THE CURRENT STATUS OF TME

I.R. SIBBALD*

SUMMARY

-Apparent and true metabolizable energy (AME, TME), and the components thereof, are defined. The assumptions underlying the AME and TME bioassays are identified. The importance of applying a nitrogen correction to AME and TME data is explained. The bioassay for TME is outlined.

One of the assumptions of the AME bioassay is false. However, the assumptions underlying the TME bioassay appear to be valid providing the excreta energy values of all birds are adjusted to zero nitrogen balance. The adjustment controls variation in metabolic plus endogenous energy loss-associated with the physiological state of the bird, the environment in which it lives, and the nature and amount of feed provided.

INTRODUCTION

A bioassay for true metabolizable energy (TME) in poultry feedingstuffs (Sibbald 1976) has stimulated research and debate in many parts of the world. Indeed, more than 300 related publications from 61 laboratories in 17 countries have since appeared (Sibbald 1983). The assay has received wide acceptance, albeit in a modified form, and the basic methodology is used in assays for bioavailable amino acids (Likuski and Dorrell 1978; Sibbald 1979a), lipids (Sibbald and Kramer 1980) and minerals (Sibbald 1982a). Much of the relevant literature is discussed in a recent review (Sibbald 1982b).

There is some controversy concerning the advisability of changing from apparent metabolizable energy (AME) to TME. Some proponents of AME have severely criticised the TME bioassay (Farrell 1981) while others have found the change from AME to TME to be advantageous (Engster et al. 1981). The controversy has led to the identification, and testing, of the assumptions underlying both the AME and TME bioassays (Sibbald and Morse 1983a, 1983b).

The purpose of this paper is to review the basic assumptions of the AME and TME assays, to demonstrate the need to correct TME data to zero nitrogen balance (TME_n) and to describe, briefly, the TME_n bioassay as currently used.

DEFINITIONS

The terminology and abbreviations used in this and subsequent sections are those of the United States National Research Council (N.R.C. 1981). By definition:

$$AME = IE - FE - UE - GE \quad (1)$$

where: IE is ingested feed energy;
FE is fecal energy;
UE is urinary energy; and
GE is gaseous energy.

*Animal Research Centre, Agriculture Canada, Ottawa, Ontario, Canada, K1A OC6

In avian bioassays for bioavailable energy the GE is assumed to be negligible and is ignored. For those feedingstuffs containing non-digestible but fermentable carbohydrates the assumption may lead to error. The lower TME values for soybean oil meal and peanut meal obtained with cecectomized birds (Kessler and Thomas 1980) probably reflects a reduction in gas production associated with a lower microbial population. Nevertheless, for practical purposes equation (1) becomes:

$$AME = IE - FE - UE \quad (2)$$

Equation (2) implies that FE and UE are derived entirely from IE, but this is incorrect. Both components comprise two parts:

$$FE = F_iE + F_mE \quad (3)$$

$$UE = U_iE + U_eF \quad (4)$$

where: F_iE is fecal energy of feed origin;
F_mE is metabolic fecal energy;
U_iE is urinary energy of feed origin; and
U_eE is endogenous urinary energy.

The $F_mE + U_eE$ are body maintenance costs and, as will be shown later, it is illogical to charge them against the feed.

The foregoing definitions describe AME in relation to feed. Another approach is to define AME in terms of its function within the body. Thus:

$$AME = RE + HE \quad (5)$$

where: RE is the energy retained as useful products; and
HE is the energy lost as heat.

The RE includes the energy of body tissues, eggs and semen. The HE is composed of several fractions resulting from basal metabolism, activity, digestion and absorption, product formation, thermal regulation, and excretion.

There are several relevant definitions which describe TME and which help to identify differences between AME and TME. The-basic definition when considering TME as an attribute of feed is:

$$TME = IE - F_iE - U_iE \quad (6)$$

However, in practical assays F_iE and U_iE are estimated by difference and a more appropriate definition is:

$$TME = IE - FE - UE + F_mE + U_eE \quad (7)$$

The utilization of TME within the body may be described as:

$$TME = RE + HE + F_mE + U_eE \quad (8)$$

Comparisons of equation (2) with equations (6) and (7), and of (5) with (8), indicate that the difference between TME and AME resides in the location of the $F_mE + U_eE$. Both AME and TME may be corrected to zero nitrogen balance (AME_n, TME_n). The procedure for making the correction is described later.

BIOASSAY ASSUMPTIONS

Most bioassays for AME are based on two assumptions: a) there is a linear relationship between FE + UE and IE; and b) the linear regression of FE + UE on IE passes through the origin. The first assumption is probably correct. When fasted birds receive a range of inputs of a feedingstuff the regression of FE + UE on IE does not deviate from linearity providing that the excreta collection period is of sufficient duration to allow clearance of feed residues from the alimentary canal (Sibbald 1977; Shires et al. 1980; Sibbald and Morse 1983a, 1983b). The second assumption is invalid because fasted birds continue to excrete FE + UE after all feed residues are voided (Sibbald 1979b).

The error in the second assumption has serious consequences. In theory (Guillaume and Summers 1970) and under experimental conditions (Sibbald 1975, 1976) AME values increase with feed intake. Indeed, when IE < $F_mE + U_eE$, AME values are negative. If feed intake and $F_mE + U_eE$ are known it is possible to adjust AME data to a common base (Fisher and McNab 1981) and comparisons among feedingstuffs are possible.

The bioassay for TME, as generally practised, is based on three assumptions: a) there is a linear relationship between FE + UE and IE; b) the intercept of the regression of FE + UE on IE, when IE is *zero*, is independent of the nature of the feed; and c) the FE + UE values obtained with unfed birds lie on the *regression* line. The first assumption is common to both the AME and TME bioassays and is generally accepted* The second assumption is the cause of controversy and there is a report that the intercepts of regressions of FE + UE on IE vary according to the neutral detergent fibre content of the test materials (Farrell 1981) but the weight of evidence favours acceptance of the assumption (Sibbald 1976, 1981; Johnsson 1980; Shires et al. 1980). Major deviations such as those attributed to neutral detergent fibre can usually be explained by incomplete excreta collection (Sibbald and Morse 1983a). The clearance time of feed residues from the alimentary canal is a function of the intake of indigestible material (Sibbald 1980); consequently, the greater the feed intake, and the lower the digestibility thereof, the greater the clearance time. When clearance of the residues of the highest intakes is incomplete the relationship between FE + UE and IE is curvilinear. Fitting a linear regression to such data is inappropriate and yields a misleading intercept; high correlation coefficients do not preclude the possibility of non-linearity. Minor deviations often reflect variations in nitrogen balance and can be controlled by applying an appropriate correction (Sibbald and Morse 1983b). The third assumption is not critical because TME values can be estimated from the slopes of regressions of FE + UE on IE (Sibbald 1975). Nevertheless there is experimental evidence which supports the third assumption (Sibbald 1976; Shires et al. 1980; Sibbald and Morse 1983a, 1983b). As with the second assumption minor deviations tend to reflect variations in nitrogen balance and can be controlled (Sibbald and Morse 1983b).

THE-NITROGEN CORRECTION

Nitrogen retained in the body, if catabolized to provide energy, is not completely oxidized; consequently, energy containing nitrogenous compounds, such as uric acid, are excreted. Theoretically the estimated bioavailable energy content of a feedingstuff will vary according to the physiological state of the assay birds, being greater for those gaining nitrogen than for those in negative nitrogen balance. To overcome this

source of variation, bioavailable energy values are corrected to zero nitrogen balance. The procedure is not new, having been used with cattle before 1918 (Armsby and Fries 1918), and is not universally accepted (Swift and French 1954; Baldini 1961).

When applied in AME bioassays the correction takes the form:

$$AME_n = IE - FE - UE - kRN \quad (9)$$

where: RN is the nitrogen retained; and
k is a constant which estimates the energy per unit weight of nitrogen in the excretory products resulting from tissue nitrogen catabolism.

There are several values for k. Those most commonly used in poultry bioassays are 34.39 kJ/gN (Hill and Anderson 1958), the energy/gN in uric acid, and 36.53 kJ/gN (Titus 1956) which is claimed to be a demonstrably superior estimate (Zelenka 1970). Recent work shows that k may vary among birds or over time and may be related to metabolic size (Sibbald and Wolynetz 1983).

Within the TME bioassay the nitrogen correction is particularly important because the birds tend to be in negative nitrogen balance. Most birds receive sub-maintenance amounts of feed energy and must catabolize carbohydrate, fat and protein, in their bodies, to make up the deficit. When carbohydrate and fat are catabolized the end-products are carbon dioxide and water but when protein is catabolized the energy containing end-products contribute to the $F_mE + U_eE$. The amount of the contribution depends upon the physiological state of the bird, the environment in which it is housed and upon the amount and nature of the feed intake. Thus it is reasonable that when energy intake is sub-maintenance the U_eE of a Lean bird will be greater than that of a fat bird of similar size. When the environmental temperature is low, or very high, the energy requirement for maintenance increases and there is an accompanying increase in $F_mE + U_eE$ (Dale and Fuller 1981; Sibbald and Wolynetz 1983). When feed is provided, the need to catabolize tissue is decreased as is $F_mE + U_eE$ (Dale and Fuller 1982; Sibbald and Morse 1983c). The foregoing supports the view that $F_mE + U_eE$ varies with the IE (van Es 1980); a major criticism of the TME bioassay.

The variation introduced into the TME bioassay by differences in RN can be controlled by correcting the FE + UE of all birds to zero nitrogen balance ($FE, + UE_n$). The calculation is as follows:

$$FE_n + UE_n = FE + UE + kRN \quad (10)$$

The RN is usually negative and $(FE_n + UE_n) < (FE + UE)$. By applying the correction, the error mean squares in TME bioassays were reduced by 40 to 76% (Sibbald and Morse 1983b, 1983c).

The data of Sibbald and Morse (1983b) were used to construct two figures which illustrate the effect of the nitrogen correction and which provide evidence of the validity of the underlying assumptions of the TME_n bioassay. Figure 1 shows the linear regressions of FE + UE on feed input for five feedingstuffs. The lines have similar intercepts when extrapolated to zero feed intake. The mean value obtained with unfed birds, denoted by the solid circle, is only slightly greater than the intercepts.

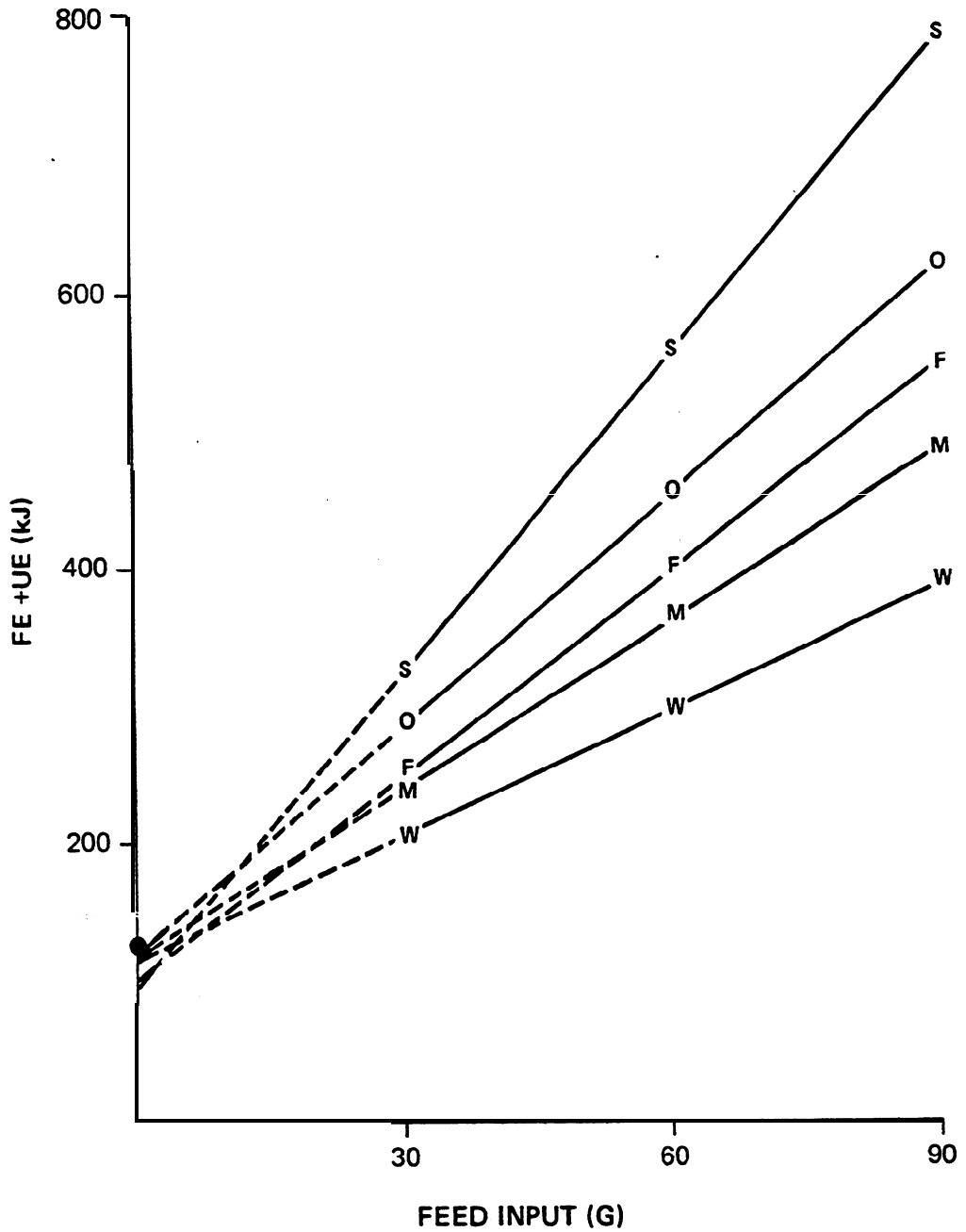

Fig. 1. The regressions of FE + UE on feed intake for soybean meal (S), oats (O), fish meal (F), wheat middlings (M) and wheat (W); the broken lines are extrapolations to zero feed intake and the solid circle is the mean value for unfed birds.

Figure 2 is similar to Fig. 1 but the nitrogen correction of 36.53 kJ/gN has been applied to the excreta energy and so $FE_n + UE_n$ is plotted against feed intake. The intercepts of the regressions at zero input do not differ from each other (P>.05) and the mean value for the unfed birds is not different from the intercepts (P>.05). A more complete description of the experiment and of the statistical treatment may be obtained from the original publication (Sibbald and Morse 1983b).

The intercepts of the regressions of FE + UE on feed intake (Fig. 1) show some variation among feedingstuffs. However, the variation is relatively small and fails to support the claim that the estimate of the intercept increases with the neutral detergent fibre content of the feed (Farrell 1981). The variation is largely due to differences in RN. When the nitrogen correction was applied the differences among intercepts became non-significant (P>.05) (Fig. 2). The three assumptions of the TME bioassay are in agreement with the relationships displayed in Fig. 2.

THE TME BIOASSAY

Birds, acclimatized to their environment, *are* fasted to ensure that all feed residues have been voided. The preferred bird is a dubbed, adult cockerel of an egg-type strain which has never had access to grit: however, other birds can yield satisfactory data. The duration of the preliminary fast depends upon the nature of the maintenance diet and the type of bird; 24 h are usually sufficient but the time should be established experimentally. A fasted bird is selected and a known quantity of the test material is placed in its crop by means of a funnel and plunger. The time is recorded and the excreta voided during the subsequent 48 h are collected. The process is repeated until each test material has been given to the desired number of replicated birds. One bird in each replication remains unfed and provides an estimate of $F_mE_n + U_eE_n$ or $(FE_n + UE_n)_{unfed}$.

The feedingstuffs are assayed for *energy,* nitrogen and dry matter at the time the rations are weighed, preparatory to the assay. The excreta are collected, frozen, dried, equilibrated with atmospheric moisture, weighed, ground and assayed for energy and nitrogen. The $FE_n + UE_n$ is calculated for each bird according to equation (10). The TME_n values are then calculated as follows:

$$TME_n = IE - (FE_n + UE_n)_{fed} + (FE_n + UE_n)_{unfed} \qquad (11)$$

where: the subscripts refer to the fed and unfed birds.

An alternative approach is to administer each feedingstuff at two or more levels and to estimate TME_n from the slope of the linear regression of $FE_n + UE_n$ on IE (Sibbald and Morse 1983b). This avoids the use of unfed birds to estimate $(FE_n + UE_n)_{unfed}$. If a similar approach is used in AME assays, TME_n data are obtained. In another variation of the assay the catabolism of body tissue, and the associated nitrogen loss, is reduced by providing the control birds with a wholly digestible energy source but this offers no noticeable advantages (Sibbald and Morse 1983c).

The bioassay is described in detail elsewhere (Sibbald 1983). The bulletin also contains a table of TME and TME_n values for a wide array of feedingstuffs plus a bibliography of related publications. Copies

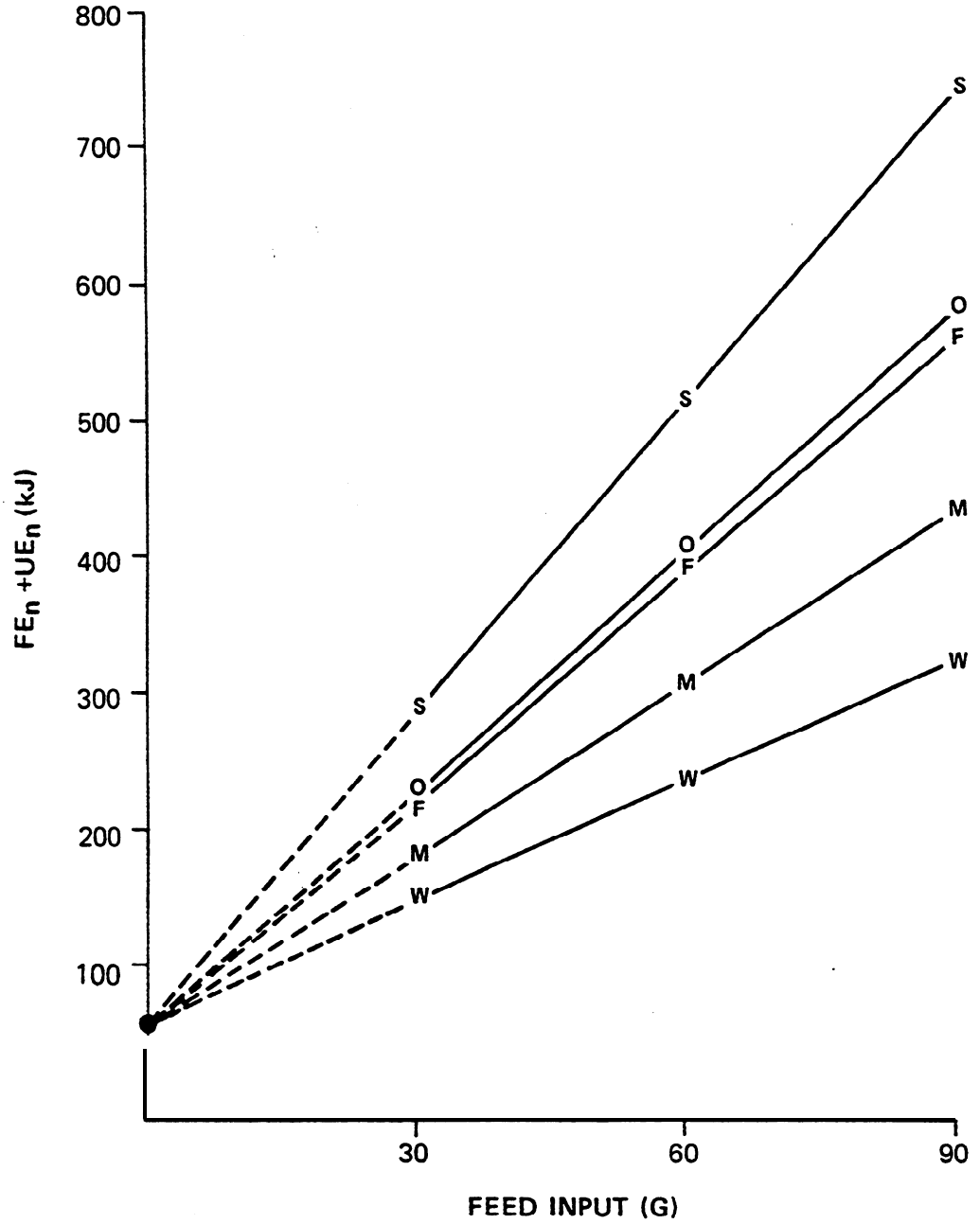

Fig. 2. The regressions of $FE_n + UE_n$ on feed intake for soybean meal (S), fish meal (F), wheat middlings (M) and wheat (W); the broken lines are extrapolations to zero feed intake and the solid circle is the mean value for unfed birds.

may be obtained, free of charge, in English or French by writing to the author.

REFERENCES

ARMSBY, H.P., and FRIES, J.A. (1918). J. Agric. Res. 15: 269.

BALDINI, J.T. (1961). Poult. Sci. 40: 1177.

DALE, N.M., and FULLER, H.L. (1981). Proc. Georgia Nutr. Conf. p.50. (University of Georgia: Athens).

DALE, N.M., and FULLER, H.L. (1982). Poult. Sci. 61: 898.

ENGSTER, H.M., SNETSINGER, D.C., and KESSLER, J.W. (1981). Proc. 3rd Eur. Symp. Poult, Nutr., p.56, editors D.W.F. Shannon and I.E. Wallace (Brit. Poult. Sci.: Edinburgh).

FARRELL, D.J. (1981). World's Poult. Sci. J. 37: 72.

FISHER, C., and McNAB, J.M. (1981). Proc. 3rd Eur. Symp. Poult. Nutr., p.45, editors D.W.F. Shannon and I.E. Wallace (Brit. Poult. Sci.: Edinburgh).

GUILLAUME, J., and SUMMERS, J.D. (1970). Can. J. Anim. Sci. 50: 363.

HILL, F.W., and ANDERSON, D.L. (1958). J. Nutr. 64: 587.

JOHNSSON, G. (1980). M. Phil. Thesis, University of Edinburgh.

KESSLER, J.W., and THOMAS, O.P. (1980). Proc. Maryland Nutr. Conf. p.27, editor J.H. Soares, Jr. (University of Maryland: College Park).

LIKUSKI, H.J.A., and DORRELL, H.G. (1978). Poult. Sci. 57: 1658.

N.R.C. (1981). Nutritional Energetics of Domestic Animals and Glossary of Energy Terms. (National Academy Press: Washington, D.C.).

SHIRES, A., ROBBLEE, A.R., HARDIN, R.T., and CLANDININ, D.R. (1980). Poult. Sci. 59: 396.

SIBBALD, I.R. (1975). Poult. Sci. 54: 1990.

SIBBALD, I.R. (1976). Poult. Sci. 55: 303.

SIBBALD, I.R. (1979a). Poult. Sci.58: 668.

SIBBALD, I.R. (1979b). Poult. Sci. 58: 446.

SIBBALD, I .R. (1980). Poult. Sci. 59: 2136.

SIBBALD, I.R. (1981). Poult. Sci. 60: 805.

SIBBALD, I.R. (1982a). Poult. Sci.61: 485.

SIBBALD, I.R. (1982b). Can. J. Anim. Sci. 62: 983.

SIBBALD, I.R. (1983). "The T.M.E. System of Feed Evaluation" Tech. Bull., Res. Branch, Agriculture Canada, Ottawa, Ontario.

SIBBALD, I.R., and KRAMER, J.K.G. (1980). Poult. Sci. 59: 316.

SIBBALD, I.R., and MORSE, P.M. (1983a). Poult. Sci. 62: 68.

SIBBALD, I.R., and MORSE, P.M. (1983b). Poult. Sci. 62: 138.

SIBBALD, I.R., and MORSE, P.M. (1983c). Poult. Sci. (in press).

SIBBALD, I.R., and WOLYNETZ, M.S. (1983). Poult. Sci. (in press).

SWIFT, R.W., and FRENCH, C.E. (1954). "Energy Metabolism and Nutrition" p.96. (The Scarecrow Press: Washington, D.C.).

TITUS, H.W. (1956). Proc. Semi-Annual Meeting, Nutr. Council, Amer. Feed Manuf. Assoc. p.10.

VAN ES, A.J.H. (1980). In "Energy Metabolism*', p.85, editor L.E. Mount. (Butterworths: London).

ZELENKA, J. (1970). Acta Univ. Agric. Fac. Agron. 18: 113, (English Abstr.).