# A FORMULA FOR ESTIMATING SURFACE AREA OF DAIRY CATTLE [1]

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## INTRODUCTION

It has long been accepted as a fact that heat production in the animal body is due to the oxidation processes within the body, and hence is an accurate measure of the rate of metabolism. In order to utilize this standard in research, it becomes necessary to devise a satisfactory method for comparing the heat production of animals of different sizes.

Very early in nutritional investigations it became apparent that that the heat production of an animal as not proportional to its live weight. In 1848 Bergmann (*3*) [3] [4] attempted to explain the relatively higher heat production of smaller animals per unit of weight by the generalization that the heat production of the animal body is proportional to its surface area. This idea found wide application and was given strong support by many investigators.

Regnault and Reiset (*10, p. 514*) [5] in their studies of the respiratory exchange of different species under diverse conditions, determined that the oxygen consumption of animals is not proportional to their weight. Obviously the heat production would have a similar ratio per unit of weight, which they explained as being due to the fact that small animals expose a relatively greater surface area to the cooling effect of the atmosphere and consequently require a greater heat production to maintain their body temperature. Some years later Rubner [6] proved that their explanation was faulty, although their general statement of facts was correct.

Thus far the idea of the relation between heat production and surface area had been entirely theoretical, since no actual measurements of the surface area of living subjects were available. In 1879 Meeh (*8*) published the actual measurements of the surface area of living subjects, the results of his own painstaking work, which included the measurements of 6 adults and 10 children.

From his measurements Meeh developed a formula by which the surface area of any individual could be determined. This formula

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[2] The writer wishes to express his appreciation to A. C. Ragsdale, Professor of Dairy Husbandry, and to Samuel Brody, Assistant Professor of Dairy Chemistry, University of Missouri, for aid in outlining the problem and for helpful suggestions in interpreting and summarizing data and in the preparation of the manuscript. The major credit for developing the idea and details of the revolving metal cylinder of the measuring instrument, is due Samuel Brody. In this he was assisted by the writer. A. C. Ragsdale, C. W. W. Turner, and Chester Sparrow (an engineering student) all had a part in developing the plan and in perfecting this new method of measuring the surface area of animals. All experimental data were taken by the author and have been presented by him in a thesis submitted at the University of Missouri in partial fulfillment of the requirements for the degree of master of arts.

[3] Reference is made by number (italic) to "Literature cited", p. 278.

[4] Cited by Benedict (*1*).

[5] Cited by Lusk (*7, p. 120.*)

[6] Cited by Lusk (*7, p. 121*).

was based on the fundamental mathematical law that the surface areas of similar solids are proportional to the two-thirds power of their volumes.

Assuming that the specific gravity was the same in each case, he substituted weight for volume so that his formula is expressed in the following form:

$$S = KW^{2/3}$$

in which $S$ is the surface area in square centimeters, $W$ the weight in kilograms, and $K$ a constant (12.312 for adults and 11.9 for children).

In 1883 Rubner (*11*) measured the surface area of a number of dogs varying greatly in weight, and also determined their heat production under comparable conditions. He found the body heat production to be quite constant per square meter of the body surface, but varying greatly per kilogram of body weight. A few years later, observations by Voit (*13*) indicated that this law is applicable over a wide range in the animal kingdom. He determined the heat production of subjects varying in size from a mature horse to a mouse and found the heat production per meter of body surface to be quite constant in all cases.

In 1916 D. Du Bois and E. F. Du Bois (*4*) measured the surface area of a number of human subjects, and from their measurements they developed a formula for estimating the surface area of humans based on the weight and height of the individual.

In general, investigators both in human physiology and pathology and in animal production have accepted the practice of calculating heat production per unit of surface area, and consequently surface area is the most common unit of reference in estimating basal metabolism.

Benedict (*5, p. 129*) and his coworkers have challenged this practice of calculating heat production per unit of body surface. They maintain that the heat production depends upon the actual mass of protoplasmic tissue within the body and not upon the cooling on the body surface. They have published an extensive series of prediction tables for determining heat production based on weight, height, sex, and age, but involving no assumption concerning derivation of surface area.

Extensive comparisons of the Benedict standard and the body-surface standard of Du Bois, show that the results obtained are almost parallel. More recently Benedict (*2, p. 159*) stated: "We believe that the accurate measurements of body-surface made possible by Du Bois may legitimately be used in a manner heretofore never practicable in metabolism experiments, provided that they are considered as physical measurements and with no erroneous conceptions as to the existence of a causal relationship between surface area and heat production."

Assuming that the surface area of the body is an accurate standard for estimating the metabolism, the investigator meets with difficulty because it has been impossible to calculate the surface area of animals with any degree of accuracy.

Earlier investigators have accepted the Meeh formula as applying to all types of animals, but the correct constants have been worked out in only a few instances, and also later investigations proved that in many instances this formula gave very erroneous results.

Trowbridge, Moulton, and Haigh (*12*) published a number of measurements of the surface area of cattle and calculated the constant for the Meeh formula. The constants varied from 7.319 to 10.74, depending on the age and the degree of fatness of the animals.

In 1916 Moulton (*9*) developed two formulas for estimating surface area of cattle, based on warm empty weight, but using a different exponent than the one used by Meeh. His formula for fat cattle is:

$$A = 0.158 W^{\frac{5}{9}}$$

and for other animals:

$$A = 0.1186\, W^{\frac{5}{8}}$$

in which $A$ is the surface area in square meters, and $W$ is the empty weight in kilograms.

Hogan and Skouby (*6*) considered the work of Trowbridge, Moulton, and Haigh, and that of Moulton, as proof that the surface area of cattle could not be accurately calculated as a power function of weight, and they developed a formula for estimating surface area of cattle and swine, patterned after the height-weight formula of Du Bois (*4*), in which both weight and body length are factors. Their formula is:

$$S = W^{.4} \times L^{.6} \times K$$

in which $S$ is surface area in square centimeters, $W$ the live weight in kilograms, $L$ the length of the body in centimeters, and $K$ a constant (217 for cattle and 175 for swine).

The purpose of the work set forth in this paper was to actually measure the surface area of normal dairy cows, and to develop a simple formula for estimating the surface area of dairy cattle.

## MEASUREMENT OF SURFACE AREA

It was rather difficult to find a satisfactory method for measuring the surface area of living animals with a fair degree of accuracy. The method finally used consisted in rolling a revolving metal cylinder of known area, attached to a revolution counter, over the entire surface of the animal, and then simply multiplying the number of revolutions of the roller by the area of the roller. This gave an approximately accurate surface-area measurement with a very small amount of computation, and the measuring instrument was not difficult to use.

The technique involved in taking surface area was simple. In most cases, only half of the body surface the right side of the animal was actually measured, and the results were multiplied by two. First, the dorsal and ventral median lines were marked with colored crayon. Then, starting at the base of the horn, the roller was passed along the dorsal median line to the posterior mid line. Lower down on the side of the animal, measurement was from the outline of the jawbone to the posterior mid line. The roller was equipped with a crayon marker which plainly marked the path of the roller. Then, by keeping the outer edge of the roller along the mark made the previous trip, the entire surface was covered. The only region which was difficult to measure accurately was around the udder and inside of the hind leg, but with a little extra care this was accomplished very satisfactorily. The legs were measured by moving the roller spirally down them. The head and ears were measured last. The area of the tail was not measured with the roller, but it was estimated by multiplying the length, a figure representing the average of the diameters at the root and at the base of the switch.

Figures 1 and 2 are illustrations of the measuring apparatus. *A* is the brass roller. This roller is 2 inches long and 2 inches in diameter. Repeated trials with rollers of different lengths and diameters established this one as most satisfactory. A smaller roller did not turn uniformly, and a larger one was inconvenient in measuring around the flank, udder, armpit, etc. *B* is the milled rim of a disk which served as a marker. *C* is the dial of the revolution counter. *D* is the handle. *E* is a metal tube containing a fine spring which holds the crayon against the milled rim of the marking

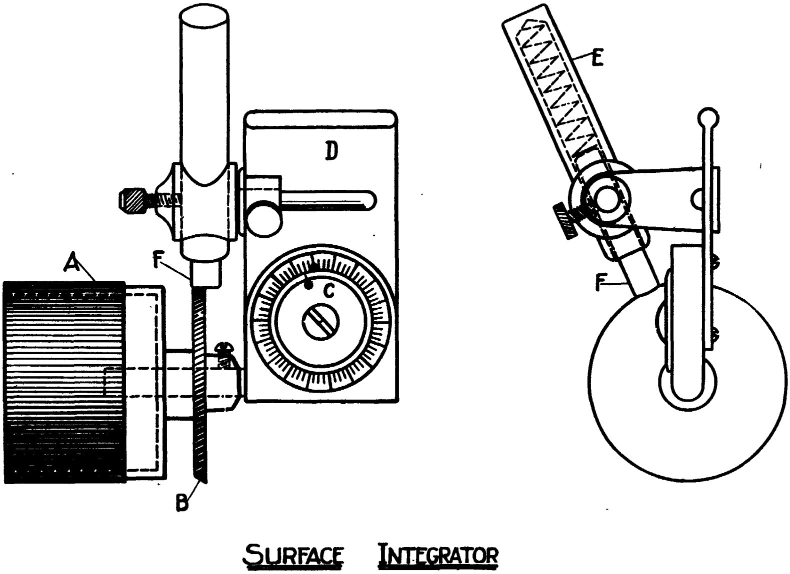


FIG. 1.—Instrument used for measuring surface area of animal. *A*, brass cylinder; *B*, milled rim of disk which makes a chalk line; *C*, revolution counter; *D*, handle; *E*, metal tube containing spring; *F*, chalk crayon. (Drawing from photograph)

disk. F is the crayon. The milled rim made a fine but distinct chalk line on the animal. Figure 3 is a photograph of the measuring operation.

An effort was made to determine the quantitative error in the measured area as compared to the actual surface.

Two animals—cow 129 and heifer 27—were slaughtered. Both animals were measured with the roller on the morning before they were slaughtered. After they were slaughtered, the outlines of the hides were traced on paper and the areas of the tracings were measured. The results obtained are as follows:

*Cow 129*

| | |
|---|---|
| Body area of live cow | 42,635 sq. cm. |
| Area of hide | 42,883 sq. cm. |
| Difference | +248 sq. cm. |
| Per cent difference (based on area of hide) | +0.58 per cent |

*Heifer 27*

| | |
|---|---|
| Body area of live heifer | 14,821 sq. cm. |
| Area of hide | 14,701 sq. cm. |
| Difference | −120 sq. cm. |
| Per cent difference (based on area of hide) | −0.82 per cent |

The two methods gave approximately the same results.

### DESCRIPTION OF ANIMALS USED

The data presented in this paper were all taken on Holstein and Jersey animals. Practically every animal of these two breeds in the University of Missouri dairy herd have been measured, and in some cases, in order to obtain more data, certain young animals were measured two or more times at different ages. The data include

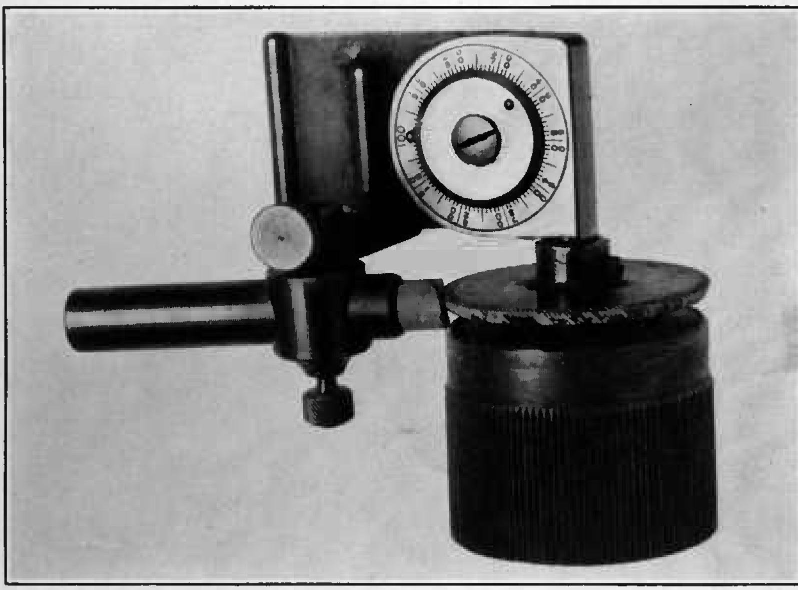

FIG. 2.—Photograph of instrument for measuring surface area of animal

measurements of animals varying in age from a few hours to 10 years, and in weight from 17.6 to 653 kilograms. The animals represent many variations in degree of fleshing, body conformation, and stages of lactation and gestation.

### LIVE WEIGHT OF ANIMALS

In all cases the weight of the animal was taken immediately before the surface area was measured. No attempt was made to withhold either feed or water before weighing.

## DEVELOPMENT OF FORMULA

When the live weight was plotted against surface area, as in Figure 4, a simple parabolic curve was obtained with all the points falling reasonably close to the curve. Such a curve indicated that surface area is a direct power function of weight, and hence may be determined by a simple formula as

$$X = Ky^n$$

By plotting surface area against weight on logarithmic paper as in Figure 4, a straight line was obtained having a slope of 0.56 which designated the value of the exponent $n$ in the equation. In general, the values for the Holsteins were slightly greater than those for Jerseys (fig. 4). In reality, the value 0.57 for Holsteins and of 0.55 for Jerseys is more nearly exact than the average figure 0.56, but a few trial calculations indicated that the slight increase in accuracy of results obtained by using a different exponent in the formula for the different breeds was not sufficient to justify the use of two separate formulae.

Knowing the live weight and the surface area of the animals and the value of $n$, it remained to solve for $K$ in the formula. By choosing values that fell on the weight-surface area curve, and substituting them in the formula, it was possible to solve for $K$.

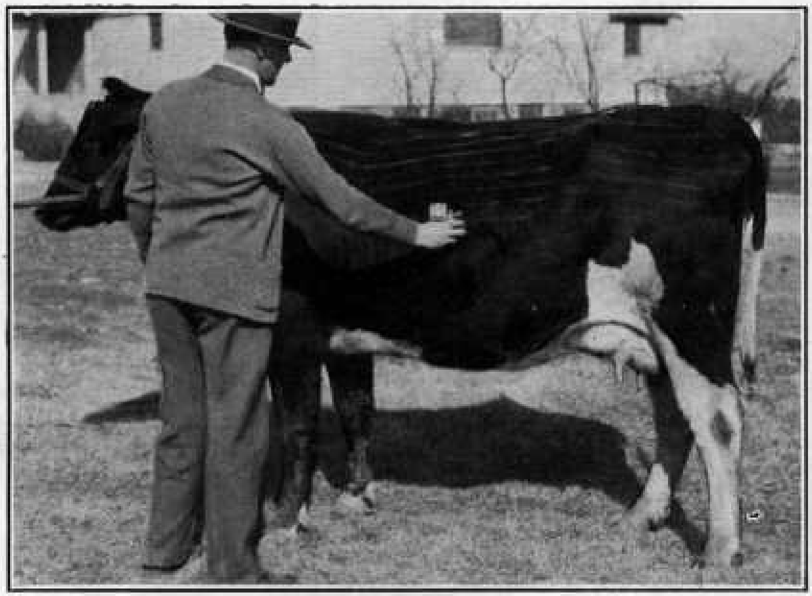

FIG. 3.—Measuring the surface area of a cow, with the instrument shown in Figures 1 and 2

$$S\ A = K W^{n} \text{ or } \frac{S\ A}{W^{n}} = K$$

Using logarithms, the equation becomes

$$\text{Log } S\ A - 0.56 \text{ Log } W = \text{Log } K$$

The value of $K$ was 1,470. Then the formula in its final form becomes

$$S\ A = 1{,}470\ W^{0.56}$$

in which $S\ A$ is the surface area in square centimeters, $W$ is the live weight in kilograms, and 1,470 is a constant.

The values of $W$ for the different animals were substituted in the formula, and the equations solved to determine the surface area. These computed values for surface area were then compared with the observed values. These results are given in Table I. In all but 4 cases, or in 96 per cent of all animals measured, the computed value was within ±5 per cent of the observed value. The remaining 4 animals had computed values varying from 5.4 per cent to 6.17 per cent above the observed values. The average per cent deviation in all animals, regardless of sign, was 1.95. Among the 46 animals having a

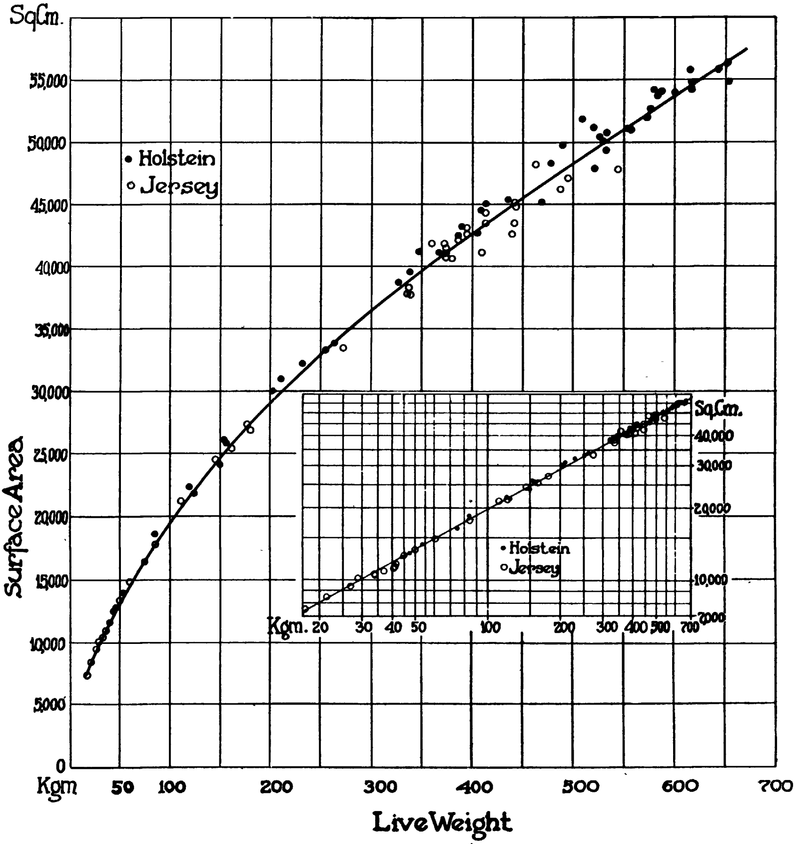


FIG. 4.—Relation between the live weight and the surface area of dairy cows

computed value greater than the observed value the average per cent of deviation was 1.99, and among the 50 animals having a computed value lower than the observed value the average per cent of deviation was 1.92.

The area was also computed according to the Meeh formula (8). These results are given in Table I in order that they may be compared with the values obtained from the new formula.

TABLE 1.—*Data used in developing formula and computed values*

JERSEYS

| Herd No. of animal[a] | Age of animal | Live weight, kgm. | Surface area: Measured — Surface, sq. cm. | Computed, $S=1470\,W^{0.56}$ — Surface, sq. cm. | Computed, $S=1470\,W^{0.56}$ — Error, per cent | Computed, $S=839\,W^{2/3}$ — Surface, sq. cm. | Computed, $S=839\,W^{2/3}$ — Error, per cent |
|---|---|---|---|---|---|---|---|
| 1 | 10 hours | 17.6 | 7,296 | 7,375 | 1.08 | 5,676 | −22.20 |
| 2 | 2 days | 21.5 | 8,433 | 8,232 | −2.38 | 6,466 | −23.33 |
| 170 | 3 days | 27.0 | 9,404 | 9,421 | 0.18 | 7,587 | −19.32 |
| 187 | 16 days | 29.0 | 10,076 | 9,767 | −3.06 | 7,918 | −21.41 |
| 189 [1] | 23 days | 34.0 | 10,557 | 10,681 | 1.17 | 8,803 | −16.61 |
| 188 [1] | 35 days | 34.0 | 10,395 | 10,681 | 2.75 | 8,803 | −15.31 |
| 189 [2] | 38 days | 40.5 | 11,368 | 11,785 | 3.66 | 9,893 | −12.97 |
| 188 [2] | 40 days | 41.5 | 11,692 | 11,980 | 2.46 | 10,088 | −13.71 |
| 186 [1] | 44 days | 41.0 | 11,469 | 11,867 | 3.47 | 9,974 | −13.03 |
| 157 [1] | 50 days | 34.0 | 10,443 | 10,681 | 2.27 | 8,803 | −15.70 |
| 157 [2] | 70 days | 37.0 | 10,954 | 11,201 | 2.25 | 9,314 | −14.97 |
| 164 | 80 days | 50.0 | 13,466 | 13,267 | −1.47 | 11,381 | −15.48 |
| 185 [1] | 72 days | 45.0 | 12,671 | 12,505 | −1.31 | 10,613 | −16.24 |
| 27 | 3 months | 61.0 | 14,821 | 14,839 | 0.12 | 12,997 | −12.30 |
| 182 [1] | 4 months | 85.0 | 17,892 | 17,883 | −0.05 | 16,223 | −9.32 |
| 181 [1] | 5 months | 111.0 | 21,291 | 20,779 | −2.40 | 19,373 | −9.00 |
| 186 [2] | 6 months | 122.0 | 21,672 | 21,915 | 1.12 | 20,633 | −4.79 |
| 183 | 6 months | 161.0 | 25,510 | 25,614 | 0.41 | 24,823 | −2.69 |
| 185 [2] | 6 months | 145.0 | 24,540 | 24,160 | −1.54 | 23,150 | −5.66 |
| 182 [2] | 7 months | 177.0 | 27,294 | 27,016 | −1.02 | 26,359 | −3.42 |
| 182 [2] | 8 months | 179 | 26,817 | 27,188 | 1.38 | 26,640 | −0.66 |
| 181 [2] | 9 months | 181 | 26,970 | 27,358 | 1.44 | 26,753 | −0.80 |
| 180 | 12 months | 272 | 33,423 | 34,401 | 2.92 | 35,209 | 5.34 |
| 180 | 1 year, 4 months | 336 | 37,853 | 38,744 | 2.35 | 40,395 | 6.71 |
| 177 | 1 year, 7 months | 324 | 38,964 | 37,959 | −2.57 | 38,664 | −0.77 |
| 176 | 1 year, 7 months | 336 | 38,365 | 38,744 | 0.98 | 40,537 | 5.66 |
| 173 | 1 year, 10 months | 374 | 41,051 | 41,151 | 0.24 | 43,536 | 6.05 |
| 172 | 1 year, 11 months | 395 | 43,094 | 42,435 | −1.53 | 45,151 | 4.77 |
| 171 | 1 year, 11 months | 359 | 41,959 | 40,215 | −4.15 | 42,364 | 0.96 |
| 170 | 2 years, 1 month | 413 | 43,544 | 43,512 | −0.07 | 45,512 | 4.51 |
| 166 | 2 years, 7 months | 374 | 40,750 | 41,151 | 0.98 | 43,536 | 6.83 |
| 167 | 2 years, 7 months | 372 | 41,822 | 41,027 | −1.90 | 43,382 | 3.73 |
| 165 | 2 years, 8 months | 381 | 40,609 | 41,583 | 2.39 | 44,078 | 8.54 |
| 164 | 2 years, 11 months | 338 | 37,773 | 38,874 | 2.91 | 40,696 | 7.73 |
| 157 | 4 years, 1 month | 374 | 41,424 | 41,151 | −0.65 | 43,536 | 5.10 |
| 156 | 4 years, 1 month | 395 | 42,595 | 42,435 | −0.37 | 45,151 | 6.00 |
| 154 | 4 years, 10 months | 463 | 48,263 | 46,401 | −3.85 | 50,575 | 4.79 |
| 151 | 5 years, 3 months | 545 | 47,900 | 50,858 | 6.17 | 55,958 | 16.82 |
| 129 | 7 years | 442 | 42,635 | 45,205 | 6.02 | 48,684 | 14.18 |
| 126 | 7 years, 4 months | 495 | 47,161 | 48,179 | 2.15 | 52,482 | 11.28 |
| 127 | 7 years, 7 months | 444 | 44,850 | 45,320 | 1.02 | 48,811 | 8.83 |
| 120 | 7 years, 10 months | 386 | 42,135 | 41,889 | −0.58 | 44,463 | 5.52 |
| 121 | 8 years | 442 | 43,430 | 45,205 | 4.08 | 48,665 | 12.05 |
| 110 | 8 years, 1 month | 487 | 46,189 | 47,739 | 3.35 | 51,913 | 12.39 |
| 125 | 8 years, 9 months | 442 | 45,106 | 45,205 | 0.21 | 48,666 | 7.89 |
| 108 | 9 years | 410 | 41,112 | 43,334 | 5.40 | 46,287 | 12.58 |

[a] Superior numbers indicate animals measured more than one time.

TABLE 1.—*Data used in developing formula and computed values*—Continued

HOLSTEINS

| Herd No. of animal | Age of animal | Live weight, kgm. | Surface area: Measured | Surface area: Computed, $S=1470\ W^{0.56}$ | | Surface area: Computed, $S=839\ W^{2/3}$ | |
|---|---|---|---|---|---|---|---|
| | | | Surface, sq. cm. | Surface, sq. cm. | Error, per cent | Surface, sq. cm. | Error, per cent |
| 552 | 1 day | 47.5 | 12,847 | 12,907 | 0.46 | 11,017 | −14.24 |
| 274 | 3 days | 53.5 | 13,982 | 13,782 | −1.43 | 11,910 | −14.81 |
| 554 | 7 days | 41.0 | 11,600 | 11,867 | 2.30 | 9,974 | −14.01 |
| 553 | 9 days | 44.5 | 12,573 | 12,411 | −1.28 | 10,517 | −16.35 |
| 550 | 7 weeks | 75.0 | 16,466 | 16,667 | 1.22 | 14,922 | −9.37 |
| 551 | 3 months | 84.0 | 18,660 | 17,764 | −4.80 | 16,087 | −13.78 |
| 549 | 3½ months | 120.0 | 22,376 | 21,611 | −3.42 | 20,406 | −8.80 |
| 548 | 4 months | 125.0 | 21,817 | 22,210 | 1.80 | 20,847 | −4.45 |
| 545 | 4½ months | 150.0 | 24,061 | 24,615 | 2.30 | 23,668 | −1.63 |
| 546 | 5 months | 154.0 | 26,159 | 24,981 | −4.50 | 24,105 | −7.85 |
| 547 | 6 months | 156.0 | 25,820 | 25,209 | −2.36 | 24,306 | −5.86 |
| 544[1] | 7 months | 202.0 | 30,081 | 29,235 | −2.81 | 28,875 | −4.00 |
| 544[2] | 7½ months | 209.0 | 31,041 | 29,663 | −4.43 | 29,444 | −5.14 |
| 542 | 8 months | 231.0 | 32,260 | 31,381 | −2.72 | 32,709 | 1.39 |
| 541 | 10 months | 254.0 | 33,335 | 33,102 | −0.69 | 33,528 | 0.58 |
| 540 | 1 year | 263.0 | 33,870 | 33,757 | −0.33 | 34,315 | 1.31 |
| 537[1] | 1 year, 2 months | 336.0 | 39,591 | 38,744 | −2.14 | 40,646 | 2.66 |
| 534 | 1 year, 4 months | 327.0 | 38,680 | 38,157 | −1.35 | 39,824 | 2.95 |
| 535 | 1 year, 4 months | 408.0 | 44,499 | 43,216 | −2.88 | 46,136 | 3.67 |
| 537[2] | 1 year, 5 months | 389.0 | 43,194 | 42,062 | −2.62 | 44,533 | 3.09 |
| 536 | 1 year, 6 months | 469.0 | 45,242 | 46,728 | 3.28 | 50,626 | 11.90 |
| 533 | 1 year, 6 months | 413.0 | 45,091 | 43,512 | −3.50 | 46,515 | 3.15 |
| 538 | 1 year, 6 months | 406 | 42,604 | 43,096 | 1.15 | 45,986 | 7.93 |
| 532 | 1 year, 7 months | 368 | 41,076 | 40,778 | −0.72 | 43,086 | 4.89 |
| 531 | 1 year, 8 months | 347 | 41,200 | 39,446 | −4.25 | 41,432 | 0.56 |
| 530 | 1 year, 8 months | 386 | 42,495 | 41,889 | −1.42 | 44,481 | 4.67 |
| 527 | 1 year, 10 months | 436 | 45,384 | 44,859 | −1.15 | 48,253 | 6.32 |
| 526 | 2 years, 2 months | 533 | 50,841 | 50,224 | −1.21 | 55,133 | 8.44 |
| 525 | 2 years, 5 months | 553 | 51,165 | 51,276 | 0.22 | 56,503 | 10.43 |
| 521 | 2 years, 11 months | 644 | 55,925 | 55,864 | −0.11 | 62,570 | 11.88 |
| 518 | 3 years, 1 month | 531 | 50,138 | 50,119 | −0.04 | 55,017 | 9.73 |
| 517 | 3 years, 9 months | 601 | 54,044 | 53,733 | −0.58 | 59,752 | 10.56 |
| 515 | 4 years | 616 | 55,937 | 54,185 | −3.13 | 60,345 | 7.88 |
| 512 | 4 years, 2 months | 508 | 51,914 | 48,885 | −5.83 | 53,395 | 2.85 |
| 510 | 4 years, 3 months | 576 | 52,737 | 52,465 | −0.52 | 58,083 | 10.14 |
| 509 | 4 years, 3 months | 490 | 49,805 | 47,904 | −3.81 | 52,149 | 4.70 |
| 508 | 4 years, 5 months | 478 | 48,319 | 47,241 | −2.23 | 51,293 | 6.15 |
| 507 | 4 years, 6 months | 574 | 52,012 | 52,362 | 0.67 | 57,950 | 11.41 |
| 503 | 5 years | 617 | 54,334 | 54,535 | 0.37 | 60,809 | 11.91 |
| 288 | 6 years | 579 | 54,240 | 52,620 | −2.98 | 58,261 | 7.41 |
| 290 | 6 years | 653 | 54,818 | 56,302 | 2.71 | 63,151 | 15.20 |
| 292 | 6 years | 592 | 54,172 | 53,281 | −1.64 | 59,154 | 9.19 |
| 285 | 6 years, 2 months | 522 | 47,883 | 49,640 | 3.66 | 53,158 | 11.01 |
| 281 | 6 years, 7 months | 526 | 50,521 | 49,852 | −1.32 | 54,672 | 8.21 |
| 281 | 6 years, 8 months | 556 | 51,008 | 51,432 | 0.83 | 56,731 | 11.21 |
| 279 | 7 years, 4 months | 576 | 52,805 | 52,466 | −0.64 | 58,083 | 10.00 |
| 274 | 7 years, 5 months | 608 | 53,710 | 54,085 | 0.70 | 60,214 | 12.11 |
| 275 | 7 years, 5 months | 520 | 51,278 | 49,532 | −3.40 | 54,254 | 5.80 |
| 266 | 8 years, 5 months | 535 | 49,399 | 50,331 | 1.88 | 55,293 | 11.93 |
| 254 | 10 years | 617 | 54,830 | 54,534 | −0.53 | 60,810 | 10.90 |

## DISCUSSION

A comparison of the computed values by the two formulae shows that a much greater range of error was obtained by using the two-thirds power of weight than by using the 0.56 power. The former gave results which were much too low in very small animals, and much too high in large animals, the percentage of error ranging from −23.2 per cent in 2-day-old calf to +16.8 per cent in a very fat barren cow. It was found that the constant 839 gave the most uniform results, but even then the range of error was so great that such results are of little value.

It is hardly fair to compare results obtained by the new formula with those obtained by Moulton's formula (*9*), inasmuch as his formula is based on warm empty weight rather than live weight. A few trial computations, substituting live weight for *W* in Moulton's formula, showed that when the five-eighths power of weight is used the results again are too low in very small animals and too great in large animals, especially in those which are rather fat.

The results obtained by using the 0.56 power of weight were in close agreement with the observed values. Of the four animals whose computed areas varied more than 5 per cent from the observed areas three were abnormal individuals. Cows 129 and 151 were nonbreeders. Both were dry and very fat when measured. Cow 108 was a very compactly built, short-legged individual, which was dry and quite fat when measured.

The possibility of introducing a second variable factor into the formula was discarded, since it was found possible to determine surface area quite accurately as a simple power function of weight. A second variable would only complicate the formula without increasing its accuracy, because the probable error in the observed value makes it questionable whether results closer than ±5 per cent are possible.

## SUMMARY AND CONCLUSIONS

In normal dairy cattle, surface area has been found to be a direct power function of weight. The formula $SA = 1470\ W^{0.56}$, in which $SA$ is the surface area in square centimeters, and $W$ the live weight of the animal in kilograms, accurately expressed the relationship between surface area and live weight.

Both the two-thirds and the five-eighths powers of the weight gave results which were much too low in very small individuals, and much too high in large or extremely fat animals.

The surface areas of 96 dairy cattle were measured. The areas of 92 animals as computed by the proposed formula were within ±5 per cent of the observed areas, and the maximum error in the case of an extremely fat barren cow was only 6.2 per cent. The introduction of linear measurements into the formula would only complicate it without increasing its accuracy.

## LITERATURE CITED

(1) BENEDICT, F. G.
1915. FACTORS AFFECTING BASAL METABOLISM. Jour. Biol. Chem. 20: 263–299, illus.

(2) ——— and TALBOT, F. B.
1921. METABOLISM AND GROWTH FROM BIRTH TO PUBERTY. 213 p., illus. Washington, D. C. (Carnegie Inst. Wash. Pub. 302)

(3) Bergmann, C., and Leuckart, R.
1852. ANATOMISCH-PHYSIOLOGISCHE UEBERSICHT DES THIERREICHS. 690 p., illus. Stuttgart.
(4) Du Bois, D., and Du Bois, E. F.
1916. A FORMULA TO ESTIMATE THE APPROXIMATE SURFACE AREA IF HEIGHT AND WEIGHT BE KNOWN. Arch. Int. Med. 17: 863–871, illus.
(5) Harris, J. A., and Benedict, F. G.
1919. A BIOMETRIC STUDY OF BASAL METABOLISM IN MAN. 266 p., illus. Washington, D. C. (Carnegie Inst. Wash. Pub. 279)
(6) Hogan, A. G., and Skouby, C. I.
1923. DETERMINATION OF THE SURFACE AREA OF CATTLE AND SWINE. Jour. Agr. Research 25: 419–430, illus.
(7) Lusk, G.
1917. THE ELEMENTS OF THE SCIENCE OF NUTRITION. Ed. 3, 641 p., illus. Philadelphia and London.
(8) Meeh, K.
1879. OBERFLÄCHENMESSUNGEN DES MENSCHLICHEN KÖRPERS. Ztschr. Biol. 15: 425–458.
(9) Moulton, C. R.
1916. UNITS OF REFERENCE FOR BASAL METABOLISM AND THEIR INTERRELATIONS. Jour. Biol. Chem. 24: 299–320, illus.
(10) Regnault, V., and Reiset, J.
1849. RECHERCHES CHIMIQUES SUR LA RESPIRATION DES ANIMAUX DES DIVERSES CLASSES. Ann. Chim. et Phys. (3)26: 299–519.
(11) Rubner, M.
1883. UEBER DEN EINFLUSS DER KÖRPERGRÖSSE AUF STOFF- UND KRAFTWECHSEL. Ztschr. Biol. (n. F. 1) 19: 535–562.
(12) Trowbridge, P. F., Moulton, C. R., and Haigh, L. D.
1915. THE MAINTENANCE REQUIREMENT OF CATTLE. Mo. Agr. Expt. Sta. Research Bul. 18: 5–62, illus.
(13) Voit, E.
1901. ÜBER DIE GRÖSSE DES ENERGIEBEDARFES DER TIERE IM HUNGERZUSTANDE. Ztschr. Biol. (n. F. 23) 41: 113–154.