THE RATE OF GROWTH OF THE DAIRY COW.

III. The Relation Between Growth in Weight and Increase of Milk Secretion with Age.

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In a preceding communication[1] it was shown that after the age of 2 years, the rate of growth of the dairy cow declines in a non-cyclic manner, and that the course of decline in the rate of growth follows the course of decline in the rate of a monomolecular chemical reaction. Since increase in weight may be due to the storage of inert substances rather than to increase in the mass of living tissues, it is desirable to substantiate the weight data by other measurements. In this communication we report on the change of a physiological activity with age—that of milk secretion—and show that the increase of milk secretion with age follows the same course as the increase of body weight with age, and that while milk secretion and body weight follow the same course, they are largely independent of each other.

If the increase of milk secretion with age follows the same course as the increase of body weight with age then there should be a linear or directly proportional relation between milk secretion and body weight for a group of animals of all ages during the growing period. This is, in fact, the case as shown in Fig. 1 plotted from the data in Table I. The data is confined to the age interval of from 2 years, the usual age when milking begins, to 9 years, the age of maximum milk secretion and body weight of the dairy cow.

It is of interest to fit an equation to the data in Fig. 1 in order to determine whether the relation between body weight and milk secretion with age is an expression of a general law which will apply below the range of observation of 2 years. Fitting an equation of the first degree to the data, we obtain

$$F = 1.0425W - 472.32$$

[1] Brody, S., Ragsdale, A. C., and Turner, C. W., *J. Gen. Physiol.*, 1922–23, v, 445.

in which F is the yearly fat production for any body weight, W. That is, after the animal reaches the body weight of 472 pounds there is an increase of 1.0425 pounds in milk fat production per year, for an increase of one pound of body weight with age. Since the animal is about 13 months of age when she weighs 472 pounds,[2] then if this

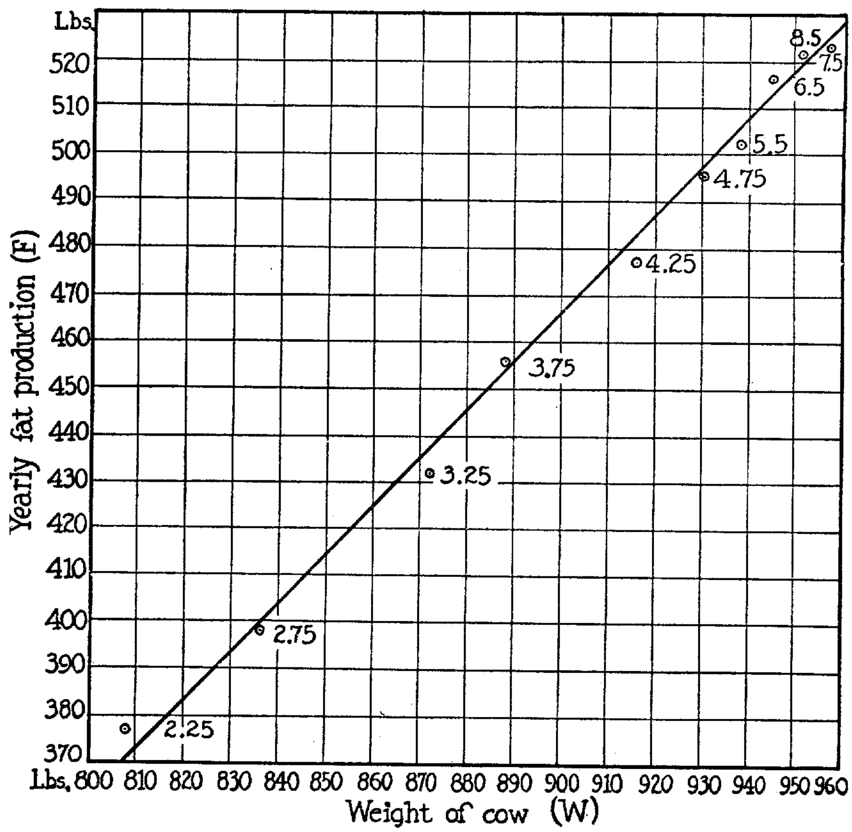

FIG. 1. The increase of milk secretion with increasing body weight with age in Jersey cattle. The smooth line passing through the observed values was plotted from the equation $F = 1.0423W - 472.32$ in which F is the yearly milk fat production for any body weight (W). From this equation an increase of 100 pounds in the weight of the body with age is accompanied by an increase of about 104 pounds of milk fat per year. The numerals on the curve represent the ages of the animals in years.

[2] *Cf.* Eckles, C. H., *Univ. Missouri Agric. Exp. Station, Research Bull. 36*, 1920.

equation is an expression of a general law, the dairy cow should be able to begin secreting milk at a little over one year of age. This is in agreement with experience. Calves have been known to conceive as early as 5 months of age, and to calve at 14 months of age. This equation therefore appears to be rational, and incidentally seems to indicate that there is no material development of mammary milk secreting tissue until the age of sexual maturity, or at any rate, until the age of adolescence is reached.

TABLE I.

*The Increase of Body Weight and Milk Secretion with Age in the Dairy Cow.**

Age.	Body weight.		Butter fat production per year.											
	Jersey.		Jersey.		Shorthorn.		Ayrshire.		Guernsey.		Holstein.			
	No. of cows included.	Average weight.	No. of cows included.	Average production.	No. of cows included.	Average production.	No. of cows included.	Average production.	No. of cows included.	Average production.	Age.	No. of cows included.	Average production.	
yrs.		*lbs.*		*lbs.*		*lbs.*		*lbs.*		*lbs.*	*yrs.*		*lbs.*	
2.25	3155	808	2829	377	123	268	817	333	3559	407	2.5	2454	508	
2.75	1449	836	1261	398	183	274	893	366	1682	423	3.5	1523	570	
3.25	1523	872	1271	432	82	251	442	367	1374	436	4.5	1238	615	
3.75	1122	888	992	456	85	317	461	389	1192	472	5.5	1116	644	
4.25	1171	916	978	477	61	348	376	408	1093	486	6.5	836	666	
4.75	916	930	809	496	64	356	340	430	884	501	7.5	583	665	
5.5	1692	938	1487	502	70	376	545	448	1133	511	8.5	396	657	
6.5	1235	945	1067	516	80	383	399	455	897	521				
7.5	965	952	837	521	66	405	298	478	572	528				
8.5	621	957	565	523	65	402	225	453	369	527				

* Compiled from the records of Register of Merit Jersey, Record of Merit Shorthorn, Advanced Register Ayrshire, Guernsey and Holstein cattle.

While the linear relation between increase in body weight and milk secretion with age in Fig. 1 definitely shows that growth in body weight and increase in milk secretion with age follow the same course, it is useful to bring out this relation by pointing to the parallelism between the two processes. In Fig. 2 the curves of increase in body weight (broken curve) and milk secretion (continuous curve) of the Jersey cow are parallel and both follow the same exponential equation

$$X = A\left(1 - e^{-kt}\right)$$

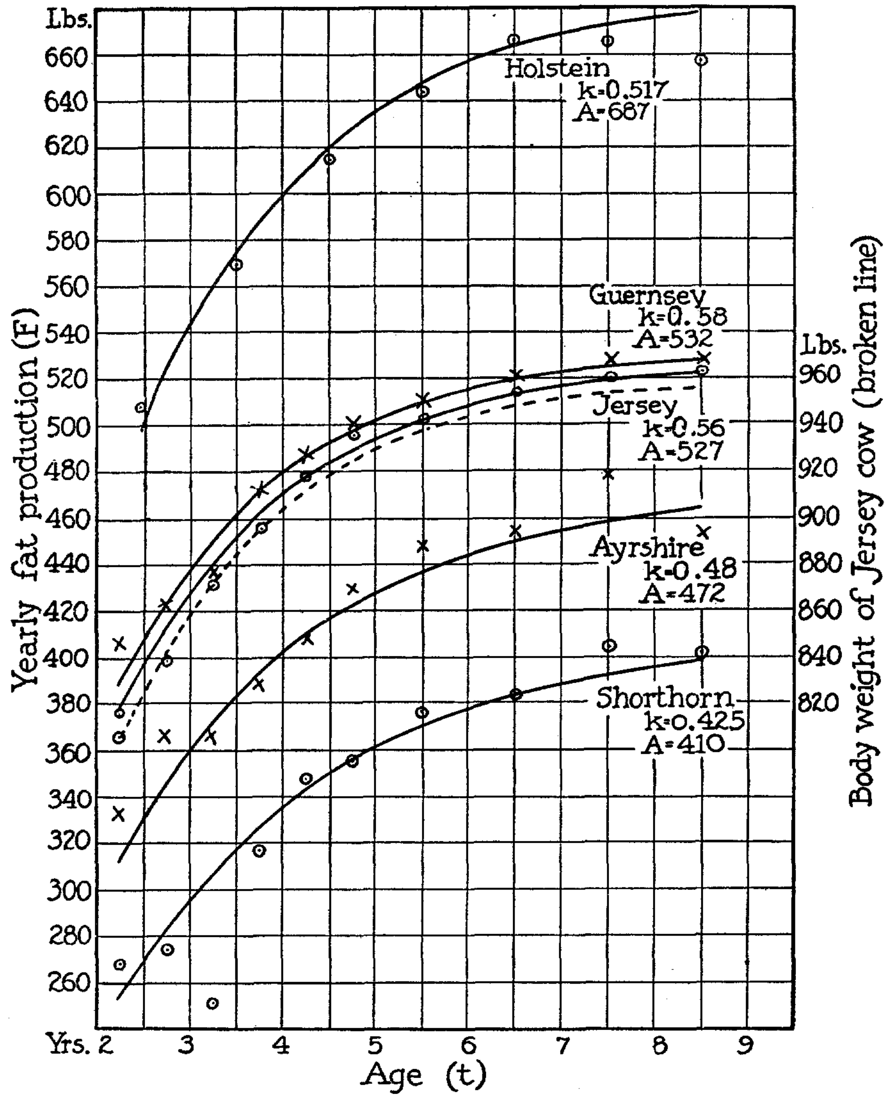

FIG. 2. The increase of milk secretion with age in the dairy cow. The smooth curves passing through the observed values were plotted from the equation $F = A(1 - e^{-kt})$ in which F is the yearly fat production at any age (t). The numerical values of the constants A and k for the several breeds are indicated on the curves. The broken curve shows the growth in weight of the Jersey cow.

where X is the body weight, or milk secretion at any age, t, and k is the velocity constant which is of approximately the same numerical value for both curves. This equation also represents the course of milk secretion of other breeds of cattle as shown by the close agreement between the values computed from this equation represented by the smooth curves in Fig. 2, and the observed values.

The data in Figs. 1 and 2 show conclusively that growth in weight, and increase of milk secretion with age follow the same course—the course of a monomolecular chemical reaction—thus further substantiating the theory that growth is limited by a chemical reaction.[3]

[3] The decline in growth with advancing age is often spoken of as due to the dying out of the "growth impulse." From the standpoint of the quantitative interpretation of this equation, the concept of growth impulse may be used in the same sense as the concept of "limiting substance." This equation shows that the growth impulse dies out, or the growth-limiting substance is used up at a constant ratio (or per cent) of itself. This idea is illustrated in the following table on the growth in weight of the Jersey cow, assuming that the mature weight, 960 pounds, is a measure of the limiting substance at the beginning of growth, and that the weight at any age t is a measure of this limiting substance used up to that age t.

Age. (t)	Weight of Jersey cow. (X)	Amount of limiting substance or impulse left, or growth yet to be made. (960-X)	Ratio of each value of (960-X) to the preceding value of (960-X).
yrs.	*lbs.*		
1.75	748	212	
			0.740
2.25	803	157	
			0.738
2.75	844	116	
			0.732
3.25	875	85	
			0.752
3.75	896	64	
			0.734
4.25	913	47	
			0.744
4.75	925	35	

The amount of limiting substance or impulse, at each age is seen to be about 74 per cent of the amount of this substance, or impulse, at the preceding age. In other words, the proportional amount of limiting growth substance, or of growth impulse, that changes in unit time is a constant.

Having determined the fact that the increase of milk secretion with age follows the same course as the increase of body weight with age, the questions arise whether the increase of milk secretion with age is dependent on the increase of body weight (*i.e.*, whether the increase of milk secretion with age is limited by the increase of nutrients circulating in the blood which are roughly proportional to the body weight); or whether the increase of milk secretion with age is dependent on the development of milk secreting tissues, and on other factors consequent to increase in age. These questions may be answered in a general way by separating, as far as practicable, the factors of age and body weight, and determining the effect of each of these factors on milk secretion. A practical, if not an entirely satisfactory[4] method of making a separation between body weight and age is to classify the animals into convenient age groups and determine the relation between the body weight of the animals within the age groups and their milk secretion; also to classify the animals into convenient body weight groups and determine the relation between the age of the animals within the weight groups and their milk secretion. This has been done and the results are shown in Fig. 3 plotted from data in Tables II and III.

Fig. 3 shows the relation between milk secretion and body weight at constant age. Qualitatively, the effect of age is apparent by the fact that each age group has its own curve which is not connected to the curves of other age groups. Quantitatively, the relative contribution of increasing body weight and of age (or rather of factors other than body weight incident to increase of age) on increasing milk secretion with age, may be roughly estimated from a comparison of the slopes of the curves of Figs. 1 and 3. From Fig. 1, showing the relation between milk secretion and body weight with age, an increase in body weight with age by 100 pounds is accompanied by an increase in yearly butter fat production of slightly over 100 pounds. From Fig. 3 showing the relation between body weight and milk secretion at constant age,

[4] This method is not entirely satisfactory because differences in body weight at the same age may be due to widely different causes; some of the causes may be purely genetic, others purely environmental, and still others to different combinations of genetic and environmental factors. These different factors and combinations of factors may differently influence milk secretion at different ages and weights.

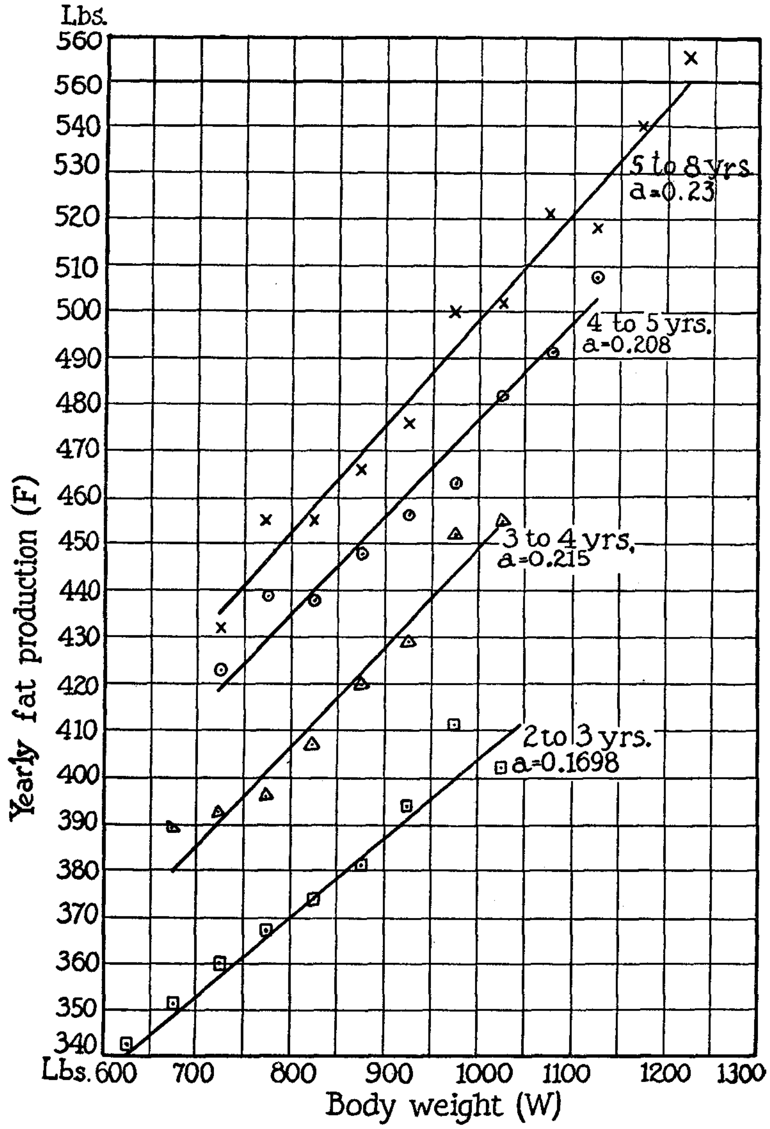

FIG. 3. The increase of milk secretion with increasing body weight at constant age. The smooth lines passing through the observed values were plotted from the equation $F = aW + b$ in which F is the yearly milk fat production for the body weight (W) at the constant ages indicated on the curves; a is the constant increase of yearly fat production for each added pound of body weight. From the values of a indicated on the curves, an increase of 100 pounds in the weight of the body is accompanied by an increase of about 20 pounds of milk fat production per year.

an increase in body weight of 100 pounds is accompanied by an increased yearly butter fat production of about 20 pounds.[5] The relation between body weight and milk secretion at constant age is linear as would be expected from the approximately linear relation between body weight and blood volume[6] which carries the nutrients for milk secretion, and from a consideration of certain work pointing to a direct proportionality between the available nutrients in an organism, and its physiological products.[7] From a comparison of the curves

TABLE II.

The Increase of Milk Secretion with Increasing Body Weight at Constant Age of Register of Merit Jersey Cattle.

Body weight.	Age of cows.							
	2 to 3 yrs.		3 to 4 yrs.		4 to 5 yrs.		5 to 8 yrs.	
	No. of animals included.	Yearly fat production.	No. of animals included.	Yearly fat production.	No. of animals included.	Yearly fat production.	No. of animals included.	Yearly fat production.
lbs.		*lbs.*		*lbs.*		*lbs.*		*lbs.*
625–	101	342						
675–	199	351	43	389				
725–	540	360	142	392	38	423	52	432
775–	584	367	255	396	101	439	156	455
825–	1043	374	573	407	315	438	458	455
875–	576	381	508	420	318	448	543	466
925–	496	394	605	429	445	456	866	476
975–	155	411	220	452	262	463	599	500
1025–	97	402	185	455	240	482	680	502
1075–					82	491	224	521
1125–					49	508	154	518
1175–							29	540
1225–							27	556

[5] It may be pointed out that the discovery that there is an increase of 20 pounds of fat production per year for an increase of 100 pounds of body weight at constant age, answers the widely discussed question among dairymen concerning the relative economy of milk production from heavy and light cows. 20 pounds of butter fat is barely sufficient to cover the cost of maintenance of 100 pounds of body weight per year.

[6] Donaldson, H. H., The rat, Memoir of The Wistar Institute of Anatomy and Biology, No. 6, Philadelphia, 1915, 96.

[7] *Cf.* Loeb, J., *J. Gen. Physiol.*, 1919–20, ii, 297.

of Figs. 1 and 3, it appears that increasing body weight with age contributes about 20 per cent to the increased milk flow with age, while the other 80 per cent of increased milk flow with age is due to other factors accompanying increased maturity.

The fact that the course of milk secretion with age is largely independent of body weight is also shown in Table III where the computed and observed milk secretions at different ages are given for the groups of animals at constant body weight. The equation of a monomolecular reaction which represents growth in body weight and increase in milk secretion with age shown in Fig. 2, also represents fairly satisfactorily the increase in milk secretion with age at constant body weight shown in Table III.

TABLE III.

The Increase of Milk Secretion with Age at Constant Body Weight of Register of Merit Jersey Cattle.

Age.	Weight of cows.											
	750 to 849 lbs.			850 to 949 lbs.			950 to 1049 lbs.			1050 to 1151 lbs.		
	No. of cows included.	Yearly fat production. (1)		No. of cows included.	Yearly fat production. (2)		No. of cows included.	Yearly fat production. (3)		No. of cows included.	Yearly fat production. (4)	
		Observed.	Calculated.		Observed.	Calculated.		Observed.	Calculated.		Observed.	Calculated.
yrs.		*lbs.*			*lbs.*			*lbs.*			*lbs.*	
2.5	1869	354	346	1289	385	381	259	405	406	23	418	389
3.5	799	401	401	1241	429	430	422	458	453	44	431	449
4.5	446	433	434	1019	458	457	513	474	478	114	496	486
5.5	239	463	454	842	483	472	476	496	491	131	519	507
6.5	174	452	466	563	475	480	503	503	498	97	524	520
7.5	130	470	474	443	487	485	499	499	501	91	529	528
8.5	87	479	478	255	487	487	492	492	503	47	533	533

(1) Computed from $F = 485(1 - e^{-0.5t})$ in which F is the fat production for the age (t).

(2) Computed from $F = 490(1 - e^{-0.6t})$.

(3) " " $F = 505(1 - e^{-0.65t})$.

(4) " " $F = 540(1 - e^{-0.51t})$.

SUMMARY.

It is shown that from 2 years, the age when milk secretion usually begins, to 9 years, the age of maximum body weight, the increase of milk secretion with age follows the course of growth in body weight—both can be accurately represented by the equation of a monomolecular chemical reaction having a velocity constant of approximately the same numerical value. While increase in milk secretion and increase in body weight with age follow the same course, it is shown that increasing body weight contributes only about 20 per cent to increasing milk secretion with age. The fact that milk secretion and body weight follow the same course, even though they are largely independent of each other indicates that increase in body weight is a good measure of growth of the dairy cow; this fact also shows that the increase of milk secretion with age may be used as a measure of growth. The fact that milk secretion, like body weight, follows the course of a chemical reaction, adds further support to the theory that growth is limited by a chemical reaction.