

THE STARCH EQUIVALENT THEORY.

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THE account given by Wood and Yule of their investigation of the records of British Feeding Trials and the Starch Equivalent Theory in part 2 vol. VI of this *Journal* is a valuable and timely paper. It contains abundant material for reflection. Consideration of the data suggests that there is room for doubt in regard to the conclusions for which a claim to "certainty" has been advanced. It is not, however, the immediate purpose of this article to discuss these conclusions—though incidentally certain points in the investigation come under review—but rather to discern, as far as possible, the direction in which the methods and arguments employed lead, and more particularly what is their bearing on the starch equivalent theory as a practical system.

In their opening remarks Wood and Yule state that "starch equivalent for this purpose (maintenance) is reckoned by the formula: starch equivalent = digestible protein \times 1.25 + digestible fat \times 2.3 + amides \times 0.6 + digestible carbohydrates + digestible fibre. The generally accepted maintenance ration for a 1000 lb. ox on this basis is 6.35 lb. of starch equivalent which includes 0.6 lb. of digestible protein." The author is not concerned to deny these statements but he desires to emphasise the fact that this formula is not Kellner's formula and that this estimate of the animal's requirements is not Kellner's estimate.

The formula differs from that of Kellner¹ in two respects. In the latter the protein is multiplied by 0.94 instead of 1.25, and a further correction which varies according to the estimated percentage value for fattening of each food is also made. The formula given by Wood and Yule is, as stated, intended to determine the value of the foods

¹ *The Scientific Feeding of Animals.* p. 355

for maintenance. Hence these differences. But, it may be asked, is it seriously proposed that the starch equivalent for maintenance should be reckoned by one formula and that for fattening by another? If so, the starch equivalent system will scarcely survive the shock, for it would be equally necessary to have another formula for milk production and still another for work. Kellner's system is fundamentally a mere convention. It does not establish a true "quantitative relationship between the amount of food and the amount of fat, work or milk it may be expected to produce." Its general applicability to these problems rests essentially upon uniformity of the method, and if this is undermined its more important advantages are destroyed.

The factor 1.25 is presumably based on the relative amounts of heat evolved from protein and starch when these substances are oxidised in the animal's body, whereas the factor 0.94 is based upon the relative amounts of fat formed from them. This point appears to have been appreciated by Kellner and to have been allowed for by him as shown below.

It is generally agreed that the total thermic energy of the digestible matter of the food is available for maintenance. It is, apparently, for this reason that Wood and Yule make no correction for the "value" of the food. Such correction is, however, the very essence of Kellner's system, and if it be not made the numbers should not be called "starch equivalents." The formula given by Wood and Yule is a reversion to the system of Wolff and his colleagues and predecessors. It differs from what was formerly called "total digestible nutrients" only in respect of the factor (1.25 instead of 1.0) applied to the protein; and so far as the foods commonly used for maintenance rations are concerned this difference is insignificant. The author suggests that if such reversion is to be countenanced it would be well to revert to the old-fashioned or some other name. Endless confusion must result if the term "starch equivalent" be promiscuously applied to essentially different things.

This at once becomes evident when we turn to consideration of the requirements of the animals. The specious similarity between Kellner's¹ estimate of 6 lb. and that of Wood and Yule of 6.35 lb. of starch equivalent per day for maintenance of a 1000 lb. ox is deceptive. The latter, according to the formula given, includes the whole of the thermic energy of the digestible matter of the food; the former corresponds to the dynamic portion only. In order to make this quite plain Kellner

¹ *The Scientific Feeding of Animals*, p. 392.

shows in his appendix tables¹ that the maintenance ration from which his 6 lb. of starch equivalent is derived must contain 0.6 to 0.8 lb. of digestible protein, 0.1 of digestible fat and 7.5 to 9.5 lb. of digestible carbohydrates and fibre. This amounts to from $8\frac{1}{2}$ to $10\frac{3}{4}$ lb. of "starch equivalent" reckoned by the formula given by Wood and Yule.

We have here to deal with a serious defect in Kellner's system. He found² that, on the average, only some 50 to 70 per cent. of the available energy of the foods used for maintenance rations is of dynamic value. Consequently the starch equivalents of these foods are from 30 to 50 per cent. below the full value. The maintenance requirements of the animals, when expressed in terms of starch equivalent, must therefore be reduced by a similar amount. The quantities of feeding stuffs necessary to maintain the animals may be estimated with approximate accuracy on this basis provided the foods are of the value assumed in the estimate of the animal's requirements, but not otherwise. For example, the quantity of maize meal which corresponds to 6 lb. of starch equivalent would be too small for maintenance of a 1000 lb. ox because it yields little or no thermic energy in addition to that represented by the starch equivalent. In practice, of course, no one would use maize meal for maintenance rations of oxen; but in the investigation undertaken by Wood and Yule the fattening ration (most of which it may be assumed was of nearly full value) was assigned for maintenance functions in order that the fattening value of the roots might be determined. In this case 6 lb. of Kellner's starch equivalent, derived from such foods, would be inadequate. As Wood and Yule did not employ Kellner's formula but another which includes the whole of the available energy of the food, this argument does not apply. It remains to be seen, however, whether the 6.35 lb. of starch equivalent, reckoned by that formula, was sufficient.

It will be seen that Kellner's estimate of 6 lb. of starch equivalent for maintenance is a purely artificial number arbitrarily adapted to the needs of his convention. That being so, it makes little difference whether the protein be multiplied by 1.25 or by 0.94. The net result of using the higher factor is that the estimates of the requirements for maintenance must be correspondingly increased. Kellner appears to have deliberately decided to ignore the difference between the heat producing and fat producing values of protein in order to attain that uniformity which his system demands, and because he saw that it

¹ *The Scientific Feeding of Animals*, p. 392.

² *Ibid.*, p. 360 et seq.

could easily be allowed for in his empirical estimate of the animal's requirements for maintenance.

Six pounds of Kellner's starch equivalent corresponds to about 20 lb. of hay of average quality. This estimate of the requirements for maintenance of a 1000 lb. ox does not differ materially from that of Wolff¹ and the older authorities, and the author has hitherto regarded it as "the generally accepted ration." It is, however, very different from that of Wood and Yule, which corresponds to only about 13 lb. of such hay. This discrepancy cannot be lightly passed over. It is too considerable, and it is of fundamental importance in regard to this and other investigations. If they adhere to their statement it would be interesting to know upon what data it is founded. It is to be hoped that they will take an early opportunity of clearing up the matter.

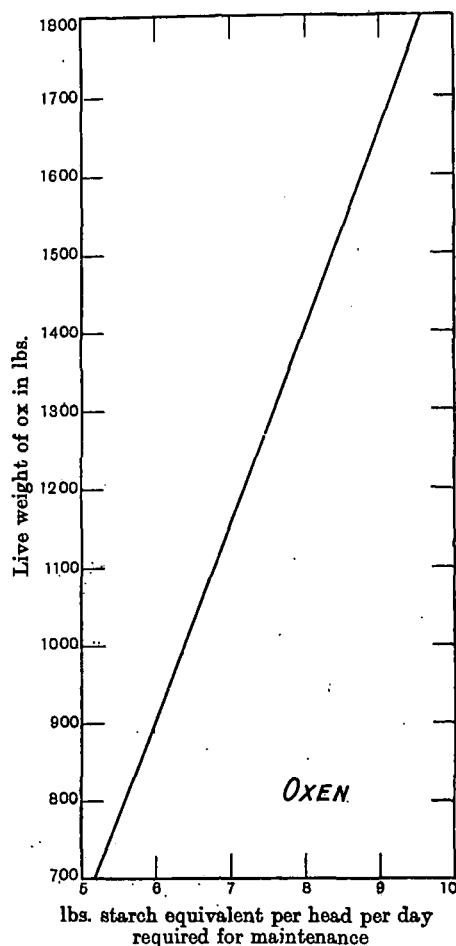
It is of course possible that Wood and Yule did not intend to propose a standard radically different from that of Kellner and Wolff. The omission from their formula of all reference to the "value" of the food may be merely a typographical error, but the statement that an ox of 1000 lb. live weight when on maintenance diet evolves 10,800 Cal. of heat per day seems to preclude this explanation. It is evident that this statement is not based upon a direct determination in the calorimeter, but that 10,800 Cal. is merely the calculated equivalent of 6.35 lb. of pure starch. It may be inferred therefore, that the formula was intended to include the whole of the available energy of the food and not the dynamic portion only. The only obvious way of escape from this conclusion is to assume that the statement involves a repetition of Kellner's mistake in calculating the amount of heat an animal should evolve from the starch equivalent instead of from the total available energy of the food. He says² that "an ox weighing 600 Kg. requires a daily supply of 12,780 Cal."; but as this corresponds to about 10,620 Cal. for an ox of 1000 lb. it is clearly inconsistent with the ration prescribed in the tables. The latter, quoted above, represents from 14,500 to 18,350 Cal. per day of available energy, and this accords well with the estimate on the next page: "For maintenance of the animal determined from other experiments—17,320 Cal."

It has hitherto been customary to assume that the requirements for maintenance of oxen were proportional to the live weights of the animals and could therefore be determined by rule of three, though it has long been known that this is not true. A notable advance has

¹ *Farm Foods* (p. 350), Gurney and Jackson, 1895.

² *The Scientific Feeding of Animals*, p. 48.

been made by Wood and Yule in discarding this assumption. They determined the variation in the requirements of oxen of different sizes by means of a diagram, which by their kind permission is reproduced below



Reduced to numerical terms, this graph may be expressed by the formula:

$$\log E = \frac{2}{3} \log M - 1.19723,$$

M is the live weight (lb.) of the animal and E is the amount (lb.) of starch equivalent required for maintenance.

The concordance between the graph and the formula is shown below:

M	800	1000	1200	1400	1600	1800
E (graph)	5.5	6.35	7.2	8.0	8.8	9.4
E (formula)	5.47	6.35	7.17	7.95	8.69	9.4

The figures from which the graph was constructed were taken from Kellner's *Ernährung*. They are not the results of direct determinations of food requirements, but, if the author is not mistaken, are derived from measurements of the relation between the body surface and live weight of certain dogs; and they involve the assumption that the requirements for maintenance vary directly as the extent of body surface. It is well that this should be recognised, but there is good reason to anticipate that when it is put to the test of experiment the assumption will prove to be well founded. Over a year ago the author published a formula¹ for maintenance rations of oxen in terms of "total digestible nutrients with an albuminoid ratio of 10 — 1." Assuming that 9.3 lb. of such nutrients is the maintenance ration for oxen of 1000 lb. live weight, this formula may be expressed as follows:

$$\log N = \frac{2}{3} \log M - 1.03152.$$

This view is confirmed by independent data of a purely mathematical kind. It also derives a certain amount of support from the fact that the requirements of animals of 40 to 170 lb. live weight, calculated by this formula, are consistent with experimental data relating to the maintenance rations of pigs of that size². The argument cannot be applied to the formula in terms of starch equivalent because the foods that are suitable for maintenance of pigs are of nearly "full value," *i.e.* they contain no thermic energy over and above the dynamic portion represented by the starch equivalent. It might be supposed that it could be applied in the case of other ruminants such as sheep, which can subsist on much the same kind of diet as oxen. Such, however, is not the case, because, owing to their thick coats of wool, these animals do not lose heat by radiation so rapidly as pigs and oxen in proportion to their body surface.

Wood and Yule have assessed the maintenance ration for sheep of 100 lb. live weight at about 6½ lb. of starch equivalent per week; but, on the ground that this shows a higher percentage utilisation of the food for fattening, they suspect that the allowance is too small. If the starch equivalent referred to was calculated by the formula given by them, *i.e.* if it includes the whole of the available energy of the food, there can be little doubt that it is too small. On the other hand, if it means Kellner's starch equivalent, it is probably too large.

¹ *The Chemistry of Cattle Feeding and Dairying* (Longmans), pp. 128. and 142.

² Sanborn's *Expers.* Bul. 28, Mo. Agr. Col. Cf. *Chemistry of Cattle Feeding and Dairying*, p. 206.

The author's estimate¹ of the maintenance requirements of sheep of 100 lb. live weight is from $7\frac{1}{2}$ to $8\frac{1}{2}$ lb. per week of "total digestible nutrients" corresponding to about 5 or $5\frac{1}{2}$ lb. of Kellner's starch equivalent. Even so, there is reason to believe that sheep retain in their bodies a larger percentage of the food in excess of the maintenance ration than oxen do.

The whole question stands in urgent need of re-examination on a fundamental basis. The estimate that the fattening increase comprises "67 per cent. of dry matter, chiefly fat, and 33 per cent. of water" is probably true only under conditions similar to those of the Rothamsted experiments in which the animals² appear to have been not fully grown. Comparison of the figures³ relating to the fat ox and the half-fat ox shows that of a fattening increase of 200 lb. something like 190 lb. was fat and only 10 lb., *i.e.* about 5 per cent., was water. It may ultimately prove that the true fattening increase—apart from growth—consists almost entirely of pure fat.

It is to be noticed also in this connection that in the attempts to estimate the maintenance rations of oxen of different size by means of graphs or formulae it is assumed that all the animals are in store condition, *i.e.* that the difference in live weight is due in all cases to greater or less growth and not to fattening. Fat animals require more food to maintain them without gain or loss of weight than those in lean condition. It is not easy to see how a single graph could be adapted to meet this difficulty, but the formula given above might be modified in some such manner as that shown below:

$$\log N = \frac{2}{3} \log M - 1.03152x,$$

where x is a number that varies inversely as the fatness of the animal. If any means can be found to express the degree of fatness in numerical terms it would probably not be very difficult to determine x . All that can be said at present is that when the animals are in store condition—whatever that may be—the value of x is 1, and that when they are fatter it is less than 1.

It may also be found eventually that herein lies the explanation of the gradually diminishing returns in the shape of increase for food consumed as the animal becomes fatter. To say that it is due to the fact that a fat animal requires more food for maintenance is not merely

¹ *Chemistry of Cattle Feeding and Dairying* (Longmans), pp. 130 and 204.

² *Cf. Scientific Feeding of Animals*, pp. 254 and 255.

³ *Rothamsted Memoirs*, Vol. III. pp. 520 and 558. *Cf. Chemistry of Cattle Feeding*, pp. 189 and 190.

a repetition of the statement in different terms, because, if true, it would be equally applicable to an animal producing milk.

The starch equivalent system is still on trial, and it is tolerably evident that it is far from perfect. It is complex in definition and difficult to apply. Farmers as a rule will have none of it, and it frequently proves a stumbling-block to scientific students. It may even betray experts as it has on occasion betrayed Kellner himself. The system originated in a praiseworthy attempt to overcome some of the more obvious objections to the old-fashioned "feeding standards" in which it was assumed that the nutrients in all kinds of foods were of equal value for all kinds of purposes. At least it is in that direction that it has found its chief application. The foregoing discussion, however, tends to show that the day of such feeding standards is over. Attempts to calculate a ration comprising two or more independent variables, *e.g.* maintenance and fattening, by a single arithmetical operation—the rule of three—which it now appears is not applicable to either are no longer defensible. Conversion of the nutrients into starch equivalents does not overcome this difficulty.

Animals require food for maintenance and for the several forms of production—growth, work, fattening, and lactation—though it rarely happens in practice that more than two, or at most three, out of these five conditions have to be satisfied at the same time in any given case. The best results will, therefore, be obtained when the digestible nitrogenous and non-nitrogenous nutrients are supplied in the proportions and quantities required for each specific purpose. The amounts required for maintenance depend upon the size of the animal and those for other purposes upon the rate of each kind of production, though probably in no case are they directly proportional to that rate. In each case the nutrients must be derived from a food suitable for the purpose. For example, the nutrients for maintenance of oxen should be derived from cheap coarse fodders, and those for fattening from the finest, most readily digestible materials. Nothing should be deducted from the former for the work of digestion, etc. From the latter there is nothing to deduct on this account. At least, except in one or two instances, the amount to be deducted is insignificant. If, however, the amounts of nutrients for the several purposes are not to be added together but directly translated into the corresponding amounts of appropriate kinds of food, it seems clear that they must be determined by a separate calculation in each case, and the *raison d'être* of the starch equivalent system disappears.

Elsewhere¹ the author has proposed that the feeding standards should be superseded by formulae. These should be in terms of "total digestible nutrients" with given albuminoid ratios for maintenance, growth, work, fattening and milk production. This would afford a simple and satisfactory solution of difficulties hitherto encountered, and it possesses many collateral advantages. Perhaps not the least of these is the fact that attempts to evolve such formulae would effectually expose our ignorance of many points at present concealed by the feeding standards and further obscured by the complexities of the starch equivalent system. In the present state of our knowledge indeed such formulae could be little more than hypotheses but they would serve to give point and direction to research.

Wood and Yule's paper shows that some progress has already been made in this direction and it encourages the hope that in the near future the rate of advance may be greatly accelerated.

¹ *Chemistry of Cattle Feeding and Dairying* (Longmans).

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