

STRAIN DIFFERENCES IN EMBRYONIC
AND EARLY CHICK GROWTH

by

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ABSTRACT

The extent to which egg weight modifies genetic differences in body weight of the embryo and chick and the correlation between embryonic growth rate and post-hatching growth rate were investigated. This was done by studying the relationships between (1) egg weight and body weight of embryo and chick; (2) strain and body weight of embryo and chick; (3) strain and percentage growth rate of embryo and chick; and (4) the relationship between embryonic growth rate and post-hatching growth rate.

This study was conducted on five strains and one strain-cross. Two of the strains were bred for meat, (White Plymouth Rock and White Cornish); two were bred for high egg production, (White Leghorns); and one was an intermediate type, (White New Hampshire). The strain-cross was derived from mating males of one White Leghorn strain with females of the other. Individual egg weights were recorded for over 2,200 eggs. Between nine and eighteen embryos of each category were weighed from each of two incubators from the ninth to the eighteenth day of incubation. Between fifteen and thirty-three chicks of each category were weighed at hatching and at weekly intervals for three weeks.

Analyses of variance of embryonic weights, chick weights, and embryonic or chick weights expressed as percentages of egg weight were done. Analyses of variance were also done on embryonic and post-hatching growth rates. Coefficients of correlation (r) between egg weight and embryonic or chick weight and also coefficients of regression of chick weight on egg weight were computed. The correlation between embryonic and post-hatching growth rates was estimated.

From the results of the above tests it was concluded that: (1) Differences in embryonic weights among the strains were due to differences in inherent genetic factors; (2) Egg weight exerted a temporary measurable influence on embryonic and chick weight, the effect being greatest at hatching; (3) Differences in post-hatching growth rate among the strains were probably due to differences in nutritional factors which contributed to a more efficient utilization of nutrients by the heavy type chicks; and (4) Approximately 65 per cent of the variation in post-hatching growth rate to three weeks of age was dependent on the variation in growth rate during the nine- to fourteen-day incubation period. The estimate of correlation between growth rate during these two periods was, however, not precise.

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INTRODUCTION

The ultimate size of an organism is under the joint control of genetic and environmental factors. The study of the comparative effects of genetic and environmental influences has posed problems for investigators of size inheritance in many organisms. Numerous investigators have used the domestic fowl for such studies. Some have confined their attention to the influence of environmental factors such as egg weight and hereditary factors such as breed or strain on body weight. A large proportion of these investigators was interested in the economic implications of the problem e.g. the effect of hatching-egg weight on growth of the chick to fryer age. They concerned themselves with the post-hatching period of development. Others, whose interests were more academic, studied the influence of egg weight and hereditary factors on embryonic growth. The contributions of both categories of investigators are briefly reviewed below.

REVIEW OF THE LITERATURE

One of the earliest reports on the influence of egg weight on chick weight was submitted by Halbersleben and Mussehl (1922). They found the average weight of the chick at hatching was 64 per cent of initial egg weight and, at thirty-five days after hatching, the chicks from small eggs were approximately the same average weight as were those from large eggs. Upp (1928) found the weight of chicks at hatching to be approximately 68 per cent of egg weight. He also found that egg weight and day-old chick weight were unreliable indices of chick weight at two, four, and twelve weeks of age.

Jull and Heywang (1930) likewise concluded that, regardless of initial egg weight, the percentage chick weight at hatching tends to be constant. They, too, found that chick weight at hatching averaged about 68 per cent of initial egg weight. Byerly (1930) reported that chick embryos of different breeds differed little in size when developed in eggs of the same size. Later on he postulated, "major differences in embryo size among embryos of like age could be satisfactorily accounted for by differences in egg size". He concluded without proof that the effect of egg size on embryo size is certainly apparent by the seventh day of incubation (Byerly, 1932). In contrast Wiley (1950a) obtained eggs from a strain of Barred Plymouth Rocks that laid large eggs, and from another that laid small eggs. He studied the development of embryos at seventy-two hours, fourteen days, and nineteen days and found no consistent differences in weight. However, he did suggest that space in the egg shell during the last two or three days of incubation has a significant effect on chick size at hatching. Wiley (1950b) also studied the effect of egg weight on the growth of Barred Plymouth Rock and White Wyandotte chicks. He found that a high correlation existed at hatching. This correlation was markedly reduced in magnitude by the third week and continued to diminish subsequently. Kosin et al. (1952) studied the influence of egg weight on actual body weight gain of the chick from hatching to twelve weeks of age. They reported that though egg size frequently exerted a significant influence on chick growth, breed and sex differences in the chicks caused extreme variations in the relationship and precluded generalizations. However, the mean growth rate determined by actual gain in body weight of chicks from large eggs was, in general, slightly greater than that of chicks from small eggs. Goodwin (1961) carried on investigations to fryer age and studied the

relationship between chick size at hatching and growth rate. He found that chick weight at hatching exerted an important effect on growth to fryer age. Bray and Iton (1962) studied the effect of egg weight on embryonic and post-hatching weight of five strains of fowl from the sixth day of incubation to eight weeks after hatching. They ranked the strains on the basis of embryonic weight and determined the correlation between these ranks and rankings of the parents' body weights and egg weights. They observed that the ranks of embryonic weights changed from a perfect correlation with parental weight at eleven days of incubation to a perfect correlation with egg weight at hatching and returned to a close relationship with parental weights at two weeks after hatching. They concluded that egg weight exerted a temporary environmental influence which concealed genetic differences in embryonic and early post-hatching growth among strains. The above investigations indicate that egg weight exerts a pronounced influence on growth during the late stage of incubation and the early post-hatching period. The evidence they provide about the influence of egg weight on the early and intermediate stages of embryonic growth is inconclusive.

Investigation of the effect of breed or strain on growth has been equally extensive as that of egg weight on growth. Henderson (1930) measured the wet weight, dry weight, and total nitrogen content of Dark Cornish and White Leghorn embryos from four to twenty days of incubation and found little difference between the breeds. Byerly (1930), in a previously mentioned study, used embryos of Rhode Island Reds, White Leghorns, and reciprocal crosses between the two. He observed that embryos of Rhode Island Reds and cross-

breeds were somewhat heavier than White Leghorn embryos from the tenth day of incubation to hatching. In eggs of the same weight from the two breeds the embryo-size difference tended to disappear toward hatching time. Blunn and Gregory (1935) measured growth by weight, cell counts, and mitotic figure counts at seventy-two hours, fourteen days, and nineteen days of incubation. They observed a consistent difference between White Leghorn and Rhode Island Red embryos in the rate of cell proliferation. The difference in the number of cells per unit volume was less at nineteen days than at fourteen days or at seventy-two hours. In spite of significant differences in the rate of cell proliferation, these investigators found no significant breed differences in embryonic weights. Byerly, Helsel, and Quinn (1938), studied embryos of White Leghorns, Silkies, Rhode Island Reds, and reciprocal crosses of Silkies and Rhode Island Reds. They found that during the period from the eleventh to the seventeenth day embryos of heavier parents were, in general, slightly heavier than embryos of lighter parents, even from eggs of similar weight. McNary, Bell, and Moore (1960) studied the growth of inbred and crossbred embryos of White Leghorns, Rhode Island Reds, and New Hampshires. They measured growth rate by counting the number of somites present after thirty-eight hours of incubation. They also recorded embryo weights after one week and two weeks of incubation. They reported significant genetic differences in all three measurements. Egg weight had little effect on embryonic weight because it explained only 0.06 per cent of the variation in embryonic weight at one week and 3 per cent of the variation at two weeks of age. Bray and Iton (1962) likewise observed genetic differences in embryonic weight. The differences were significant from the tenth day of incubation.

ation onwards.

It is evident from the foregoing review that genetic differences in growth are discernible from the early stages of embryonic development. These differences were mostly differences in actual weight of the embryos or chicks. Few investigators of size inheritance in poultry have attempted to determine genetic differences in growth on the basis of the percentage or relative rate of increase in body weight per unit time. Those who have attempted such comparisons have used mathematical formulae involving either the calculation of differences in actual weight at two or more periods of time or the fitting of an equation to the data collected. Lerner and Asmundson (1932) applied a formula of the former type to the study of growth rate of Light Sussex, Anconas, and crosses of the two breeds from three to twelve weeks after hatching. They obtained significant genetic differences. Asmundson and Lerner (1933), employing the same type of formula, found significant differences between White Leghorn families in rate of growth from two to eight weeks after hatching. Other workers have applied variations of the second type of formula to the study of embryonic growth in the domestic fowl but these applications were not designed to determine genetic differences in growth rate in this species. For instance, Murray (1925) and Brody (1927) were interested in finding linear equations that would express the relative rate of growth of the chicken embryo. Byerly (1932) used a similar type of equation to demonstrate growth rates of embryos from different genetic sources but he assumed that the rates of growth of the different types of embryos were identical. Henderson and Penquite (1934) used Brody's equation to compare embryonic growth rates of chickens with those of turkeys, ducks and geese.

The above review of literature indicates that both egg weight and inherent genetic factors influence embryonic and post-embryonic growth. It does not, however, indicate clearly the extent to which egg weight modifies genetic differences. Neither does it indicate the extent to which embryonic growth rate and post-embryonic growth rate are correlated. This study was undertaken to investigate these problems. The purpose was to study the relationships between (1) egg weight and body weight of embryo and chick; (2) strain and body weight of embryo and chick; (3) strain and percentage growth rate of embryo and chick; and (4) the relationship between embryonic growth rate and post-hatching growth rate.

The fourth aspect of this study may have practical significance. Exhaustive investigations of this aspect may indicate whether or not there is a high correlation between embryonic growth rate and post-hatching growth rate. If it can be established that a high correlation exists then evaluation of growth rate of prospective breeding stock can be made on the basis of embryonic growth rate. Thus strains that are undesirable with respect to this characteristic can be eliminated at the embryonic stage. This practice would have the advantages of reducing rearing costs and accelerating a breeding programme.

MATERIALS AND METHODS

Five strains and one strain-cross were used in this study. The parent stock was part of the flock of The University of British Columbia. The strains were of the following varieties: White Plymouth Rock, White New Hampshire, White Cornish, and White Leghorn. The strain-cross was derived from the mating of two White Leghorn strains. For the sake of convenience all six categories will hereafter be referred to as strains. They will be designated WR, WH, WC, MH, UBC, and MHxUBC, respectively. MH and UBC were White Leghorn strains, and MHxUBC was obtained from mating MH males and UBC females. WR, WH, and WC were classified as heavy or meat types, and the White Leghorns as light or egg types. On the basis of body weight at sexual maturity, the parent stock was ranked in the following ascending order of magnitude: MH, UBC, WH, WC, and WR.

Hatching eggs were collected for fourteen days. Eggs were collected at mid-morning and mid-afternoon periods and stored in a room at approximately 55°F. More frequent collections were not made because the air temperature of the hen houses was considered to be low enough to prevent embryonic development. The eggs were weighed daily to the nearest gram. Table 1 shows the mean egg weights.

The total egg collection of each strain was divided into twenty-two groups. In order to minimize differences due to the effect of storage on embryonic development, eggs were assigned at random to these groups in such a way that, in general, not more than three eggs from any day were included in a group. The twenty-two groups of eggs from each strain were divided into

two subgroups of eleven. One subgroup was incubated in each of two Jamesway Model 2940 incubators. Eggs were set in eleven trays of each machine. There were six sections in each tray. Eggs from each strain occupied one section chosen at random. The trays were numbered consecutively and each was assigned a position in the incubator at random. The numbers determined the order in which the trays were withdrawn.

Embryos were weighed from the ninth to the eighteenth day of incubation. One tray was withdrawn daily from each incubator. Each developing embryo was removed from its shell and separated from its extra-embryonic membranes by cutting the yolk stalk at its proximal end. An attempt was made to remove as much amniotic fluid as possible by placing the embryo momentarily on a paper towel before weighing. The embryo was then transferred to a balance and weighed to the nearest one-hundredth of a gram. The weights of any embryos showing obvious abnormalities such as deformed beaks or undeveloped eyes were not recorded because the weights of such embryos were considered likely to bias the results. Table 2 shows the mean weights of the embryos, Tables 3a and 3b show the variability of the weights, and Table 4 shows the number of embryos weighed and the number discarded.

The eleventh tray of eggs in each incubator was candled on the nineteenth day and the fertile eggs were transferred to the hatching compartment to hatch individually. On the twenty-second day the chicks were removed from the incubators, wing-banded and weighed to the nearest gram. The chicks from both incubators were grouped according to strain and assigned at random to six compartments in a battery brooder. They were weighed at weekly intervals to three weeks of age. Table 2 shows the mean weights of chicks and Tables 5a and 5b show the variability of chick weights.

STATISTICAL METHODS

The experimental design was that of a randomized complete-block with subsampling. Incubators were considered to be blocks and each developing embryo was considered to be a subsample of an experimental unit. This design was chosen in order to determine whether or not there was a significant interaction between incubators and strains. Consequently incubator effects, strain effects and incubator-strain effects were considered to be fixed and sampling error was used for testing hypotheses concerning interaction and strain effects.

From the ninth day of incubation to the eighteenth day inclusive subsamples of nine embryos were selected at random for analyses of variance. On the twenty-second day six chicks were similarly selected. Nine embryos and six chicks were the maximum numbers that could be thus selected in order to have equal numbers from each strain. Analyses of variance were done on embryonic weights, egg weights, embryonic weights expressed as percentages of egg weights, and also on growth rates. Analyses of variance of egg weights were done on the eggs that yielded the selected embryos or chicks.

The validity of the assumption of homogeneity of variances of the subsamples selected for analysis was verified by Bartlett's test. Variances of embryonic weights were heterogeneous on the tenth, twelfth, and thirteenth days. Variances of embryonic weights expressed as percentages of egg weights were heterogeneous on the tenth, thirteenth, and seventeenth days, and variances of egg weights were heterogeneous on the tenth day. These variances were

not analyzed. Analyses of variance were not done on the grand total of pooled subsamples of egg weights because Bartlett's test showed that the variances were heterogeneous. The alternative approach of conducting separate analyses of variance on egg weights subsampled each day was resorted to because variances were homogeneous on every day except the tenth. Duncan's new multiple-range test as described by Steel and Torrie (1960) was used to make comparisons among strain means in all analyses of variance where significant differences were indicated. Tukey's test for non-additivity was applied to the embryonic weights expressed as percentages of egg weights in order to determine whether or not a transformation was necessary. Snedecor (1956) advocates the use of this test for this purpose.

Another method used to examine the data was the determination of the product moment coefficients of correlation between egg weight and embryonic or chick weight. From the ninth day of incubation to hatching coefficients were computed separately for each strain and each incubator. Separate analyses were done in order to compare the results obtained from each incubator. Since the chicks were separated after hatching on the basis of strain and not on the basis of the incubator in which they were hatched, computation of the coefficients on the latter basis was not justified for the post-hatching period. For the correlation analyses the weights of all embryos and chicks and the weights of the eggs that yielded them were used. Coefficients of regression of chick weight on egg weight were also computed.

A method different from those described above was adopted to examine the effect of strain on embryonic and post-hatching growth rate. Growth rate

in this report means the percentage increase in body weight at any instant. The computation of growth rate was based on the exponential function proposed by Brody (1927). The function is:

$$W = Ae^{kt}$$

where

W = the weight of the embryo or chick at any observation point,

t = the time, i.e. the day or week at which the observation was made,

e = the base of natural logarithms,

k = a constant which when multiplied by 100 gives the percentage growth rate,

and A = the weight of the individual when $t = 0$.

The parameter A has only theoretical significance. It does not indicate the actual weight of the zygote at time zero, the instant of fertilization. Extrapolation of this value to time zero is not justified because the constant was computed from data for the ninth day of incubation onwards.

The above function was used because it provided a means of comparing the strains on the basis of percentage increase in weight rather than on actual increase in weight per unit time. The former basis was preferred because the object of interest was increase per unit weight. The natural logarithm of the function provided the equation, $\ln W = \ln A + kt$, from which the curves were plotted on arith-log paper. This equation was fitted to the data by the method of least squares.

Byerly (1932) criticized Brody's method of fitting a straight line by inspection to points plotted on arith-log paper. He stated that the eye is a poor judge of goodness of fit. Because of this criticism Student's t test was applied to the data to determine whether or not there was a linear relationship between $\ln W$ and t for each strain.

Differences in growth rate among the strains were tested for significance by analyzing the variance of rate of growth from day to day in the case of embryos and from week to week in the case of chicks. The variables to which the analyses of variance were applied were obtained from the equation $k = \frac{\ln W_2 - \ln W_1}{t_2 - t_1}$, where the subscripts 1 and 2 indicate the weights of the individuals at the beginning (t_1) and at the end (t_2) respectively, of the period. $t_2 - t_1$ was equal to unity in every case.

To determine whether there was a significant relationship between growth rate during the embryonic period and growth rate during the three-week post-hatching period, product moment coefficients of correlation were computed for the following time intervals: (1) nine to fourteen days of incubation, and zero to three weeks after hatching; and (2) fifteen to eighteen days of incubation and zero to three weeks after hatching. The fifteen- to eighteen-day rather than the fourteen- to eighteen-day period was chosen because there were no flexures in any of the curves during the former interval. The growth rates used in this analysis are presented in Table 17.

RESULTS AND DISCUSSION

The results of Bartlett's test of homogeneity of variance are presented in Tables 6a and 6b, and those for analyses of variance of embryonic and chick weights are presented in Table 7. The last table shows that differences among strains were highly significant at all observation points from the ninth to the eighteenth day of incubation, but were not significant on the twenty-second day. Significant differences are indicated in Table 8.

Embryos of the heavy strains were significantly heavier than MH embryos from the ninth to the eighteenth day. This finding is similar to that of Bray and Iton (1962), who, working with embryos from the same gene pool, obtained similar significant differences from the tenth to the seventeenth day. WR embryos were significantly heavier than MHxUBC embryos from the eleventh to the sixteenth day, and were significantly heavier than UBC embryos from the fourteenth to the eighteenth day. UBC and MHxUBC embryos were generally not significantly heavier than MH embryos.

The average weights of the meat-type embryos were greater than those of the egg-type embryos on every day for which tests were performed except the ninth day of incubation. The MH strain which ranked highest in egg weight ranked lowest in embryonic weight on every day except the eighteenth day of incubation. These results clearly demonstrate genetic differences in embryonic weight from the eleventh to the eighteenth day of incubation.

Table 9 shows the results of analyses of variance of egg weights based on a completely random design. There were non-significant differences

on all but the eleventh and twelfth days. Since for the most part there were no significant differences among egg weights, the significant differences among embryonic weights were attributed to inherent genetic factors that influenced growth of the embryos. This finding is contrary to Byerly's postulate that major weight differences among embryos of the same age can be satisfactorily accounted for by differences in egg weight.

Egg weights did not differ significantly on the eighteenth day or at hatching. Embryonic weights differed significantly on the eighteenth day, but chick weights at hatching did not. Consequently, it was concluded that egg weight, or, more precisely, yolk weight exerted an influence on embryonic weight between the eighteenth day of incubation and hatching. This was expected since yolk absorption occurs during this interval, and according to Jull and Heywang (1930) yolk material accounts for 15.30 per cent to 19.92 per cent of chick weight at hatching.

Embryonic weights expressed as percentages of egg weights are shown in Table 10. Results of Tukey's test for non-additivity are shown in Table 11. This test indicated that the percentages did not require transformation. Consequently, analyses of variance were conducted on the actual percentages. Table 12 shows that there were genetic differences at all ages except at hatching. On the twelfth day an interaction between incubators and strains was present. There was no reason to believe that this type of interaction would occur on one day only. Therefore this occurrence was attributed to sampling error.

Table 13 shows that, except on the twelfth day, embryonic weights expressed as percentages of egg weight were not significantly different among heavy strains on the days for which the test was performed. In contrast there were significant differences among the light strains on every day except the fifteenth and sixteenth. The heavy strains all ranked higher than the light ones on every day except the eleventh and twelfth. The measurements of the heavy strains were significantly greater than those of the MH on all days, but there were fluctuations in the significance of the differences among the heavy strains and the other two light ones. On all days the MH strain ranked lowest in measurement. These results agree substantially with those for actual body weight and manifest genetic differences in embryonic growth. In all strains chick weight averaged about 68 per cent of initial egg weight. This value agrees with those of Upp (1928) and Jull and Heywang (1930).

Heavy-type embryos accounted for a significantly greater percentage of their egg weights than MH embryos did up to the eighteenth day but there were no significant differences at hatching. This evidence suggested that the yolk absorbed by MH embryos towards the end of the incubation period represented a greater percentage of chick weight than it did in the heavy strains. This phenomenon indicates either that yolk weight accounted for a greater percentage of initial egg weight in the MH strain than it did in the heavy ones or that the heavy-type embryos utilized a greater percentage of their yolk prior to the eighteenth day than MH embryos did. The findings of Jull and Heywang (1930) provide evidence to support this conclusion. These authors calculated the mean percentage yolk weight of egg weight for different hens and found significant differences between several pairs of hens. They also

found that there were significant differences in the rate of assimilation of yolk material by the embryos from different White Leghorn hens.

Coefficients of correlation (r) between egg weight and embryonic or chick weight are presented in Tables 14a and 14b. In at least one incubator all the strains showed evidence of a consistent increase in the magnitude of the coefficients as hatching time approached. The trend to consistent increase in magnitude began on the thirteenth day of incubation in the WH strain. In the WR and light strains it began on the sixteenth day, and in the WC strain on the seventeenth day. The coefficients reached a maximum at hatching and declined thereafter. A few significant values were obtained before the seventeenth day of incubation but were not part of a consistent trend and were therefore considered to have occurred by chance. After the seventeenth day significant correlation existed for longer periods in the heavy strains than it did in the light ones. In the heavy strains correlation was significant by at least the eighteenth day in one incubator and continued to be significant at least to the end of the first week after hatching. In contrast, correlation in the light strains was significant only at hatching. At this stage high positive coefficients existed for all strains. There was thus no difference in the duration of the period for which significant values existed in the light strains but there were differences in the duration among the heavy strains. Significant values for WH existed from the seventeenth day of incubation to one week after hatching. For WR the correlation was significant from the eighteenth day of incubation to one week after hatching and for WC significant values were indicated from the eighteenth day of incubation to two weeks after hatching. These results show that significance of the correlation between egg

weight and embryonic or chick weight was different among the heavy strains and more pronounced in these strains than in the light ones.

The differences in the duration of a significant correlation may be associated with differences in the stage of development at which the yolk was absorbed by the embryos and differences in the rate at which it was utilized by the chicks after hatching. Perhaps the yolk of heavy strains started passing into the intestine at an earlier stage than it did in the light ones and was absorbed at a slower rate by the chicks of the heavy strains. Romanoff (1960) reported that yolk persists for varying periods of time in different chicks. The periods, he stated, range from two to thirty-four or more weeks.

Table 15 shows the results of the analysis of regression of chick weight on egg weight. As was expected these results were similar to those of the correlation analysis. At hatching the coefficients of all strains were significant. Thereafter values of the light strains were non-significant. At one week of age the WR coefficient was significant at the 1 per cent level, whereas the WC and WH coefficients were significant at the 5 per cent level. At two weeks of age the WC coefficient was still significant at the 5 per cent level, whereas the others were non-significant. All values were non-significant at the end of the third week. Coefficients at hatching indicated that the increase in chick body weight that could be expected per gram increase in egg weight ranged from an average of 0.66 grams in the MHxUBC strain to an average of 0.84 grams in the WR and MH strains. According to magnitude of regression coefficient the strains ranked in the following ascending order: MHxUBC, WC, WH, UBC, WR, MH. There was thus no obvious relationship between magnitude of coefficient and type of chick i.e. meat or egg type.

The analyses of variance, correlation and regression considered jointly showed that significant strain differences in body weight existed between the ninth and eighteenth days of incubation, that any such differences which might have been present at hatching were almost entirely masked by the effect of egg weight and that there were strain differences in significance of the relationship between egg weight and body weight to two weeks after hatching.

The results of Student's *t* test which was applied to show the relationship between the natural logarithm of body weight and time are presented in Table 16. The test showed that there was a linear relationship between these two variables in each strain. Figures 1 and 2 demonstrate growth rate plotted on arith-log paper and Figures 3a to 4b demonstrate curves of growth plotted on arithmetic coordinate paper. The curves in Figures 1 and 2 show for each strain three periods of different growth rate between the ninth day of incubation and three weeks after hatching. The rate of growth during each period was calculated as a constant. For all strains except UBC and MH the periods occurred between (1) the ninth and fourteenth days of incubation; (2) the fourteenth and eighteenth days of incubation; and (3) hatching and three weeks thereafter. The second period for UBC was different; it occurred between the fourteenth and seventeenth days of incubation. The first and second periods for MH were different; they occurred between the ninth and fifteenth days of incubation and between the fifteenth and eighteenth days of incubation respectively.

These results conform with patterns observed by previous investig-

ators. Brody (1927) found that the relative rate of growth of the chick embryo tends to remain constant during certain intervals. Henderson and Brody (1927) reported that the chicken embryo passes through several distinct stages of growth during which the percentage-rate of growth is constant and that percentage-rate diminishes progressively from stage to stage. They also stated that the rates of growth as well as the duration of each stage are influenced by temperature. Romanoff (1929) suggested that there are at least three well-defined cycles of embryonic growth in the chicken; one of these ends at nine and another at sixteen days of incubation. He, too, observed that a change in incubation temperature can shift the time of occurrence of the cycles. Henderson (1930) suggested that these stages were more closely related to attained weight than to time. The data of the present study indicate that the stages were more closely related to time than to weight, because changes in growth rate occurred on the fourteenth day of incubation in strains among which there were highly significant differences in embryonic weight.

Growth rates are presented in Table 17 and results of the analyses of variance of growth rates in Tables 18a and 18b. There were no significant differences in the rate of embryonic growth among strains or between heavy and light types, but there were significant differences in the rate of post-hatching growth among strains and highly significant differences between heavy and light types. The heavy types considered as a group grew at a significantly greater rate than the light types considered as a group.

The evidence so far considered indicates that differences in embryonic weights were significant but differences in embryonic growth rates were not

significant. This situation is explicable on the basis of the nature of the growth process. Reproducing cells tend to reproduce exponentially, i.e. at a constant percentage rate in a geometric progression. In this manner two individuals differing in initial weight may double their weights in the same time interval, but the one with the greater initial weight will be the heavier at the end of the interval. Thus minute differences at the beginning will show up as considerable differences at a later stage. Differences in weights may, therefore, be simply a reflection of differences in the sizes and, by inference, the weights of zygotes which gave rise to the embryos. There are reports indicating that differences in cell size may be responsible for differences in total size of an organism. Lerner (1937) has cited a number of workers who have found that body size was roughly proportional to cell size.

The existence of significant differences in embryonic weight and non-existence of significant differences in embryonic growth rate may also be explained in other ways. For instance it is possible that the test applied to the growth rate data was not sufficiently sensitive to detect such differences. It is also possible that differences in growth rate were so small as to be not significant at this stage. Another factor that might have influenced the results of the test on embryonic growth rate is that growth rate was calculated on the basis of average weights of different groups of embryos rather than on the same individuals from day to day.

The last factor mentioned above did not exist during the post-hatching period because growth rate was computed on the basis of observed weights of the same individuals throughout this period. This may be one of the reasons for significant differences being manifest during this period and not during the

embryonic period. But different environmental conditions might also have had a bearing on the magnitude of differences in growth rate at this stage. For example the source of nutrients during the post-hatching period was the ration fed to the chicks whereas the source of nutrients during the embryonic period was the egg. It is possible that the faster growing strains utilized nutrients from the ration more efficiently than the slower growing ones did during the post-hatching period whereas during the embryonic period there was no difference in the efficiency of utilization of nutrients among the strains. Another condition involving differences in efficiency of utilization of nutrients during the post-hatching period might have had some influence on the magnitude of differences in growth rate. It concerns the duration of the period in which egg weight was significantly correlated with chick weight. The suggestion was made in an earlier discussion that the yolk persisted for a longer period in the heavy type chicks than it did in the light type ones. If this longer persistence did occur then it is possible that the yolk material with its high fat content enabled the heavy type chicks to utilize the protein in the ration more efficiently than the light ones did. The significantly greater growth rate of the heavy type chicks probably resulted from a more efficient utilization of protein in the ration. Card (1961) has reported that during the early post-hatching weeks chicks utilize protein with increasing efficiency as the percentage of fat in the diet increases. There is, of course, a limit to the extent to which the percentage of fat may be increased with beneficial results.

The final phase of the investigation involved the determination of coefficients of correlation between embryonic growth rate and post-hatching growth rate. The coefficient of correlation (r) between growth rates for the

periods nine to fourteen days of incubation and zero to three weeks after hatching was 0.805. This value is significantly different from zero at the 10 per cent level, but not at the 5 per cent level where a value of 0.811 is required for significance. The 95 per cent confidence limits for this estimate were -0.02 and 0.95. Approximately 65 per cent of the variation in post-hatching growth rate to three weeks of age was dependent on the variation in growth rate during the nine- to fourteen-day incubation period. However, an estimate of correlation with so wide a confidence interval is not precise and was therefore considered to be of little practical importance. A coefficient of -0.45 was obtained for the periods fifteen to eighteen days of incubation and zero to three weeks after hatching.

In evaluating the results of this study one must bear in mind that the sample sizes were small. Small sample size imposes certain limitations on an experiment. The most important of these limitations are that (i) the smaller the sample size the less accurate is an estimate of a parameter likely to be; and (ii) a test performed on a sample that is too small is more likely to fail to detect significant differences than one performed on a sample that is large.

Another point that must be considered in evaluating the results is that an implied assumption in all the tests used to investigate differences in embryonic weight and growth rate was that the average incubation temperature was optimum for all the strains. Should this assumption be erroneous the results could be misleading.

If investigation of the correlation between embryonic and post-hatching growth rates is to be conducted with a view to applying the results to breeding programmes, the problem of possible differences in optimum incubation temperature among strains will have to be considered. The importance of this consideration suggested itself when differences in the time of occurrence of flexures in the growth curves were observed. Henderson and Brody (1927) and others have shown that temperature greatly affects the position of flexures in the growth curve of the chicken embryo and also in the value of k , the relative rate of growth. A unit change in incubation temperature may not affect embryonic growth of different strains to the same extent. Consequently it is conceivable that, for different incubation temperatures, the correlation between embryonic and post-hatching growth rates may vary among strains in such a way as to complicate interpretation of the results. Such complications would have a bearing on any generalizations that may be made about the relationship. This problem of different optimum incubation temperatures is a question arising from the present study that may warrant further investigation.

CONCLUSIONS

The conclusions that can be drawn from the foregoing results apply only to the embryos and chicks that were used in this study and to the conditions under which the investigation was conducted. The conclusions are:

- (1) Differences in embryonic weights among the strains from nine to fourteen days of incubation were due to differences in inherent genetic factors.
- (2) Egg weight exerted a temporary measurable influence on embryonic and chick weight. This influence was evident from the last four or five days of incubation to two weeks after hatching. At hatching the effect of egg weight almost completely concealed the effect of strain on chick weight.
- (3) Differences in post-hatching growth rate among the strains were probably due to differences in nutritional factors which contributed to a more efficient utilization of nutrients by the heavy type chicks.
- (4) Approximately 65 per cent of the variation in post-hatching growth rate to three weeks of age was dependent on the variation in growth rate during the nine- to fourteen-day incubation period. The estimate of correlation between growth rate during these two periods was, however, not precise. i.e. the true value of the estimate could not be established within narrow limits.

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TABLE 1

MEAN EGG WEIGHTS IN GRAMS

WR	WC	WH	UBC	MH
62.26 \pm 4.35	60.54 \pm 4.42	62.27 \pm 4.90	61.73 \pm 3.75	62.68 \pm 4.42

TABLE 2

MEAN EMBRYONIC AND CHICK WEIGHTS IN GRAMS

(AVERAGES OF ALL EMBRYOS AND CHICKS WEIGHED)

	Days of Incubation										Weeks After Hatching			
	9	10	11	12	13	14	15	16	17	18	22	1	2	3
WR	1.55	2.52	3.47	5.51	7.29	11.16	13.78	17.32	20.72	23.46	43.85	96.08	169.38	264.12
WC	1.51	2.37	3.43	5.26	6.91	10.51	12.72	16.29	20.35	23.02	40.33	90.43	174.57	283.62
WH	1.52	2.47	3.34	5.01	6.97	10.42	13.26	17.10	20.87	25.10	43.42	89.00	166.52	261.30
UBC	1.54	2.25	3.29	4.65	6.63	9.30	11.88	15.73	19.50	21.46	41.78	80.65	142.12	209.65
MHxUBC	1.56	2.24	3.20	5.02	6.48	10.00	12.21	15.55	19.46	22.84	42.38	76.90	142.76	212.05
MH	1.35	2.11	3.04	4.20	5.65	9.04	11.66	14.99	18.34	21.47	42.12	79.69	140.47	207.06

TABLE 3a

VARIABILITY OF EMBRYONIC WEIGHTS

Day	Incub- ator	WR			WC			WH		
		No. of Embryos	Mean Wt (GM)	Standard Deviation (GM)	No. of Embryos	Mean Wt (GM)	Standard Deviation (GM)	No. of Embryos	Mean Wt (GM)	Standard Deviation (GM)
9	1	13	1.44	+0.17	10	1.47	+0.19	18	1.39	+0.18
	2	15	1.65	+ .54	16	1.54	+ .19	16	1.67	+ .21
10	1	15	2.53	+ .19	14	2.39	+ .22	14	2.54	+ .15
	2	14	2.52	+ .14	15	2.35	+ .29	17	2.41	+ .15
11	1	15	3.57	+ .42	12	3.42	+ .41	17	3.47	+ .26
	2	14	3.37	+ .25	12	3.43	+ .30	17	3.22	+ .30
12	1	12	5.74	+ .47	11	5.65	+ .29	15	5.19	+ .59
	2	15	5.33	+ .40	13	4.93	+ .56	18	4.86	+ .75
13	1	16	7.42	+1.24	14	7.08	+1.22	14	7.37	+ .92
	2	15	7.14	+ .92	13	6.73	+ .54	18	6.66	+ .59
14	1	16	11.28	+0.79	10	10.74	+0.94	15	10.65	+1.03
	2	13	11.01	+1.12	13	10.33	+ .81	17	10.22	+1.27
15	1	10	13.91	+1.19	14	13.04	+ .92	17	12.82	+1.04
	2	13	13.68	+ .85	13	12.37	+1.10	16	13.73	+1.07
16	1	10	17.06	+ .93	16	16.43	+1.31	15	16.74	+1.74
	2	9	17.62	+1.43	13	16.11	+ .91	17	17.43	+1.24

TABLE 3a (continued)

Day	Incub- ator	WR			WC			WH		
		No. of Embryos	Mean Wt (GM)	Standard Deviation (GM)	No. of Embryos	Mean Wt (GM)	Standard Deviation (GM)	No. of Embryos	Mean Wt (GM)	Standard Deviation (GM)
17	1	14	20.66	± 2.01	12	19.90	± 1.70	17	21.04	± 1.53
	2	16	20.78	± 1.98	10	20.89	± 1.75	13	20.64	± 1.01
18	1	15	23.97	± 1.07	14	23.25	± 1.11	15	25.24	± 2.51
	2	9	22.60	± 2.51	16	22.81	± 1.66	17	24.97	± 2.24

TABLE 3b

VARIABILITY OF EMBRYONIC WEIGHTS

Day	Incub- ator	UBC			MHxUBC			MH		
		No. of Embryos	Mean Wt (GM)	Standard Deviation (GM)	No. of Embryos	Mean Wt (GM)	Standard Deviation (GM)	No. of Embryos	Mean Wt (GM)	Standard Deviation (GM)
9	1	10	1.48	+0.20	10	1.45	+0.11	12	1.26	+0.19
	2	11	1.60	$\pm .19$	14	1.65	$\pm .17$	10	1.45	$\pm .08$
10	1	12	2.21	$\pm .24$	13	2.36	$\pm .16$	11	2.03	$\pm .15$
	2	12	2.29	$\pm .21$	13	2.12	$\pm .29$	13	2.17	$\pm .13$
11	1	9	3.32	$\pm .19$	14	3.13	$\pm .32$	13	3.22	$\pm .18$
	2	12	3.27	$\pm .23$	11	3.30	$\pm .21$	10	2.81	$\pm .23$
12	1	13	4.74	$\pm .36$	14	5.13	$\pm .33$	12	4.22	$\pm .55$
	2	11	4.54	$\pm .18$	12	4.89	$\pm .31$	12	4.18	$\pm .49$
13	1	12	6.99	$\pm .71$	13	6.63	$\pm .25$	12	6.04	$\pm .39$
	2	13	6.30	$\pm .67$	12	6.32	$\pm .92$	14	5.32	$\pm .60$
14	1	12	9.26	+1.16	10	9.93	$\pm .49$	12	9.30	$\pm .79$
	2	10	9.36	$\pm .84$	12	10.06	$\pm .73$	9	8.69	$\pm .65$
15	1	11	11.89	+1.07	13	12.33	$\pm .71$	12	12.00	$\pm .93$
	2	9	11.87	$\pm .57$	12	12.07	+1.24	13	11.35	$\pm .85$
16	1	14	16.01	+1.24	13	15.92	$\pm .61$	11	15.37	+1.42
	2	11	15.37	+1.00	11	15.11	+1.51	13	14.68	+1.04

TABLE 3b (continued)

Day	Incub- ator	UBC			MHxUBC			ME		
		No. of Embryos	Mean Wt (GM)	Standard Deviation (GM)	No. of Embryos	Mean Wt (GM)	Standard Deviation (GM)	No. of Embryos	Mean Wt (GM)	Standard Deviation (GM)
17	1	13	19.53	± 1.47	13	19.61	± 1.14	12	18.51	± 1.17
	2	11	19.46	± 1.64	13	19.30	± 1.57	13	18.19	± 2.13
18	1	9	21.97	± 1.96	12	23.60	± 2.17	13	22.29	± 1.78
	2	12	21.09	± 2.00	14	22.20	± 1.88	10	20.40	± 1.45

TABLE 4

TOTAL NUMBER OF EMBRYOS EXTRACTED		
	Number Weighed	Number Discarded
WR	269	4
WC	261	3
WH	323	1
UBC	227	0
MHxUBC	249	2
MH	237	0

TABLE 5a

VARIABILITY OF CHICK WEIGHTS

Week	Incub- ator	WR			WC			WH		
		No. of Chicks	Mean Wt (GM)	Standard Deviation (GM)	No. of Chicks	Mean Wt (GM)	Standard Deviation (GM)	No. of Chicks	Mean Wt (GM)	Standard Deviation (GM)
0	1	13	44.00	+ 4.91	12	41.67	+ 3.96	19	43.74	+ 4.62
	2	13	43.69	+ 3.31	9	38.56	+ 3.37	14	43.00	+ 2.45
1		26	96.08	+11.31	21	90.43	+10.19	33	89.00	+ 7.74
2		26	169.38	+19.74	21	174.57	+20.08	33	166.52	+16.94
3		26	264.12	+28.18	21	283.62	+36.22	33	261.30	+37.50

TABLE 5b

VARIABILITY OF CHICK WEIGHTS

Week	Incub- ator	UBC			MHxUBC			MH		
		No. of Chicks	Mean Wt (GM)	Standard Deviation (GM)	No. of Chicks	Mean Wt (GM)	Standard Deviation (GM)	No. of Chicks	Mean Wt (GM)	Standard Deviation (GM)
0	1	10	41.80	+ 3.03	12	41.67	+ 1.89	10	42.30	+ 2.86
	2	8	41.75	+ 3.67	9	43.33	+ 2.36	6	41.83	+ 3.39
1		17	80.65	+ 7.37	21	76.90	+ 7.10	16	79.69	+ 5.00
2		17	142.12	+13.56	21	142.76	+15.20	15	140.47	+10.08
3		17	209.65	+24.28	21	212.05	+27.49	16	207.06	+14.71

TABLE 6a

RESULTS OF BARTLETT'S TEST OF HOMOGENEITY OF VARIANCE

 $\chi^2_{.05}$ for 5 degrees of freedom = 11.1

Day	Embryo or Chick Weight	χ^2	
		Embryo or Chick Weight as % Egg Weight	Egg Weight
9	1.90	1.33	5.39
10	16.07 ^{AA}	154.46 ^{AA}	12.15 ^A
11	7.20	4.23	2.08
12	22.39 ^{AA}	10.99	8.73
13	19.89 ^{AA}	17.90 ^{AA}	5.39
14	9.54	10.72	3.26
15	1.72	7.13	3.35
16	7.50	0.79	3.55
17	9.96	13.60 ^A	4.06
18	8.36	5.66	3.91
22	3.48	5.18	2.06

^{AA} Significant at P=0.01

^A Significant at P=0.05

TABLE 6b

RESULTS OF BARTLETT'S TEST OF HOMOGENEITY OF VARIANCE

$$\chi^2_{.05} \text{ for } 5 \text{ degrees of freedom} = 11.1$$

χ^2		
9-14 days incubation	15-18 days incubation	0-3 weeks post-hatching
10.59	4.14	3.93

TABLE 7

ANALYSES OF VARIANCE OF EMBRYONIC AND CHICK WEIGHTS

Source of Variation	Degrees of Freedom	Mean Squares							
		Day							
		9	11	14	15	16	17	18	22
Incubators(I)	1	1.17	0.35	4.69	1.00	3.86	0.01	20.23	1.39
Strains (S)	5	0.14 ^{AA}	0.40 ^{AA}	11.51 ^{AA}	11.67 ^{AA}	13.32 ^{AA}	23.49 ^{AA}	30.89 ^{AA}	11.12
I x S	5	0.01	0.19	0.60	1.10	2.59	3.26	6.19	26.92
Sampling Error	96 (60)#	0.03	0.10	0.87	1.07	1.63	3.18	4.46	11.62
Total	107 (71)#	1.35	1.04	17.67	14.84	21.40	29.94	61.77	51.05

^{AA} Significant at P=0.01

Statistic for 22nd day.

TABLE 8

RESULTS OF DUNCAN'S NEW MULTIPLE-RANGE TEST USED
ON MEAN EMBRYONIC AND CHICK WEIGHTS IN GRAMS

Age (Days)							Standard Error of The Mean
9	MH 1.34	WC <u>1.46</u>	WH 1.54	MHxUBC 1.56	UBC 1.56	WR <u>1.56</u>	<u>+0.04</u>
11	MH 3.04	MHxUBC <u>3.18</u>	UBC <u>3.28</u>	WH 3.33	WC 3.42	WR 3.43	<u>+0.08</u>
14	MH <u>8.95</u>	UBC <u>9.27</u>	MHxUBC <u>10.01</u>	WH 10.30	WC <u>10.50</u>	WR 11.11	<u>+0.22</u>
15	MH <u>11.76</u>	UBC 11.81	MHxUBC <u>12.18</u>	WC <u>12.54</u>	WH <u>13.34</u>	WR 13.69	<u>+0.24</u>
16	MH 15.12	MHxUBC 15.32	UBC <u>15.82</u>	WC 16.48	WH <u>16.62</u>	WR 17.38	<u>+0.31</u>
17	MH 18.03	UBC <u>19.39</u>	MHxUBC <u>19.81</u>	WC 20.73	WR 20.88	WH 20.98	<u>+0.42</u>
18	UBC <u>21.38</u>	MH 21.46	MHxUBC <u>22.79</u>	WC 23.10	WR <u>23.18</u>	WH 24.92	<u>+0.50</u>
22	MH <u>41.75</u>	WH 41.75	WC 41.83	UBC 42.17	MHxUBC 42.42	WR <u>44.25</u>	<u>+0.98</u>

Any values not underscored by the same line are significantly different.

Any values underscored by the same line are not significantly different.

TABLE 9

ANALYSES OF VARIANCE OF EGG WEIGHTS

Source of Variation	Degrees of Freedom	Mean Squares									
		Day									
		9	11	12	13	14	15	16	17	18	22
Strains	5 (5)#	14.54	73.86 ^{★★}	45.13 [★]	21.40	23.93	21.16	10.25	43.47	52.51	6.11
Error	102 (66)#	16.89	20.91	18.63	16.24	15.68	16.79	17.45	22.23	25.26	18.88
	107 (71)#	31.43	94.77	63.76	37.64	39.61	37.95	27.70	65.70	77.77	24.99

★★ Significant at P=0.01

★ Significant at P=0.05

Statistic for 22nd day

TABLE 10

EMBRYONIC AND CHICK WEIGHTS EXPRESSED AS PERCENTAGES OF EGG WEIGHT

(AVERAGES OF ALL EMBRYOS WEIGHED)

	Days of Incubation										
	9	10	11	12	13	14	15	16	17	18	22
WR	2.47	3.96	5.52	8.92	11.50	18.10	21.98	27.41	33.30	38.40	68.43
WC	2.48	3.98	5.63	8.88	11.36	17.12	20.70	26.32	34.25	37.73	67.44
WH	2.46	3.98	5.23	7.93	11.43	16.80	21.34	27.60	33.62	39.63	68.47
UBC	2.49	3.66	5.49	7.46	10.83	15.04	18.89	25.19	31.59	34.17	67.44
MHxUBC	2.49	3.56	5.32	8.28	10.52	16.40	20.00	25.27	31.25	36.80	68.73
MH	2.11	3.35	4.78	6.69	9.34	14.29	18.62	23.96	29.80	33.43	67.94

TABLE 11

RESULTS OF TUKEY'S TEST FOR NON ADDITIVITY

(EMBRYONIC AND CHICK WEIGHTS EXPRESSED AS PERCENTAGES OF EGG WEIGHT)

	Degrees of Freedom	Mean Squares										
		Day										
		9	10	11	12	13	14	15	16	17	18	22
Error	96 (60)#											
Non-Additivity	1	.01	.01	.08	.72	.03	.07	.02	.16	.21	.90	.09
For Testing	95 (59)#	.11	.21	.43	.89	2.52	3.38	3.97	5.19	12.17	12.44	4.82

Statistic for 22nd day.

TABLE 12

ANALYSES OF VARIANCE OF EMBRYONIC AND CHICK WEIGHTS
EXPRESSED AS PERCENTAGES OF EGG WEIGHT

Source of Variation	Degrees of Freedom	Mean Squares							
		Day							
		9	11	12	14	15	16	18	22
Incubators (I)	1	3.05	0.08	10.99	8.98	4.40	9.76	28.76	5.80
Strains (S)	5	0.38 [★]	1.71 [★]	17.23 ^{★★}	38.50 ^{★★}	35.85 ^{★★}	34.01 ^{★★}	106.52 ^{★★}	8.20
I x S	5	0.05	0.78	2.70 [★]	2.34	4.23	7.12	15.22	4.07
Sampling Error	96 (60) [#]	0.11	0.43	0.89	3.35	3.93	5.14	12.32	4.74
Total	107 (71) [#]	3.59	3.00	31.81	53.17	48.41	56.03	162.82	22.81

★ Significant at P=0.05
 ★★ Significant at P=0.01
 # Statistic for 22nd day

TABLE 13

RESULTS OF DUNCAN'S NEW MULTIPLE-RANGE TEST USED ON MEAN EMBRYONIC AND CHICK WEIGHTS
EXPRESSED AS PERCENTAGES OF EGG WEIGHT

Age (Days)							Standard Error of The Mean
9	MH <u>3.38</u>	MHxUBC <u>3.50</u>	UBC <u>3.66</u>	WC <u>3.87</u>	WH 4.05	WR 4.08	<u>+0.08</u>
11	MH 4.74	WH <u>5.18</u>	MHxUBC <u>5.26</u>	WR 5.38	UBC 5.53	WC 5.60	<u>+0.16</u>
12	MH 6.52	UBC <u>7.45</u>	WH <u>7.80</u>	MHxUBC <u>8.35</u>	WC <u>9.01</u>	WR 9.06	<u>+0.23</u>
14	MH <u>14.13</u>	UBC <u>15.09</u>	MHxUBC <u>16.33</u>	WH <u>16.71</u>	WC <u>17.58</u>	WR 17.95	<u>+0.43</u>
15	MH 18.56	UBC 18.62	MHxUBC <u>19.93</u>	WC <u>20.69</u>	WH 21.32	WR 21.99	<u>+0.47</u>
16	MH 24.08	MHxUBC 24.98	UBC <u>25.32</u>	WC <u>26.75</u>	WH 27.00	WR 27.64	<u>+0.54</u>
18	MH <u>33.20</u>	UBC <u>34.22</u>	MHxUBC <u>36.86</u>	WR 37.93	WC 38.40	WH 39.30	<u>+0.83</u>
22	MH <u>67.51</u>	WH 67.82	WC 68.07	UBC 68.14	MHxUBC 68.85	WR 69.78	<u>+0.62</u>

Any values not underscored by the same line are significantly different.

Any values underscored by the same line are not significantly different.

TABLE 14a

COEFFICIENTS OF CORRELATION (r) BETWEEN EGG WEIGHT
AND EMBRYONIC OR CHICK WEIGHT

Age	WR		WC		WH	
	Inc 1	Inc 2	Inc 1	Inc 2	Inc 1	Inc 2
9 Days	-.350	.063	-.710 [☆]	.131	.114	-.068
10	.300	-.409	-.480	-.478	.670 [☆]	.084
11	.340	-.374	-.090	.024	-.440	-.172
12	.125	-.196	-.092	-.068	.290	.001
13	-.098	-.634 [☆]	.180	-.566 [☆]	.036	.291
14	.116	.197	-.205	-.313	.240	.123
15	-.062	.450	.760 [☆]	-.366	.418	.156
16	.360	.094	.325	.076	.456	.772 [☆]
17	-.236	.225	.091	-.239	.652 [☆]	.290
18	.542 [☆]	.493	.230	.594 [☆]	.616 [☆]	.811 [☆]
22 (Hatch)	.947 ^{☆☆}	.895 ^{☆☆}	.887 ^{☆☆}	.902 ^{☆☆}	.976 ^{☆☆}	.843 ^{☆☆}
1 Week	.501 [☆]		.534 [☆]		.419 [☆]	
2 Weeks	.149		.445 [☆]		.261	
3 "	.043		.297		.082	

☆ Significant at P=0.05

☆☆ Significant at P=0.01

TABLE 14b

COEFFICIENTS OF CORRELATION (r) BETWEEN EGG WEIGHT
AND EMBRYONIC OR CHICK WEIGHT

Age	UBC		MH		MHxUBC	
	Inc 1	Inc 2	Inc 1	Inc 2	Inc 1	Inc 2
9 Days	-.170	.186	-.620 [★]	-.275	.068	.176
10	.680 [★]	.356	.040	-.089	-.226	.125
11	.072	.142	-.450	-.178	-.614 [★]	-.440
12	.024	-.188	-.061	-.145	.160	.241
13	.100	.344	.380	.021	.710	.333
14	.297	-.261	-.410	-.063	.610	.005
15	.301	.511	.385	-.018	.229	.590 [★]
16	.158	-.028	.272	.211	.058	.156
17	.291	-.153	.392	.058	.385	.286
18	.549	-.503	.422	-.353	.410	.347
22 (Hatch)	.910 ^{★★}	.832 [★]	.895 ^{★★}	.971 ^{★★}	.889 ^{★★}	.945 ^{★★}
1 Week	.425		.284		.239	
2 Weeks	.118		.030		.181	
3 "	-.044		.018		.139	

★ Significant at P=0.05

★★ Significant at P=0.01

TABLE 15

REGRESSION COEFFICIENTS : GRAMS OF CHICK WEIGHT ON GRAMS OF EGG WEIGHT

		Age (Weeks)			
Incubator		0	1	2	3
WR	1	.905 ^{AA}			
	2	.768 ^{AA}			
WC	1	.703 ^{AA}	1.245 ^{AA}	.647	.269
	2	.718 ^{AA}			
WH	1	.746 ^{AA}	1.050 ^A	1.719 ^A	2.07
	2	.795 ^{AA}			
UBC	1	.856 ^{AA}	.663 ^A	.904	.628
	2	.754 ^A			
MH	1	.991 ^{AA}	.884	.451	-.301
	2	.704 ^{AA}			
MHxUBC	1	.565 ^{AA}	.403	.087	.075
	2	.757 ^{AA}			
			.563	.913	1.271

A Significant at P=0.05

AA Significant at P=0.01

TABLE 16

RESULTS OF TESTS FOR LINEAR RELATIONSHIP BETWEEN $\ln W$ AND TIME

Strains	t Values		
	Incubation	Periods	Post-Hatching Period
	9-14 Days $t_{.05} = 2.776$	14-18 Days $t_{.05} = 4.303$	0-3 Weeks $t_{.05} = 4.303$
WR	30.82	10.79	11.02
WC	33.87	9.88	41.57
WH	36.64	18.54	13.85
UBC	86.81	13.06 [#]	12.72
MHxUBC	36.67	15.79	14.91
MH	22.28	13.69	13.50

[#] $t_{.05} = 12.71$

TABLE 17

EQUATIONS USED TO PLOT GROWTH CURVES

Incubation Period (Days)	Class	Equation	Growth Rate
9-14		$\ln W = \ln A + kt$	(100k) Daily
	WR	$\ln W = -2.9956 + .3868t$	38.68
	WC	$\ln W = -2.97283 + .3810t$	38.10
	WH	$\ln W = -2.91142 + .3752t$	37.52
	UBC	$\ln W = -2.78441 + .3594t$	35.94
	MH	$\ln W = -2.79025 + .35297t$	35.30
14-18	MHxUBC	$\ln W = -2.88044 + .3693t$	36.93
	WR	$\ln W = -0.01238 + 0.17744t$	17.74
	WC	$\ln W = -0.42924 + 0.2000t$	20.00
	WH	$\ln W = -0.56522 + 0.2113t$	21.13
	UBC	$\ln W = -1.22952 + 0.2477t$	24.77
	MH	$\ln W = -0.56726 + 0.20316t$	20.32
Post-Hatching Period (Weeks)	MHxUBC	$\ln W = -0.63164 + 0.21015t$	21.02
			Weekly
	WR	$\ln W = 3.87042 + 0.59502t$	59.50; (8.50) [★]
	WC	$\ln W = 3.77720 + 0.65052t$	65.05; (9.29)
	WH	$\ln W = 3.83405 + 0.60099t$	60.10; (8.59)
	UBC	$\ln W = 3.79487 + 0.54099t$	54.10; (7.73)
0-3	MH	$\ln W = 3.79728 + 0.53399t$	53.40; (7.63)
	MHxUBC	$\ln W = 3.78465 + 0.54500t$	54.50; (7.79)

★ Daily rates in parentheses

TABLE 18a

ANALYSES OF VARIANCE OF GROWTH RATES

Source of Variation	Degrees of Freedom	Mean Squares		
		Period		
		9-14 Days Incubation	15-18 Days Incubation	0-3 Weeks Post-Hatching
Incubators (I)	1	.016	.0005	.015
Strains (S)	5	.003	.0009	.068 ^a
I x S	5	.001	.0003	.006
Sampling Error	48 ^a 24 ^b 204 ^c	.009	.0057	.020
Total	59 ^a 35 ^b 215 ^c	.029	.0074	.109
^a Significant at P=0.05		^b Statistic for 15-18 days		
^a Statistic for 9-14 days		^c Statistic for 0-3 weeks		

RESULTS OF DUNCAN'S MULTIPLE-RANGE TEST

MH	MHxUBC	UBC	WH	WR	WC
.530	.537	.539	<u>.594</u>	.609	<u>.631</u>

Any values not underscored by the same line are significantly different.
Any values underscored by the same line are not significantly different.

TABLE 18b

ANALYSES OF VARIANCE OF GROWTH RATES				
Source of Variation	Degrees of Freedom	Mean Squares		
		Period		
		9-14 Days Incubation	15-18 Days Incubation	0-3 Weeks Post-Hatching
Types	1	.008	.0001	.31 ^{AA}
Error	58 ^a 34 ^b 214 ^c	.007	.0042	.02
Total	59 ^a 35 ^b 215 ^c	.015	.0043	.33

^{AA} Significant at P=0.01

^a Statistic for 9-14 days

^b Statistic for 15-18 days

^c Statistic for 0-3 weeks

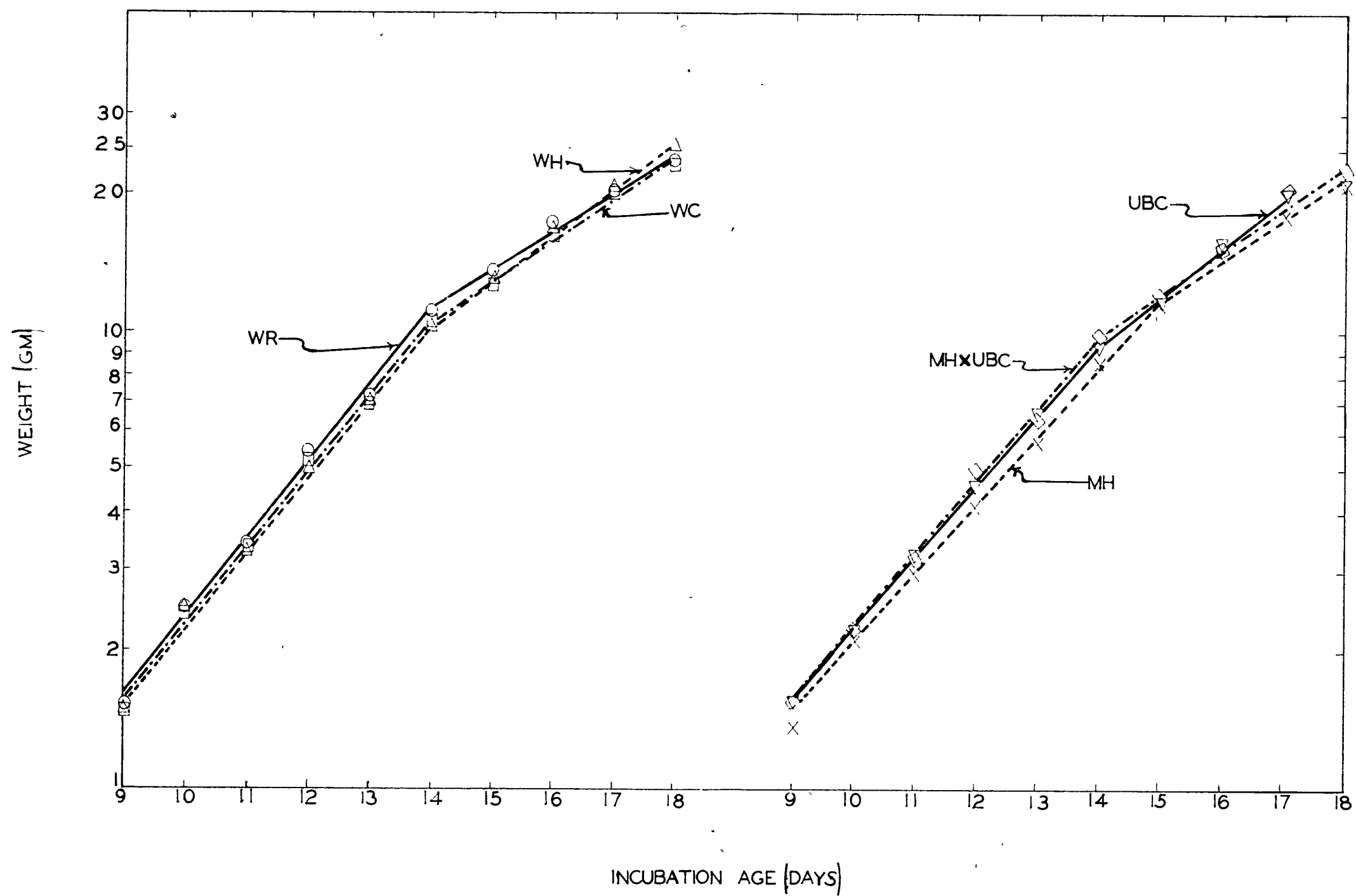


Figure 1 Arith-log graphs of growth rate obtained from the equation: $\ln W = \ln A + kt$.

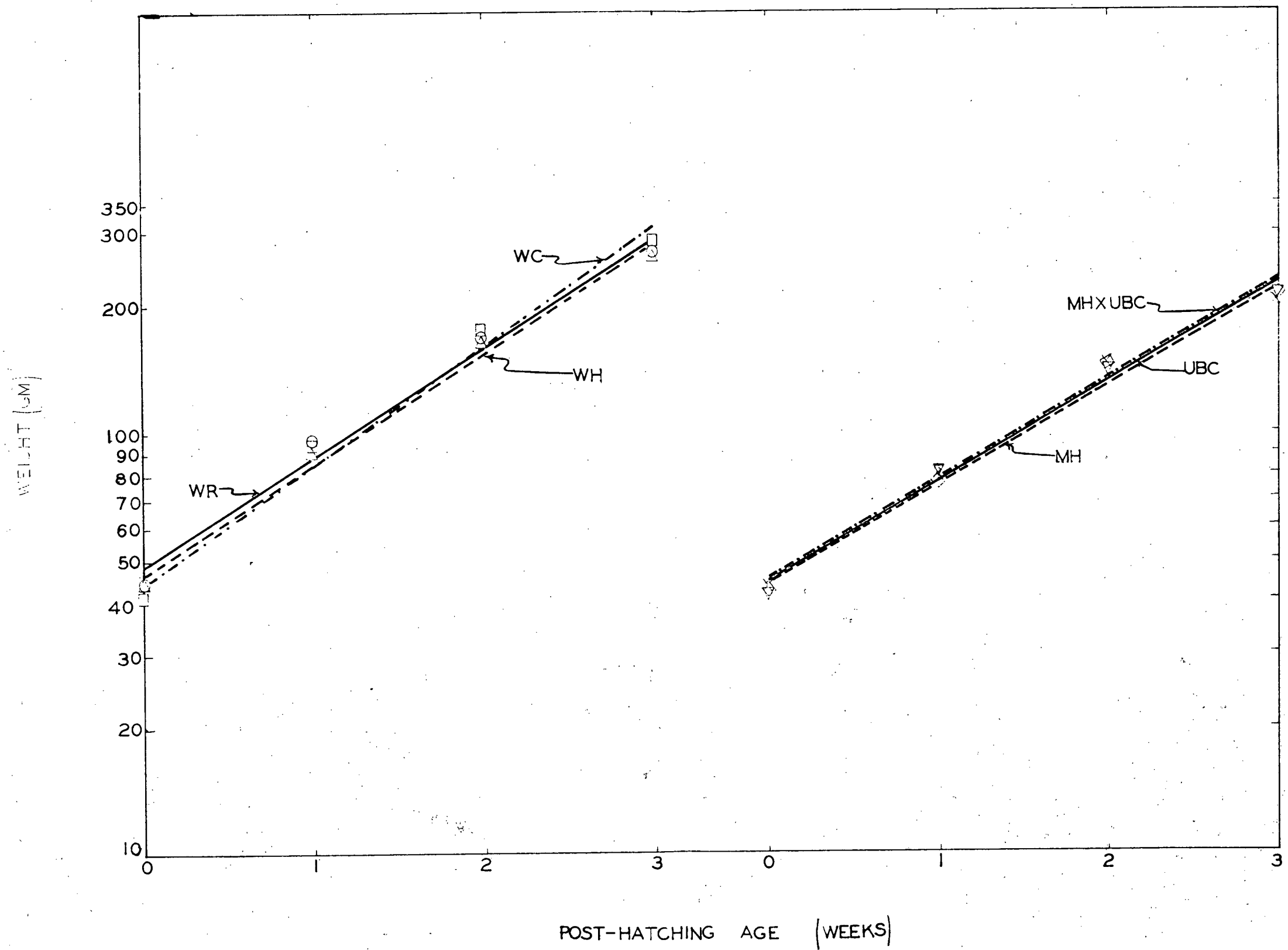


Figure 2. Arith-log graphs of growth rate obtained from the equation: $\ln W = \ln A + kt$.

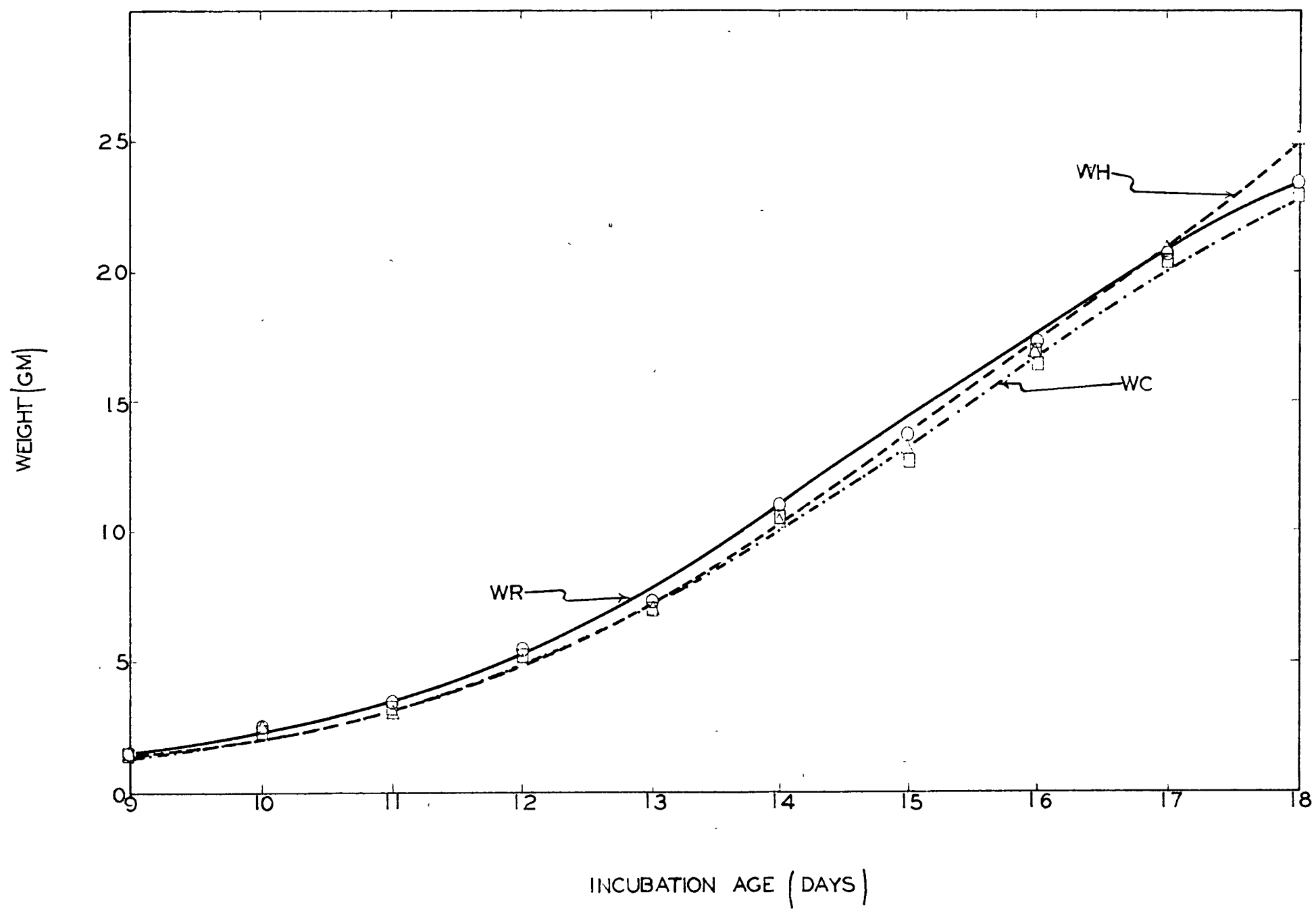


Figure 3a Arithmetic graphs of growth rate

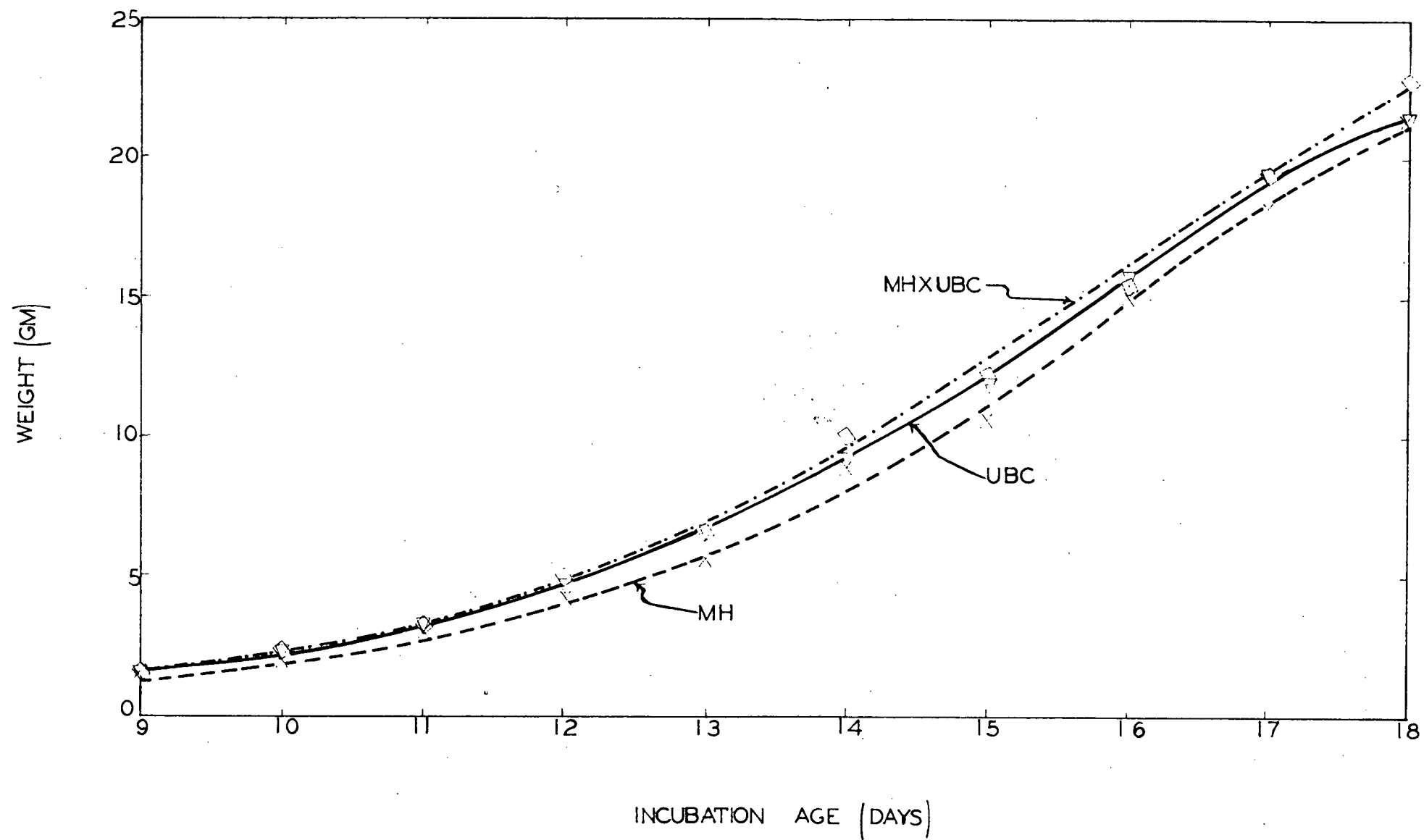


Figure 3b. Arithmetic graphs of growth rate.

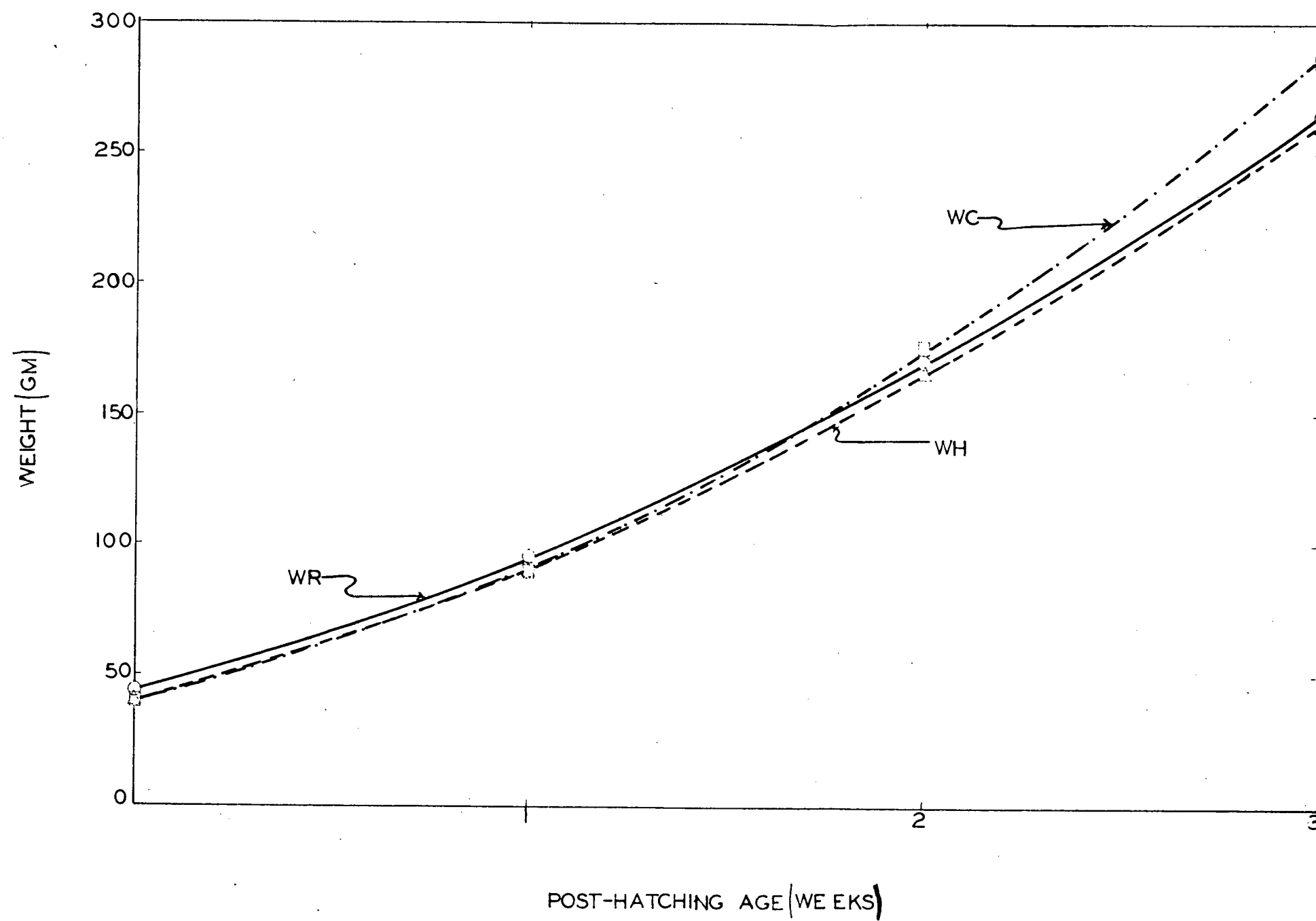


Figure 4a. Arithmetic graphs of growth rate.

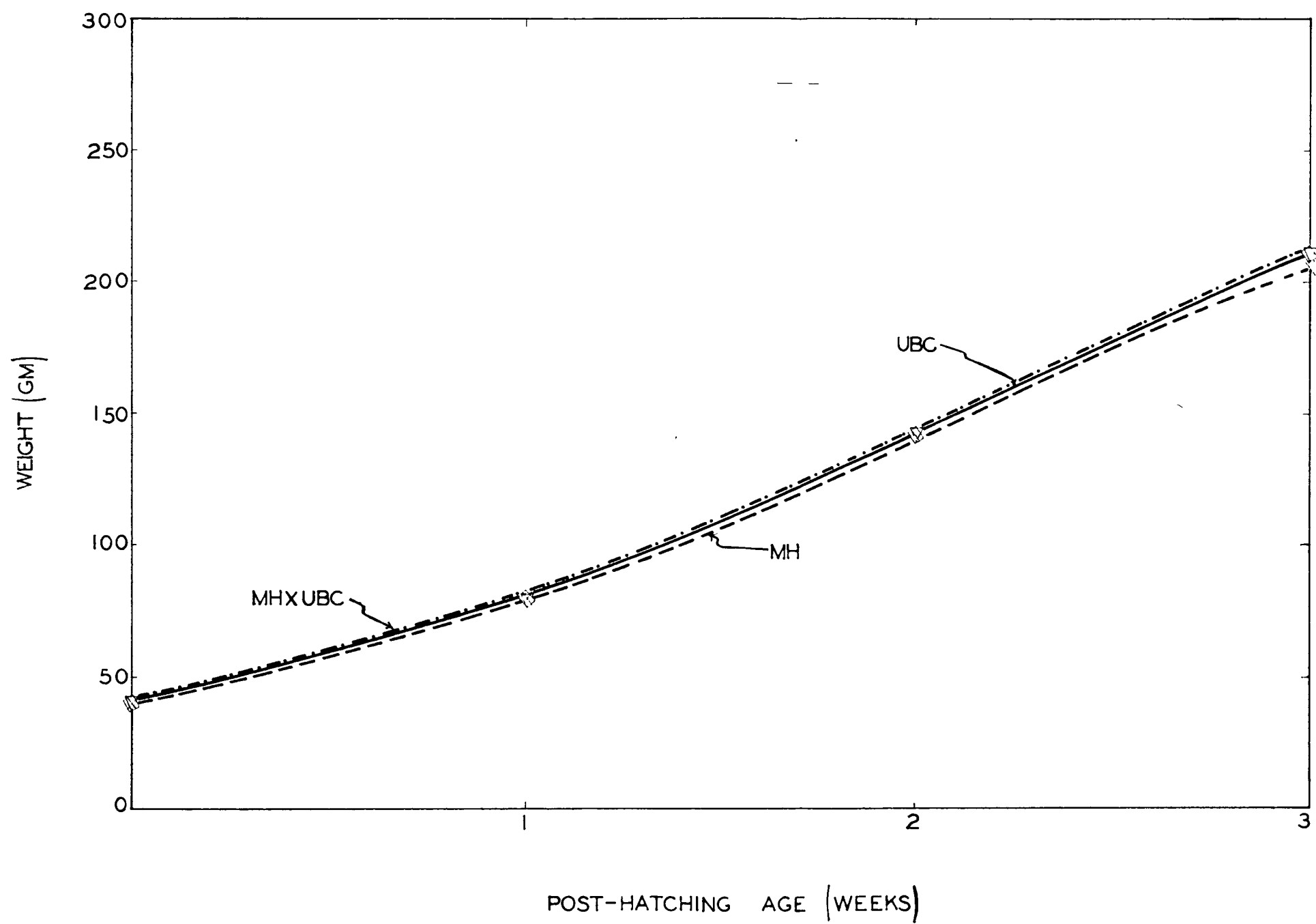


Figure 4b Arithmetic graphs of growth rate