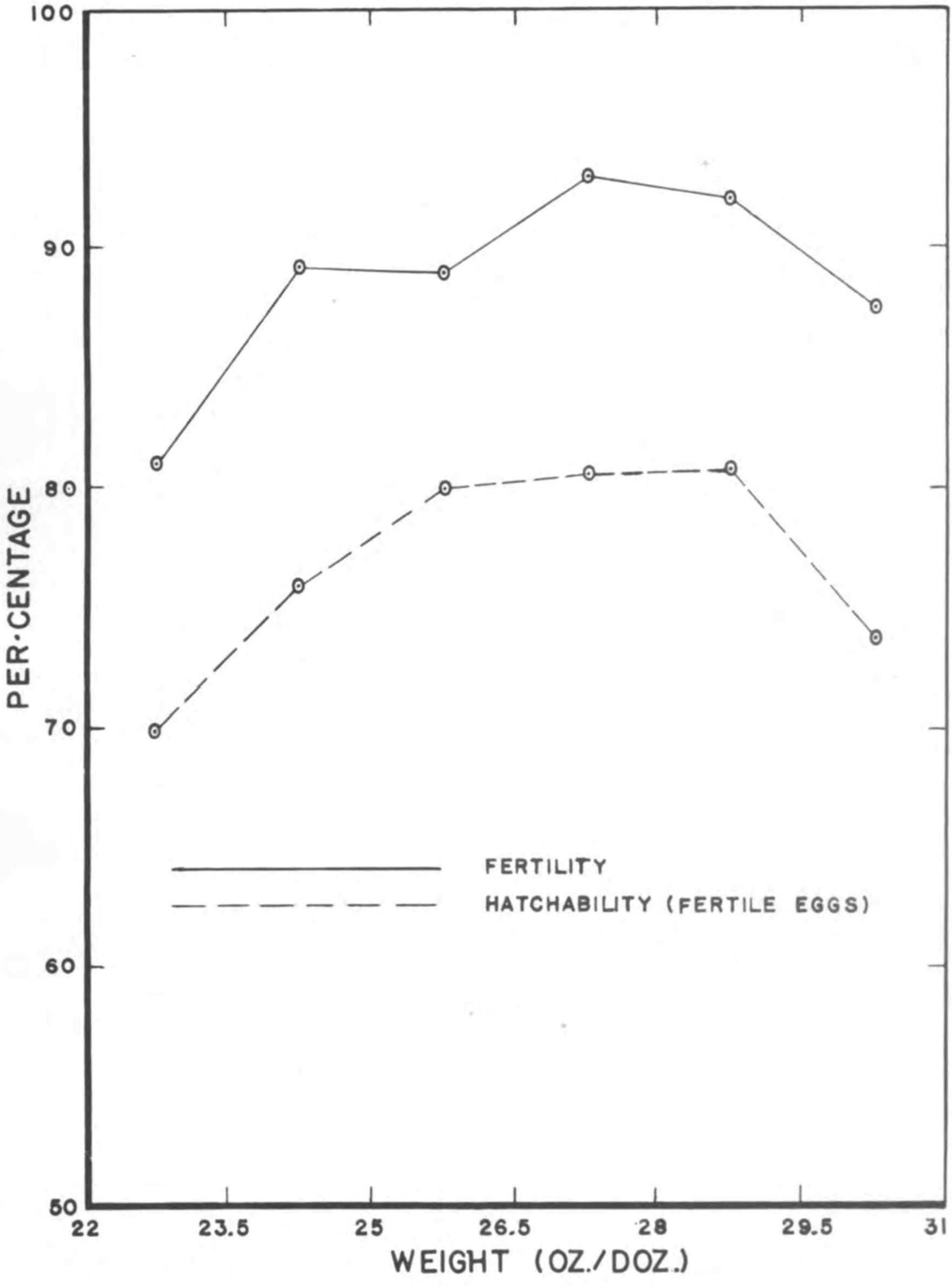

Fig. 8--Relation of egg weight to hatchability and fertility.

test for independence based upon hatch of fertile eggs yields a value of 9.115 whereas it should be as high as 11.070 to reach the .05 point of significance. The failure to obtain significant differences in this data, even though the percentage hatch differs considerably, is largely due to the small number of eggs in the two extreme egg weight classes.

Table 3 -- Egg weight as related to fertility and hatchability.

Egg weight (oz./doz.)	Eggs set	Fertility	Hatch of fertile eggs	Hatch of all eggs
	No.	%	%	%
22 - 23.5	90	81.1	69.9	56.7
23.5 - 25	320	89.1	75.8	67.5
25 - 26.5	515	88.9	79.9	71.1
26.5 - 28	608	92.9	80.5	74.8
28 - 29.5	402	92.0	80.8	74.4
29.5 - 31	144	87.5	73.8	64.6

That fertility tends to increase with increase in egg weight is interesting (Table 3 and Fig. 8). This close correlation between fertility and hatchability of fertile eggs is in line with the commonly reported observation of hatcherymen that when fertility is high hatchability is also high. No definite explanation can be given for this relationship between fertility and hatchability of eggs of various weight classes. However, it is conceivable that if an appreciable percentage of embryos died at such early stages of development as to be unnoticed macroscopically in the broken out egg and hence classified as infertile, it is logical that there would be more such cases in groups of eggs with low hatchability than in groups of eggs with high hatchability.

The results with regard to egg weight differ from those reported by other investigators in that the extremely large eggs hatched better than the small eggs, and in that maximum hatchability was obtained in eggs weighing from 25 - 29.5 oz./doz. instead of from approximately 24 - 26 oz./doz. This could be due, in part, to the fact that very few eggs over 31 oz./doz. (73 grams) were produced and these were excluded from these studies. Examination of the data of Axelsson (4, p.31) and of Godfrey (19, p.295) show their extremely low hatchability was obtained from eggs weighing more than 70.5 and 72 grams, respectively. These figures would correspond to egg weights of 29.8 and 30.5 ounces per dozen.

The probable cause of the differences between these data and that presented by other investigators is the extremely large average egg size found in this strain of New Hampshires. The fact that maximum hatchability was obtained in the eggs weighing very close to the flock mean (26.72 oz./doz.), which is approximately 2 oz./doz. heavier than normal, indicates that hatching results do not depend upon absolute egg size, but rather upon genetic and physiological factors controlling egg size. Eggs deviating greatly in size from the average are produced under abnormal physiological conditions (47, p.81) and do not hatch as well (13, p.110). Thus, it might be expected that the 22 - 23.5 oz./doz. eggs used in this study would hatch poorly, since they deviate greatly from the mean egg weight.

Although Fig. 1 indicates that small eggs tend to be lighter in color than large eggs, this was found by weighting to have little influence upon the variation in hatchability due to egg weight.

Fig. 9 shows the effect of egg size upon hatchability of three specific gravity groups -- low (under 1.075) medium (1.075 to 1.0825) and high (above 1.0825). It can be seen that the large eggs gave the highest average hatchability in the medium and high specific gravity groups and the lowest hatchability in the low specific gravity group. The hatching power of the small eggs was relatively low in all three specific gravity groups, but somewhat better in the two groups of eggs having the higher specific gravity scores. It is interesting that the curve obtained in the low specific gravity eggs is very similar to that observed by other investigators representing hatchability of all fertile eggs. No explanation can be given for this phenomenon.

Color.

Eggs with medium to dark brown egg shell color hatched better than did either the light or very dark colored eggs. (Fig. 10 and Table 4). When the data are tested statistically with the chi square test, a value of 17.30 is obtained, which is significant at the .01 error point.

As previously pointed out (Fig. 7) egg shell color has an influence on the hatchability of low specific gravity eggs. By classifying the eggs into three specific gravity groups, it can be seen

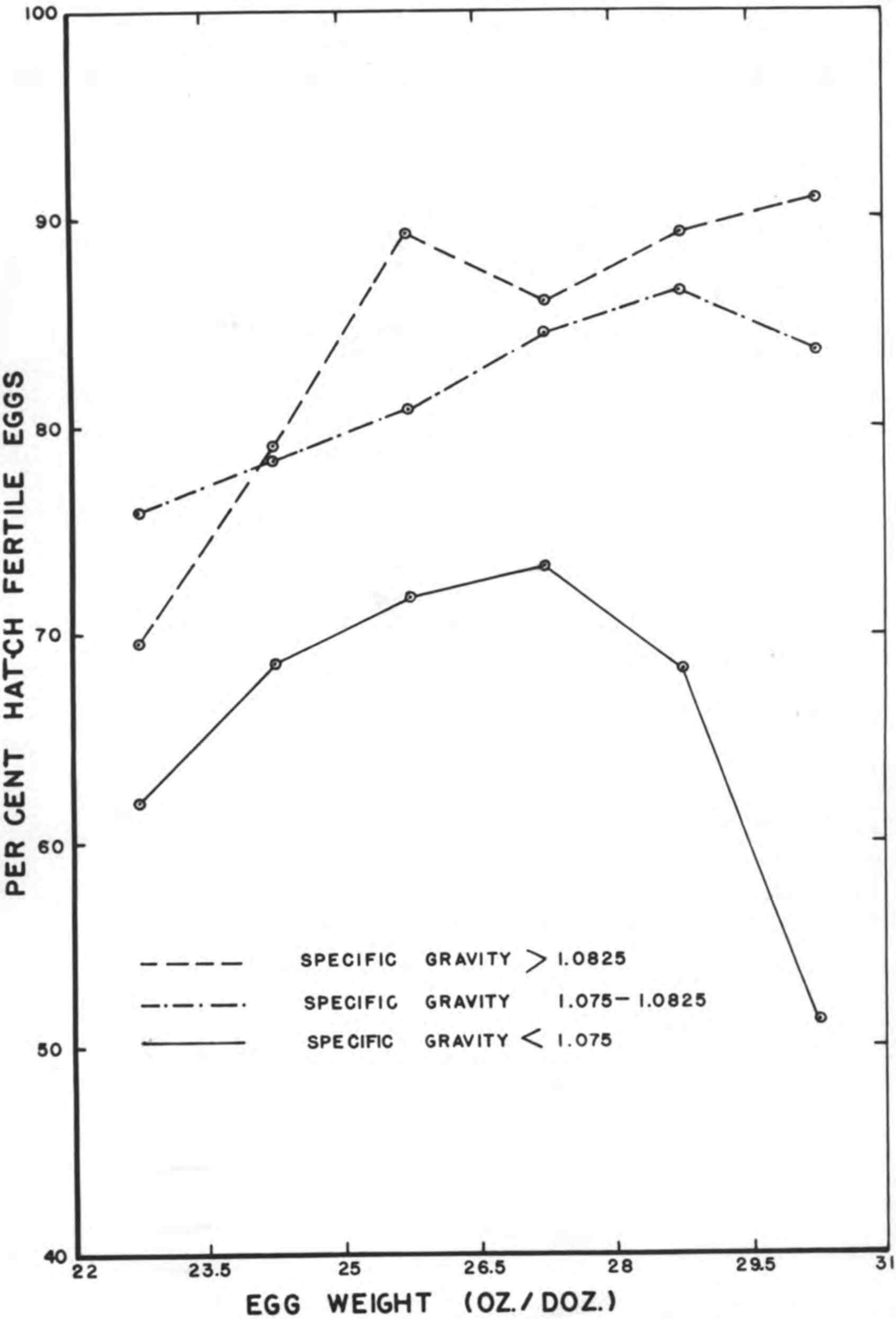

Fig. 9--Relation of egg weight to hatchability in low, medium and high specific gravity eggs.

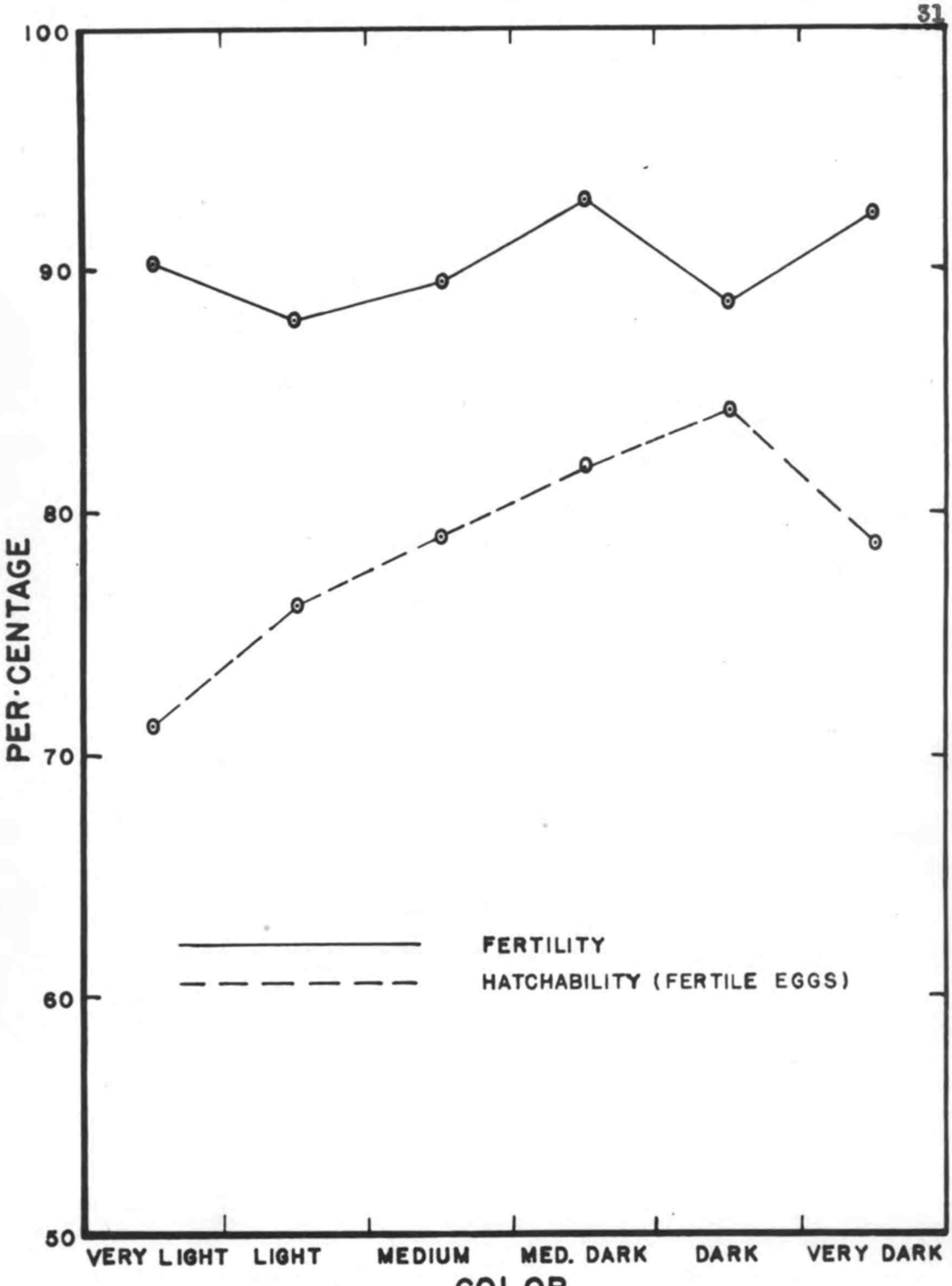

Fig. 10--Relation of egg shell color to hatchability and fertility.

(Fig. 11) that shell color has little effect upon hatchability in eggs whose specific gravity is greater than 1.0775. With eggs below 1.0775 in specific gravity the very light, light and very dark colored eggs hatched very poorly.

The tendency for eggs with extremely dark shell color to hatch poorer than eggs with a medium to dark brown color (Table 4 and Fig. 10) is in agreement with previous observations at this station by Hopp and Mikesell (unpublished). Godfrey (20, p.387) (21, p.882) and Funk and Forward (17, pp.578-579) found that very dark brown eggs tend to be laid by low producing hens. This may account for the fact that in the present investigations very dark eggs gave poorer hatching results than medium to dark eggs. To test this hypothesis, all hens

Table 4 -- Egg shell color as related to fertility and hatchability.

Color	Eggs Set	Fertility	Hatch of fertile eggs	Hatch of all eggs
	No.	%	%	%
Very light brown	273	90.1	71.1	64.1
Light brown	314	87.9	76.1	66.9
Medium brown	339	89.4	78.9	70.5
Medium dark brown	362	92.8	81.8	76.0
Dark brown	376	88.6	84.1	74.5
Very dark brown	415	92.3	78.6	72.5

which laid throughout the 12-day period in which eggs were saved for hatching were classified according to rate of lay and egg shell color. The analysis of variance using the number of eggs laid by each hen during the 12-day period shows that classes of hens laying different

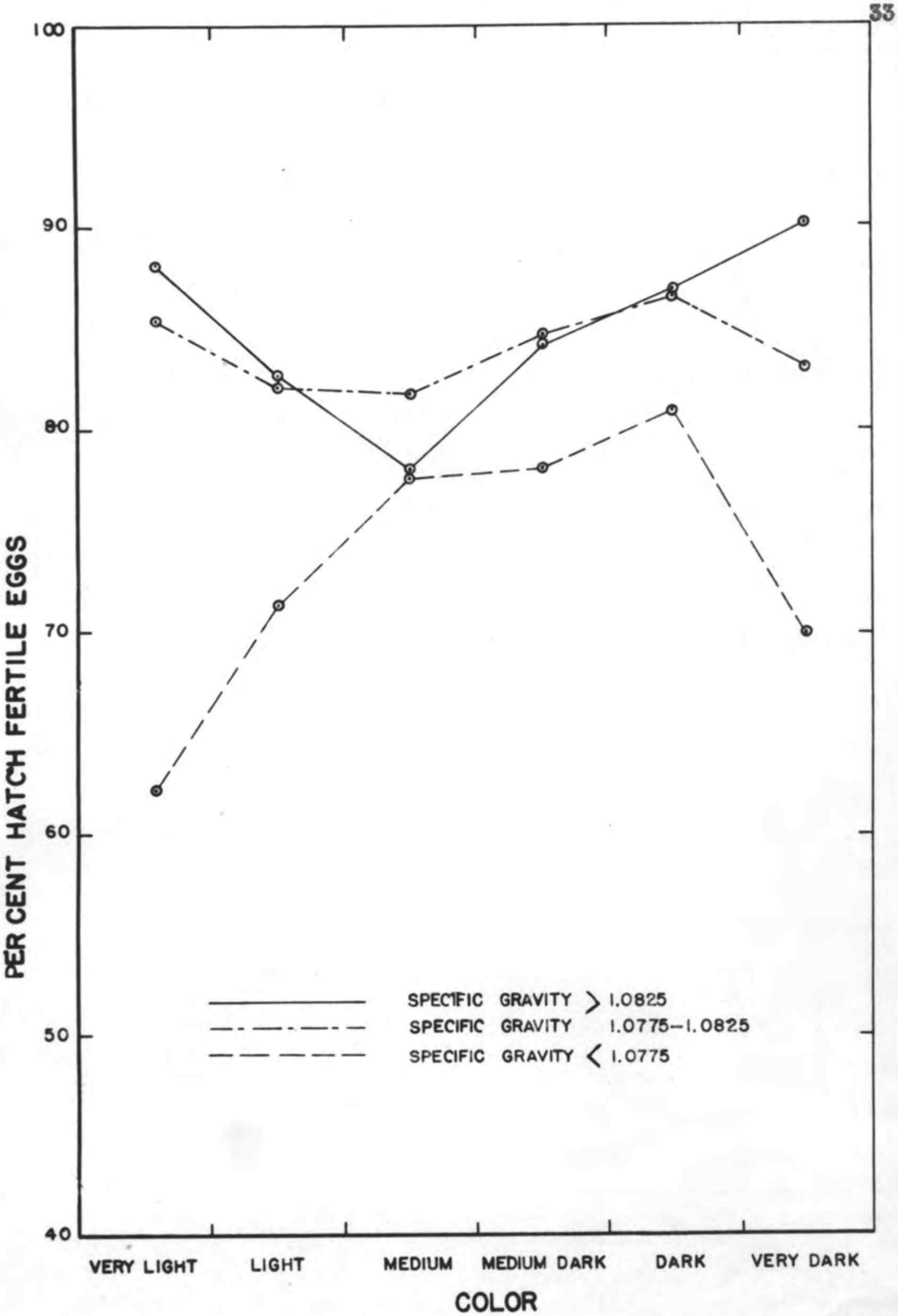

Fig. 11--Relation of egg shell color to hatchability in high, medium and low specific gravity eggs.

colors of eggs do not differ significantly with respect to their rates of egg production. Table 5 likewise shows that there is very little relationship between the color of eggs hens lay and rate of lay. Thus, it would appear that the effect of egg shell color upon hatchability of hens' eggs is not influenced by differences in intensities of egg production of hens laying eggs of different colors.

Table 5 -- Egg shell color as related to intensity of production.

Average shell color	Number hens	Average per cent production
Very light brown	45	66.29
Light brown	49	65.81
Medium brown	54	67.59
Medium dark brown	54	65.27
Dark brown	53	70.10
Very dark brown	24	65.47

Time of Lay.

The results of observations on the effect of time of day eggs are laid on their hatchability are shown in Table 6. Since only a very few eggs were laid after 3 P.M., no class is included for eggs laid after that time. Except for eggs laid between 1:30 and 3 P.M., hatchability decreased as the time of laying was later in the day. However, the differences in hatchability between the groups of eggs laid at various times during the day were not statistically significant (chi square value 3.719 $<$ P.05). There was no apparent relationship between time of lay and fertility.

When the data relative to time of lay and hatchability were considered on the basis of rate of lay of the hens, it was observed that

Table 6 -- Time of lay as related to fertility and hatchability.

Time of lay	Eggs set	Fertile	Hatch of fertile eggs	Hatch of all eggs
	No.	%	%	%
Before 7:30	242	88.8	82.3	73.1
7:30 - 9:00	544	91.5	79.7	73.0
9:00 - 10:30	469	90.4	78.1	70.6
10:30 - 12:00	350	89.4	78.9	70.6
12:00 - 1:30	274	88.7	75.7	67.2
1:30 - 3:00	200	92.0	78.3	72.0

eggs from hens laying 75 per cent or better (for the 12-day period of egg collection) hatched at a relatively uniform rate regardless of time of day the eggs were laid (Fig. 12). With hens that laid less than 75 per cent, hatchability of eggs was highest for eggs laid before 7:30 A.M. and next highest for eggs laid between 7:30 and 9 A.M. Hatchability of eggs laid during the later periods of the day by low intensity hens was relatively constant and considerably below the hatchability of eggs from the better laying or high intensity hens for corresponding times of the day. A number of investigators including Jull (32, p.329), Byerly, Titus and Ellis (11, p.21), Funk (14, p.10) and Bernier (6, p.58) have reported that hatchability of hens' eggs is positively correlated with current egg production.

The observation in this study that the effect of time of lay on hatchability is influenced by the rate of production of hens may be at

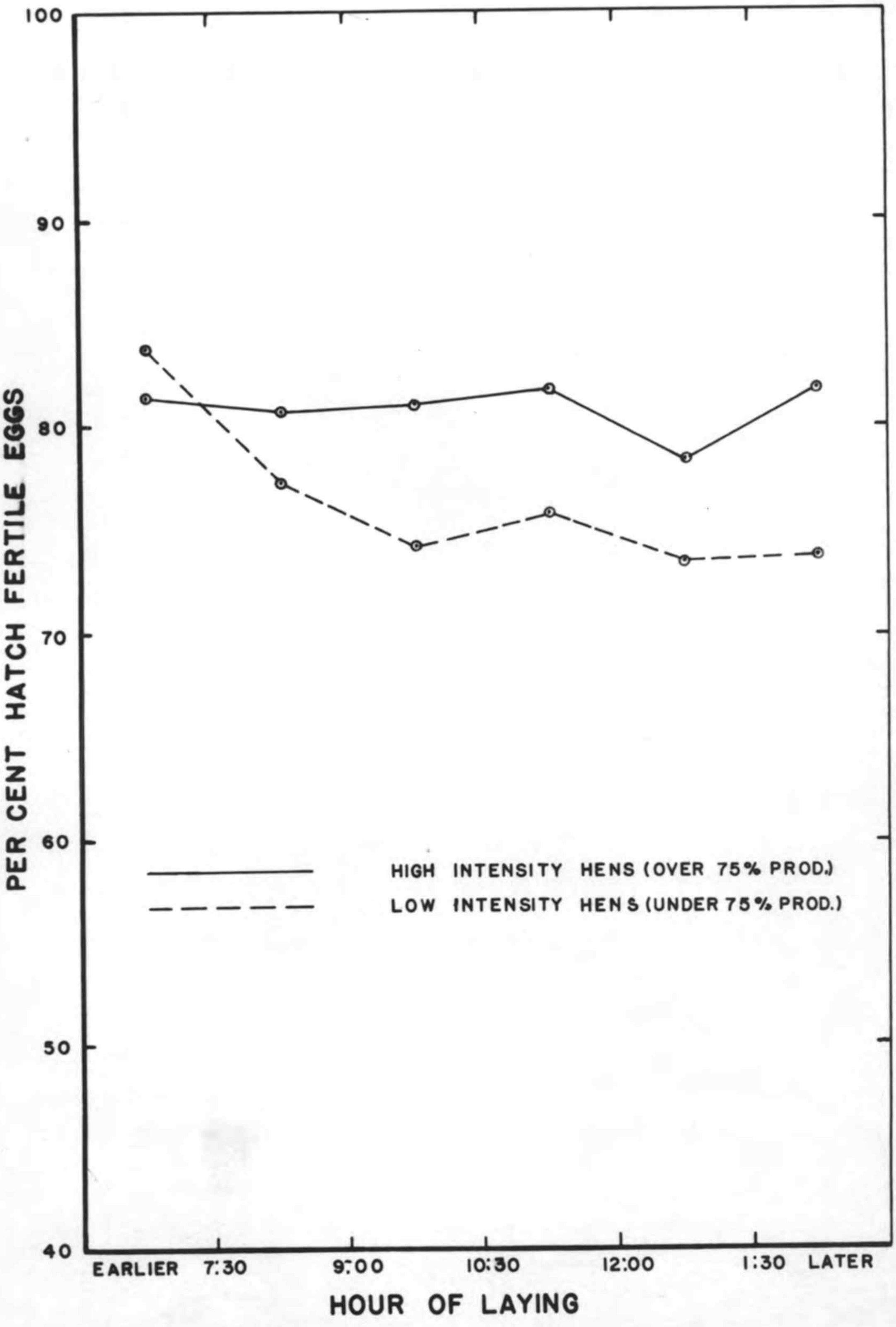

Fig. 12--Relation of hour of day to hatchability of eggs from high intensity and low intensity hens.

least a partial explanation for the differences in the results of different investigators, which have been previously pointed out.

The decrease in hatchability of eggs laid later in the day by low intensity hens might be due to increased time intervals between successive eggs in a clutch. McNally and Byerly (38, p.281), Hays (24, p.637) and Bernier (6, p.63) have shown that eggs laid with short and long time intervals after preceeding eggs hatched less well than eggs laid with intermediate intervals. Table 7 shows the relation of time of lay to time interval between eggs in a clutch. The data show that the average time interval between eggs laid by both high and low intensity hens is longer in eggs laid in the afternoon. However, the average time interval between eggs laid at any period of the day after 7:30 A.M. is somewhat longer in eggs laid by low intensity hens than for eggs laid by high intensity hens.

Table 7 -- Relation of time of day eggs are laid to time interval between successive eggs of a clutch.

Time of lay	Time intervals	
	High intensity hens (over 75% production)	Low intensity hens (under 75% production)
	hours	hours
Before 7:30	24	24
7:30 - 9:00	24.6	24.8
9:00 - 10:30	25.3	25.7
10:30 - 12:00	25.6	26.3
12:00 - 1:30	26.4	27.2
1:30 - 3:00	26.8	27.6

The hatchability of eggswhich occupy the first clutch position and of eggs laid at various time intervals thereafter is given in

Table 8. The observed differences in hatchability are not statistically significant and indicate that eggs laid after intermediate time intervals hatch no better than eggs laid after longer or shorter time intervals. The observation that time interval is not significantly related to hatchability of hens' eggs is not in agreement with that found to exist by previous investigators. Eggs laid in the first clutch position hatched at approximately the same rate as eggs later in the cycle. The respective hatch of fertile eggs being 82.3 and 80.6 per cent in eggs from hens in 75 per cent production or better and 77.4 and 77.5 per cent in eggs from hens laying less than 75 per cent. These data do not mean that eggs of all clutch positions hatch equally well, but rather the average hatchability of eggs laid subsequent to the first egg of each clutch is equal to that of the first eggs.

Since eggs of the first clutch position hatched as well as subsequent eggs and since length of time interval between subsequent eggs was not related to hatchability the decreased hatching power of eggs from low intensity hens laid after 9:00 A.M. must be due to factors other than the length of time interval between eggs.

Table 8 -- Relation of time interval between successive eggs of a clutch and hatchability in high and low intensity hens.

Time Interval	High intensity hens*		Low intensity hens**		Pooled	
	Fertile eggs	Hatchability	Fertile eggs	Hatchability	Fertile eggs	Hatchability
Hours	No.	%	No.	%	No.	%
1st eggs of clutch	220	82.3	314	77.4	534	79.4
24	272	79.4	59	77.9	331	78.9
25.5	336	81.2	149	73.1	485	78.9
27	174	81.0	158	79.7	332	80.4
28.5	32	84.4	70	80.0	102	81.4
30			12	75.0	12	75.0

*over 75% production.
**under 75% production.

DISCUSSION

The results of this study are in agreement with earlier workers by indicating that specific gravity of eggs is correlated with hatchability. This was true regardless of egg shell color, egg size or hour of lay. However, an increase in intensity of egg shell color lowers the "critical point" in specific gravity below which hatchability declines very rapidly (Fig. 7); these points being 1.0775 for light brown eggs, 1.075 for medium brown eggs and 1.0725 for dark brown eggs. This observation is significant in that it points out that the value of the specific gravity test in selecting hatching eggs may depend upon the variation in egg shell color or upon factors involved during the disposition of shell pigments. It also shows that it would be possible for the hatcheryman to subject only light shell colored eggs to the specific gravity test and obtain nearly as great an improvement in hatchability as by taking the specific gravity of all eggs. A comparison of the two methods in these data show that by measuring the specific gravity of all eggs (2079) and discarding 33.2 per cent (690) below specific gravity 1.075, the percentage hatch of all eggs was improved 4.1 per cent. Upon taking the specific gravity of 587 light colored eggs and discarding 60 per cent (352) below specific gravity 1.0775 the percentage hatch of all eggs set was improved 2.9 per cent. A similar comparison, based on fertile eggs show improvements of 4.7 per cent and 3.0 per cent, respectively.

Further evidence showing that specific gravity of eggs is primarily concerned in the hatchability of light colored eggs is presented in Fig. 11. Eggs with specific gravity scores above 1.0775 hatched better than eggs with specific gravity scores below this point in eggs of each color grade. However, the difference in hatchability in favor of the eggs with specific gravity scores above 1.775 is only 4.2 to 6.5 per cent in the medium and dark brown eggs while it is 25.9 per cent greater in the very light brown eggs and 11.4 per cent greater in the light brown eggs.

On the basis of these data it would seem that the improvement in hatchability which could be obtained by taking the specific gravity of all eggs would not justify the extra work and expense of producing extra hatching eggs. On the other hand, by taking the specific gravity of only the light shell colored eggs the work required would be reduced to approximately one-half, while the improvement in hatchability would be roughly three-fourths of that obtained by taking the specific gravity of all eggs. It should be pointed out, however, that Munro obtained an 8.3 per cent increase in hatch of total eggs by eliminating only 22 per cent of the eggs. Later work by Munro (40, p.704) has shown that when there is wide variation in specific gravity of eggs the specific gravity test is most efficient as a measure of hatchability. This latter observation may account for the difference in results since the variation in specific gravity of eggs used in these investigations was considerably less than the variation in specific gravity of eggs in Munro's experiments.

The observation that low specific gravity eggs (below the "critical point" 1.075) laid by high producing hens hatch considerably better than similar eggs laid by low producing hens is significant in that it points out that the effect of specific gravity upon hatchability is not entirely due to weight loss during incubation, but is directly related to physiological factors concerned in the formation of the shell. It also indicates that the improvement in hatchability which may be attained through the selection of hatching eggs on the basis of their specific gravity may be greater during periods or seasons when rate of egg production is low. This is further pointed out by the fact that the difference in hatchability between eggs above and below the "critical point" is considerably greater in eggs laid by low producing hens.

The observation that a higher percentage of eggs laid by low producing hens are low in specific gravity as compared to eggs laid by high producing hens points out that selection of hatching eggs on the basis of their specific gravity would not result in a high proportion of eggs from the best layers being discarded. The data, although limited to a 12-day hatching period, do not indicate that continued selection of hatching eggs for high specific gravity to improve hatchability would have an adverse affect on egg production, but rather suggest that such a practice would increase the percentage of chicks coming from high producing hens.

The fact that egg shell color is not related to hatchability in medium and high specific gravity eggs (Fig. 11) may explain the lack of relationship between these factors which has been reported in high hatchability strains, Brooks and Ellis (unpublished data quoted from 50, p.4) and in some strains bred for meat production, Skoglund (50, p.6). It is possible that the variability of egg shell quality in these strains was small and that the majority of the hens laid eggs of good shell quality. As the influence of egg shell color is restricted to low specific gravity eggs, it is conceivable that in flocks that produce eggs of uniformly good shell texture (i.e. eggs with uniformly high specific gravity) color of shell would bear little if any relationship to hatchability. Also, since there is a seasonal effect on egg shell thickness (54, p.71) shell color might be related to hatchability of eggs produced at one season and might not be related to hatchability at another season or period when the shells of eggs are thicker and more uniform.

It is difficult to explain the observation that large eggs (29.5 to 31 oz./doz.) which have medium and high specific gravity scores gave the best hatching results while large eggs with low specific gravity gave the poorest. (Fig. 9). It is likely that under incubation conditions which are optimal for "normal eggs", evaporation is probably too high for small eggs and too low for excessively large eggs. The fact that the large, high specific gravity eggs which would have a comparatively lower weight loss during incubation gave the highest hatchability indicates the possibility that under our incubation conditions above normal evaporation occurred. On the other hand, the fact that in the low specific gravity group the large eggs hatched more poorly than medium and small eggs (Fig. 9) would not indicate that evaporation was excessive, but rather that other factors are involved. Before definite conclusions can be drawn these data should be verified by further work and correlated with actual weight loss during incubation.

The results of this study with regard to the influence of hour of lay upon hatchability are in agreement with those of Hutt and Pilkey (30, p.202) and Pritsker (45, quoted from 36, p.105) by indicating that the hatching quality of eggs laid before 9 A.M. is slightly better than eggs laid during the afternoon. However, the increased hatching power of early morning eggs in these investigations is restricted to eggs from low intensity hens (below 75 per cent). The fact that eggs from high intensity hens (above 75 per cent) hatched relatively uniform throughout the day may explain why Hays (25, p.89) was unable to detect any relationship between hour of lay and hatchability in the Massachusetts strain of Rhode Island Reds bred for high egg production. It appears that hens which are physiologically capable of laying at a high rate will produce eggs of high hatchability regardless of the time of day they are laid.

No relation between time interval between eggs and hatchability could be detected in eggs from either the high or low intensity hens. This is interesting in view of the results of Bernier (6, p.99) and McNally and Byerly (38, p.281) which showed that time interval between eggs was a reliable index of the degree of embryonic development at the time of laying and also was related to hatchability.

Since length of time interval between eggs is highly correlated with embryonic development at the time of lay it appears that the latter does not account for the poorer hatching results obtained from eggs laid after 9 A.M. by low intensity hens. It seems likely that these differences are due to the fact that a positive correlation exists between rate of production and hatchability (Table 2) and that the best layers in this group produce the majority of eggs laid before 9 A.M., with poor layers laying most of their eggs later in the day. Such an explanation is in harmony with the observation of Funk (15, p.187) that the use of all night lights tends to minimize the differences in hatchability which exist between eggs laid at different hours of the day.

SUMMARY

During the period from May 8th to May 19, 1950, 2079 eggs from the Oregon State College flock of New Hampshires were classified according to weight, shell color, specific gravity and hour of lay.

The following partial correlation coefficients were calculated between the measurements: color x specific gravity, .142; color x weight, .242; color x time of lay, .008; specific gravity x weight, -.058; specific gravity x time of lay, .066; and weight x time of lay, -.072. All are significant at the .01 level except between color and time of lay.

Hatchability data show that high specific gravity eggs hatched significantly better than low specific gravity eggs. The difference in hatchability between eggs above specific gravity 1.075 (critical point) and eggs below specific gravity 1.075 was greater in eggs laid by low producing hens and in light shell colored eggs. Eggs laid by low producing hens have the lowest average specific gravity scores as well as the highest percentage of their eggs below the "critical point".

Egg shell color was related to hatchability in low specific gravity eggs, but not in medium and high specific gravity eggs. In the low specific gravity group medium and dark colored eggs hatched significantly better than either light or extremely dark colored eggs.

Eggs weighing between 25 and 29.5 oz./doz. gave higher hatchability than eggs weighing from 22 to 25 or from 29.5 to 31 oz./doz.

No relationship between hour of lay and hatchability could be detected in eggs from high producing hens (over 75 per cent production). Eggs laid before 9 A.M. by low producing hens hatched better than eggs laid later in the day. These differences could not be attributed to the length of time interval between eggs.

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