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GROWTH AND DEVELOPMENT

With Special Reference to Domestic Animals

XII. Additional Illustrations of the Influence of Food Supply on the Velocity Constant of Growth and on the Shape of the Growth Curve.

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GROWTH AND DEVELOPMENT

With Special Reference to Domestic Animals

XII. Additional Illustrations of the Influence of Food Supply on the Velocity Constant of Growth and on the Shape of the Growth Curve.*

SAMUEL BRODY

ABSTRACT.—Additional comparisons are made between the age curves of growth of animals under several degrees of normality of food supply. The nearer the approach to an optimum food supply, the steeper is the age curve; that is, the more rapidly is the mature size approached, and the higher is the numerical value of the velocity constant of growth. The mature weight is also increased by the relatively improved food supply, but the relative increase in mature size is negligible as compared to the relative increase in the speed of approach to the mature weight. The same exponential equation may be used to represent the age curves of growth of animals on the various planes of nutrition, but the velocity constant, *k*, which is a numerical value of the speed of approach to the mature weight differs in value. It is suggested that body weight rather than age be used as a criterion for first breeding of farm animals, and that dairy heifers be first bred when reaching two-thirds of the expected mature body weight.

Illustrations of the influence of food supply on the shape of the age curve of growth and on the numerical values of the velocity constants of growth have been previously given (see pp. 22 to 25 and 94-95 of Research Bulletin 96 of this series; pp. 18 and 21 and Table 1 of Research Bulletin 101; Figs. 13, 14, 22a, 22b, 22c, of Research Bulletin 102). The differences in the velocity constants of growth in a given species are particularly striking in Figs. 13 and 14 of Research Bulletin 102, in which a comparison is made between the age curves of the Norway and of the Albino rat. One month in the Albino rat was found to be equivalent to 3.3 months of the Norway rat. The question was raised whether the difference in the speed of approach to the mature weight in the two races of rats is due to genetic or environmental factors. An examination of the data on the influence of nutritional factors on growth favors the view that as far as the rat, at any rate, is concerned, the differences are principally due to the character of the food supply (compare, for example, the values of *k* of the rat of Sherman or Hoskins, with those of Donaldson or Greenman in Table 1, Research Bulletin 101, or in the equivalence charts Figs. 22a and 22b of Research Bulletin 102).

The most significant data indicating that certain improvements in the "normal" diet accelerate the speed of growth were recently furnished by Osborne and Mendel. Dr. Osborne and the writer dis-

*The writer is indebted to Professors A. C. Ragsdale and M. J. Regan for exceedingly valuable ideas relating to the possible influence of food supply on earliness of maturity in dairy cattle.

cussed this problem and they have decided that it would be desirable to make a comparison between the growth curves obtained on the "normal" and on the "improved" diets of Osborne and Mendel. Dr Osborne furnished the numerical data for this purpose. Figs. 1 to 5 in this bulletin are based on these data.

These figures indicate that while the increase in the mature weight of the animals on the improved diet is relatively negligible, the increase in the speed of approach to the mature weight is very considerable indeed.

Employing the terminology of the agriculturist, the improvement in the diet resulted in a much earlier maturity. Employing the terminology of the chemist, the increase in the effective concentration of the growth limiting constituents in the system resulted in a remarkable increase in the numerical value of the velocity constant of the process. Thus the numerical value of the velocity constant k of the rat of Donaldson, for example, is 0.0135, while that of the rat of Osborne and Mendel is 0.0266. In other words, following the age of puberty, the speed of approach to the mature value is twice as great in the animals on the improved diet as for the animals on the normal diet. Detailed values concerning the ages at which different fractions of the mature weights are reached are given in the table in Fig. 1.

The ideas suggested by these charts on the rats may have only limited economic application to farm animals. But whatever economic possibilities they do have are of the greatest significance. The reason for this statement consists in the fact that most of the food consumed by the young animal is used not for growth (or other productive purposes) but for maintenance. The lowering of the age of maturity therefore implies the saving of the corresponding cost of maintenance, which as pointed out, is the largest item in the cost of growth.

That these ideas have some relation to farm practice may be inferred from figures 22a, 22b, 22c, 23a, and the other figures on the same section of Research Bulletin 105 of this series. These figures show very plainly that the cows on official test approach their maximum milk production at a greater velocity than the cows not on test. Since, as has been shown in Research Bulletins 96 and 105, the milk yield is a partial function of the body size of the cow, it is reasonable to explain that the more rapid approach to the mature milk production in cows on official test is due to the earlier maturity of these animals, which in turn is due to the more liberal food supply offered to the animals on test. This idea of the influence of food supply on growth of dairy cattle is substantiated by Davidson (Illinois Agr. Exp. Sta. Bul. 302, 1928) in his analysis of the causes for the greater milk production of re-entry cows as compared to cows on test for the first time. "The re-entry cows attain a greater weight at maturity and increase in weight more rapidly than do the original entry cows. It was found that there is no genetic difference between the original entry and re-entry cows for body size; hence it may be assumed that the greater size and the more rapid rate of growth of the re-entry cows is due largely to the more favorable environment under which they are kept". Again, in the same bulletin, Davidson concludes "The fat yields of the re-entry cows are far superior to the fat yields of the original entry cows and increase at a greater rate with advancing age. The genetic difference for milk production between the original entry and re-entry cows, altho significant, was not great enough to account for the superior productive ability of the latter." Therefore Davidson infers that "the re-entry cows are kept under an environment which gives them a better chance to develop than the original entry cows. . . . This conclusion is in agreement with the experimental work of Eckles and Swett (1918) wherein they describe a difference in the course of growth between heavy-fed cows and light-fed cows similar to that evidenced between re-entry and original-entry Jersey cows." Figure 7, plotted from the data by Davidson, indicates clearly that at a given age the re-entry cows are heavier than the original entry cows and that the higher milk production of the re-entry cows is due in part to their greater body weight.

The present report was prepared, then, first because of the exceedingly important economic implications of the ideas involved, and second because of the physico-chemical interest of the fact that increasing the effective concentration of the growth limiting constituent results in an increase in the value of the velocity constant of growth without appreciably changing the course of growth as indicated by the applicability of the same equation to the age curves of growth obtained on different levels of nutrition.

Figure 8, based on data by Dr. M. A. Jull (numerical data cited in Research Bulletin 96 of this series), is presented in this connection to indicate the influence of the addition of milk to an otherwise "normal" ration on the velocity of approach to the mature weight in chickens.

Incidentally it is of some interest to note that the above ideas discussed in connection with the growth of rats, cattle, and chickens are applicable to the growth of children. Thus, Fig. 9 shows that the average English "laboring" individual appears to be not only smaller than the average "non-laboring" individual, but the children of the laboring class take longer to reach a given stage of growth in weight than do the children of the non-laboring class. It is reasonable to assume that this difference is due, in part at least, to differences in environmental conditions, particularly in the food supply available to the children of the two classes. (For a discussion of the environmental condition of the laboring classes in England consult the recent reports of the (English) Medical Research Council, as for example Special Report Series No. 101 on "Poverty, Nutrition and Growth" by Drs. D. Noel Paton and Leonard Findlay, 1926.) In Fig. 9 an 18-year-old child, for example, of the given laboring class appears to have the development of a 16-year-old child of the given non-laboring class. The same differences are shown in Figs. 10 and 11. This, by the way, may account in part for the fact that the intelligence quotients of the children of the laboring class are below the quotients for the other classes of the population. It is not unreasonable to suppose that the mental development is associated with physical development, and a delay in the physical development through unfavorable environment may result in a delay in the mental development.

The practical applications of the above analysis to farm practice are obvious. The environmental conditions, and particularly the differences in degree of the character and amount of food intake classed as "normal", exert a very marked influence on earliness of maturity. Earliness of maturity (for animals of a given mature weight) means efficiency of growth. The reason for this is that, as pointed out, the cost of maintaining animals is by far the largest item in the cost of growth, other conditions remaining the same. The obvious practical application of this fact is to grow animals rapidly and thereby save much of the cost of maintenance.

Another application is this: since as we have seen (see Figs. 1, 2, 3, 5, 7, and 8 of this bulletin, and Section 4, pp. 63 and 64 of Res. Bul. 97 of this series) that chronological age is not necessarily identical with physiological age, the current discussion in agricultural literature concerning the earliest age at which animals should be bred is not as important as the question of the minimum body weight at which animals should be bred. The existence of the question relating to the age of first breeding is due to the fact that lactation, particularly in dairy cattle, retards growth. But if a given animal is well grown, then what does it matter if it is young with respect to age. The second application of this discussion to farm practice, therefore, is that the degree of physical development of the animal rather than the age, should be taken as an index of the fitness of the animal for breeding. Body weight being the best available index of physical development, it is suggested that the relative weight of the animal as compared to its expected mature weight should be taken as an index for the time of first breeding. It is tentatively suggested that dairy animals be first bred on reaching two-thirds of their expected mature weight, so that the first lactation period will begin by the time the animals are somewhat over three-fourths of their expected mature weight.

Bibliography—The references, not given in this bulletin, may be found in the bibliography of Mo. Agr. Expt. Sta. Res. Bul. 96.

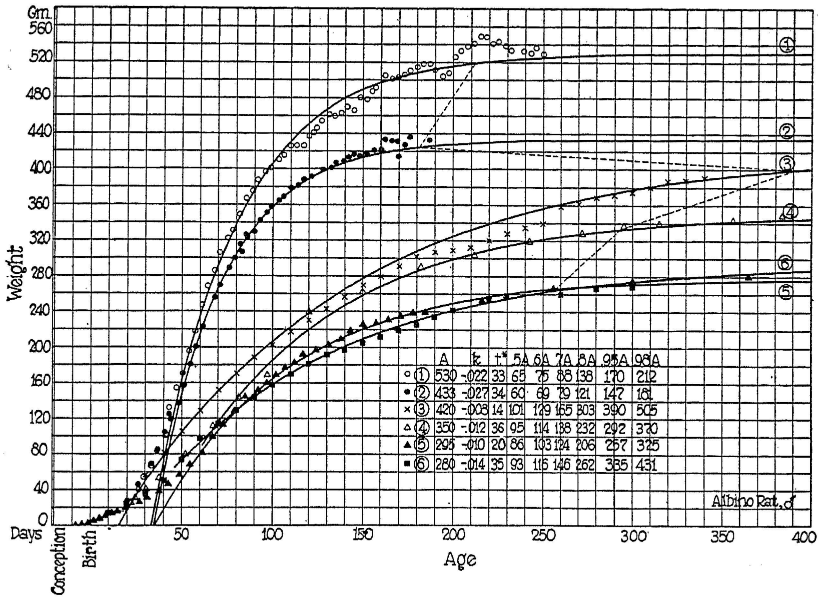

Fig. 1.—Age curves of "maximum" and of "normal" growth. Curve (1) represents rat 3414 of Osborne and Mendel (probably the largest animal on record). Curve (2) represents the average of rats B2135, B2132, B2164, B2161, B3380, B3432, B3414, B3441, B581, B693, B1978, B1974, B2264, B226, B3218. All of these rats were reared by Osborne and Mendel on the "improved" diet described in J. Biol. Chem., 1926, LXIX, 668. Curve (3) represents the 1925 averages for the normal rats of Osborne and Mendel. Curve (4) represents the animals of Greenman and Duhring. Curve (5) represents the data by Donaldson, Dunn, and Watson. Curve (6) represents data obtained by Ferry in the laboratory of Osborne and Mendel. The data represented by curves (1), (2), and (3) have not been published and they were supplied by Dr. Osborne for the present analysis. Greenman and Duhrings data were taken from H. H. Donaldson's "The Rat," 1924. The data by Donaldson, Dunn and Watson, and the data by Ferry were taken from H. H. Donaldson, "The Rat," 1915. The numerical values of A represent mature weights. The values .5A, .6A, etc., represent the ages in days from birth when 50 per cent, 60 per cent, etc., of the mature weight, A, are reached. The term t* represents the ages from birth at which the extrapolated (smooth) curves meet the age axis. The term $100k$ represents the daily percentage decline in the successive weight increments during the period of growth following puberty. The smooth curves represent the equation $W = A(1-e^{-k(t-t^*)})$ in which W is the weight at the age t. Since the value of k is an index of the speed of approach to the mature weight (during the period following puberty), hence the rats represented, for example, by curve (2), approach the mature weight two times as rapidly as the rats represented by curve (6). The points connected by the broken curve represent ages at which 98% of the mature weight, A, is reached. The difference between the steepness of the curves is too striking to need any verbal comment; yet they all follow the same course, being represented by the same equation.

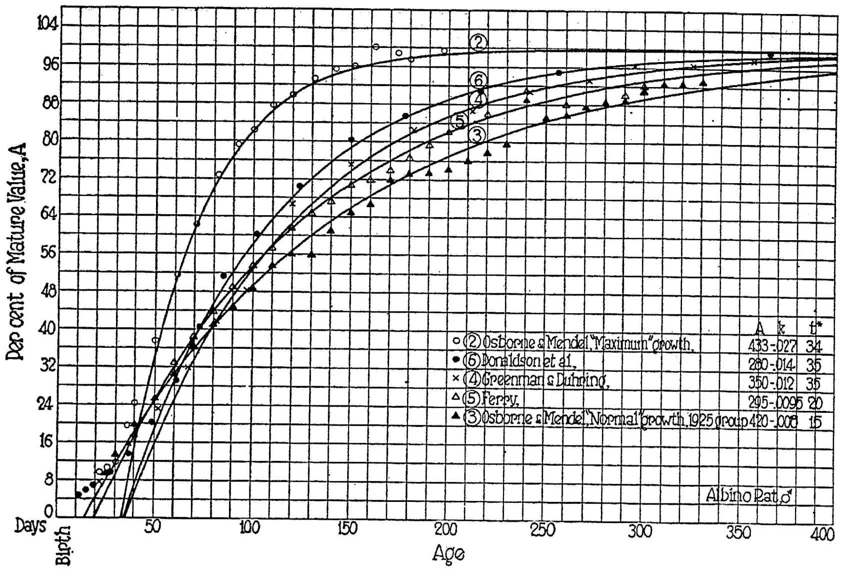

Fig. 2.—The absolute values plotted in Fig. 1 are here represented in terms of percentages of the mature weights, *A*. In this chart the relative steepness of the curve of the rats on the improved diet is made somewhat more striking than in Fig. 1.

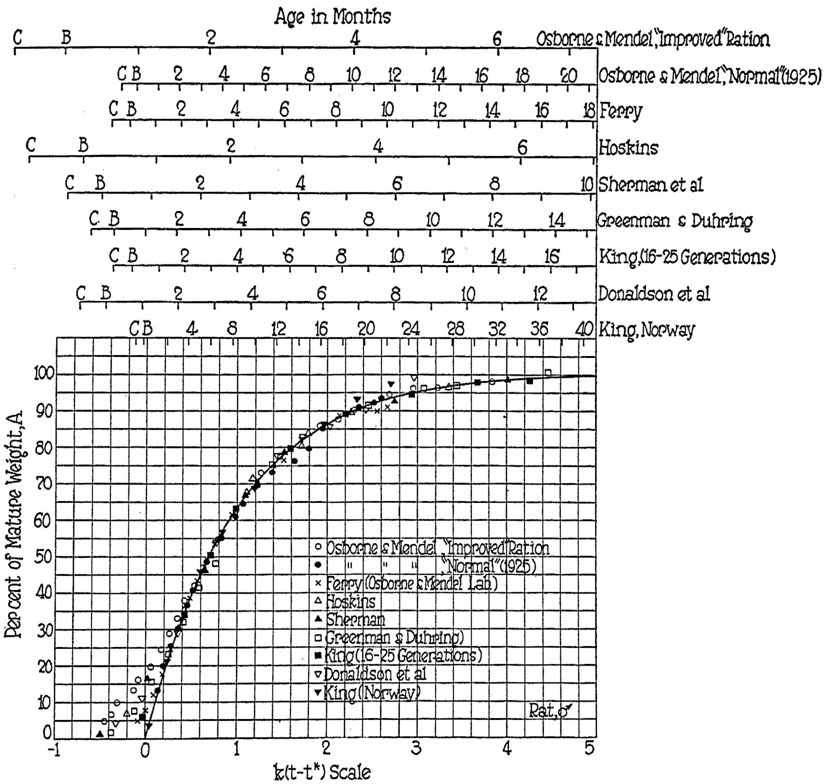

Fig. 3.—The data plotted in Fig. 1, and several other sets of data, were plotted in such a manner that they would fall along the same curve. This was accomplished by plotting $100 \frac{W}{A}$ against $k(t-t^*)$ in the equation $W = A[1-e^{-k(t-t^*)}]$ as explained in Research Bulletin 102 of this series. This chart shows that the mature weight was approached with the same rapidity in the rats of Osborne and Mendel (improved ration) as in the rats of Hoskin's (fed various ductless glands). However, while the average mature weight of the rats of Osborne and Mendel is about 430 grams, the mature weight of Hoskin's rats is only 230 grams. The rats of Sherman (mature weight 330 grams) fed on a whole wheat and whole milk diet are next in the order of maturity. The Norway rat (first generation) is last in the list to reach the mature weight.

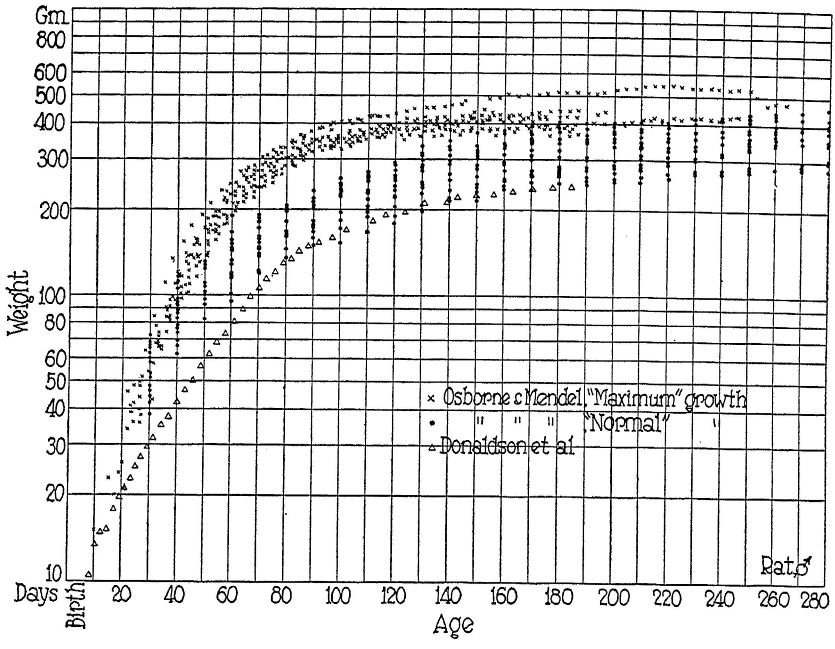

Fig. 4.—The individual data points of the rats of Osborne and Mendel, and the average weights of the rats of Donaldson are here plotted on an arithlog grid (on which equal *percentage* changes are represented by equal slopes and equal distances on the vertical scale). This chart shows that the range in percentage differences is not greater for the rapidly growing rats than for the "normally" growing rats; that is to say, the growth of both sets of rats was "normal" under the given conditions.

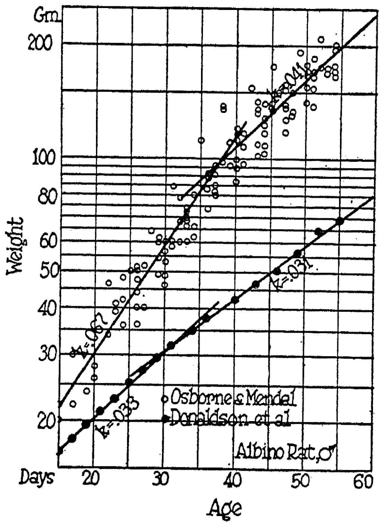

Fig. 5.—The data for the rapidly growing rats of Osborne and Mendel are here plotted, together with the data of Donaldson, on an arithlog grid. The percentage rates of growth are represented by 100 *k*. Thus between the ages of 15 and 30 days (from birth) the rats of Donaldson grew at the rate of 3.3 per cent per day while the rats of Osborne and Mendel grew at the rate of 6.7 per cent per day.

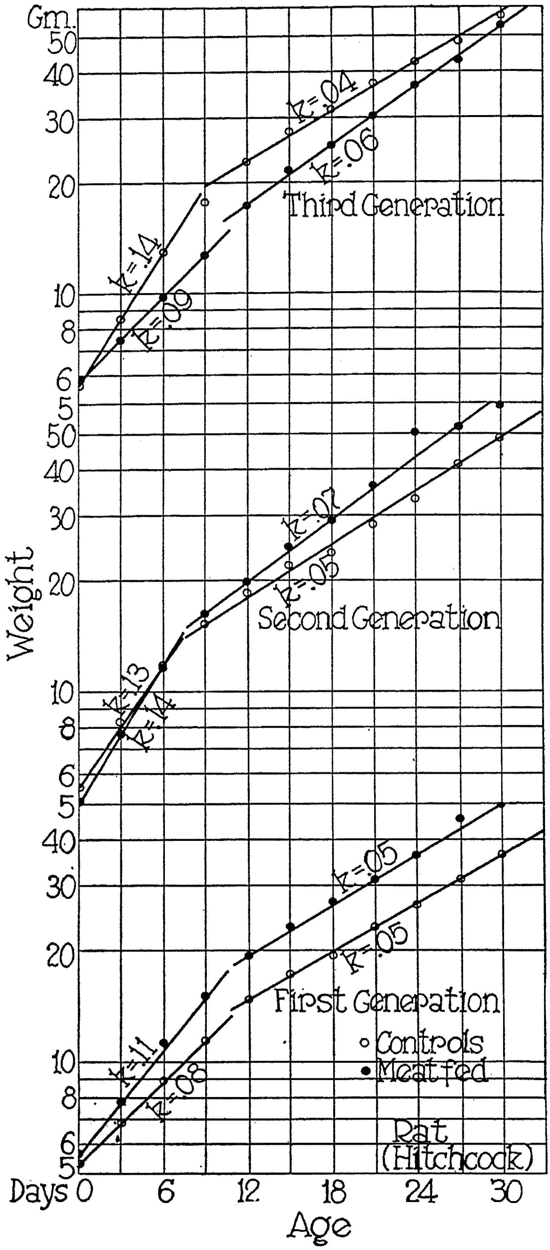

Fig. 6.—In connection with Fig. 5, this chart will be of interest to indicate the percentage rate of growth of rats in other laboratories, on other diets. Incidentally, it indicates the influence of a meat diet of the mother on the growth of the young. Note that while in this chart the curve begins at birth, the preceding chart represents the data beginning with 15 days after birth. This chart was plotted from unpublished data by Dr. Fred A. Hitchcock of the Ohio State University. For a discussion of these data and of the influence of meat in the diet on growth, see Hitchcock, Am. J. Physiology, 1926, LXXIX, 206.

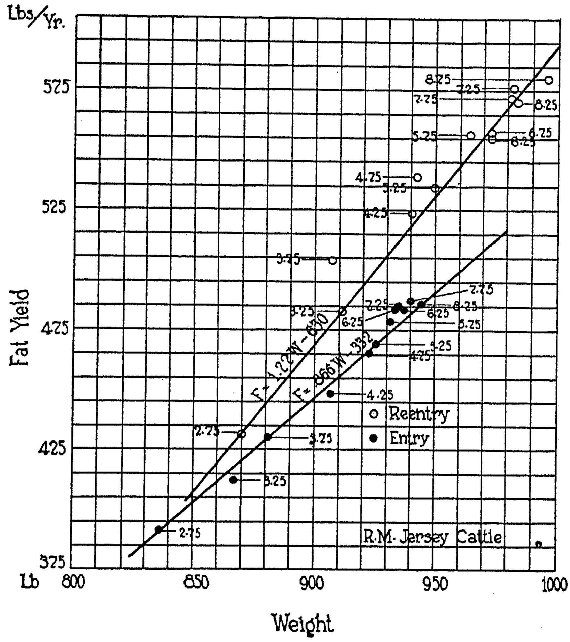

Fig. 7.—The butterfat yields, F, at different ages (indicated by numerals on the lines) are plotted against body weights, W. Note that for a given age (indicated by the numerals along the lines) the body weights as well as the butterfat yields are higher for the re-entry cows than for the original entry cows.

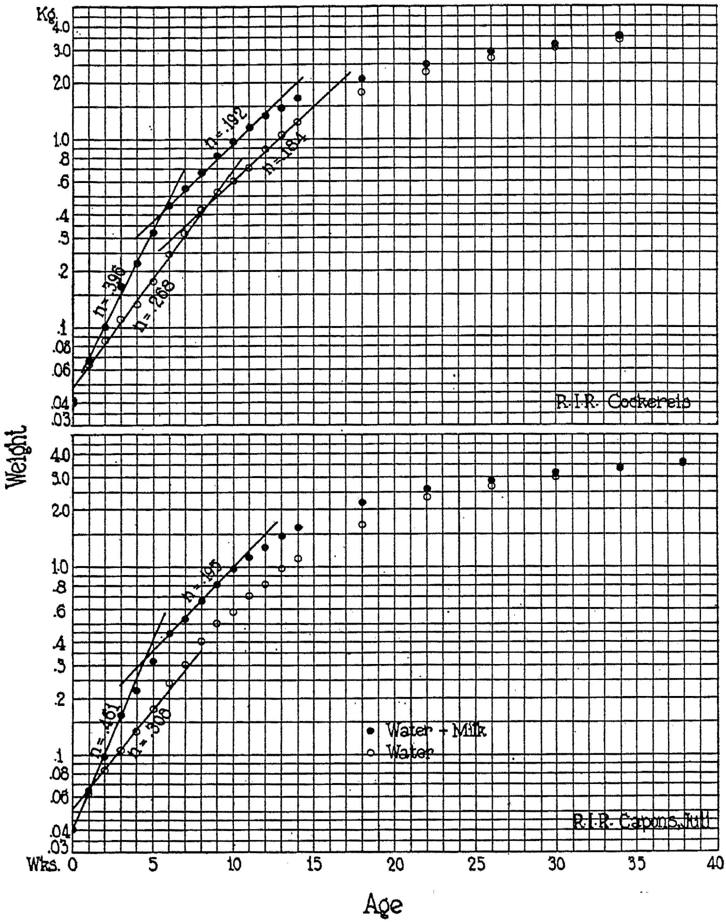

Fig. 8.—The relative growth of chickens on a "normal" diet and on the same "normal" diet plus milk to drink, plotted on an arithlog grid. The numerical values of *n* when multiplied by 100 represent the percentage-rates of growth per week.

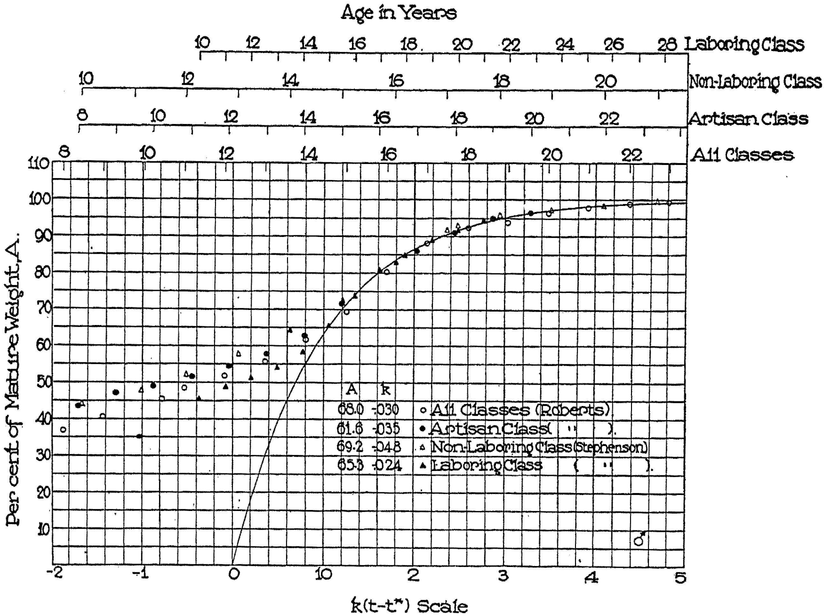

Fig. 9.—A growth-equivalence chart for English children from different socio-economic classes. The striking feature of this chart is the relatively slow approach to the mature weight of the children from the laboring class as compared to children from the non-laboring class. For sources of data see Baldwin, 1921.

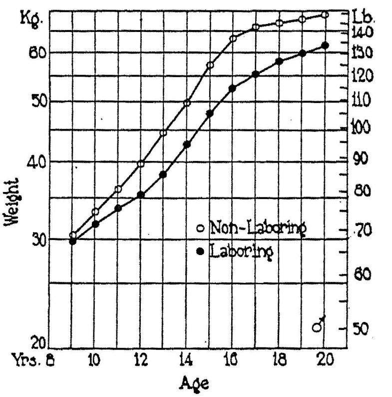

Fig. 10.—Growth of English children of the laboring and non-laboring classes plotted on an arithlog grid.

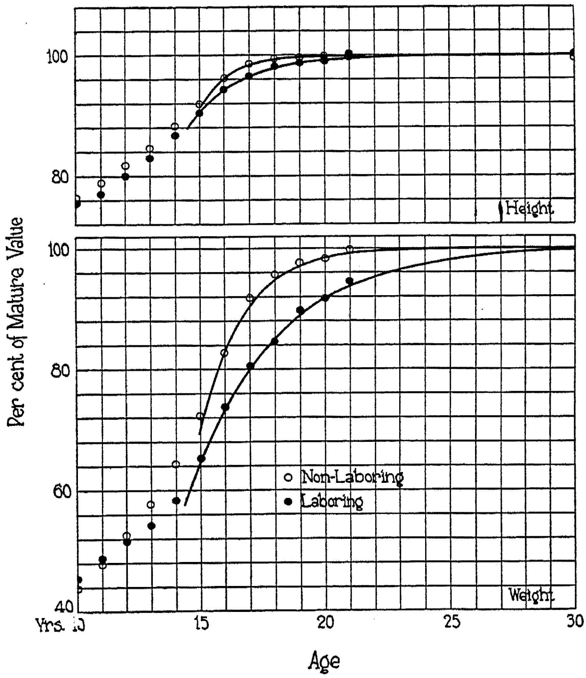

Fig. 11.—Growth of the classes of children expressed in terms of percentages of mature height (upper chart) and weight (lower chart).