FACTORS AFFECTING THE UTILISATION

OF DIETARY ENERGY

by

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ABSTRACT

Seven different but integrated experiments were conducted to study the factors affecting the utilisation of dietary energy. The first two experiments involved feeding broiler chickens diets containing either corn oil or corn starch as the supplementary source of energy at two protein levels. Herring meal was used in all diets because of the high biological value of its protein. All diets were calculated to be isocaloric and to contain the same balance of amino acids; minerals and vitamins were added to meet the requirements for these nutrients.

Live weight gain and the efficiency of food utilisation within calorie:protein regime were not improved when fat was substituted for starch in isocaloric diets. The superiority of the low-fat high-protein diet in promoting the highest metabolisability of energy, questions the validity of the claim that added dietary fat has an "extra-caloric" effect. Birds fed the high-fat low-protein diet which had a lower calorie:protein ratio, deposited more abdominal adipose tissue, indicating that in evaluating growth performance, the balance between energy and protein is of greater significance than the source of supplementary energy.

Formulation of isocaloric diets has necessitated the inclusion of the so-called nutritionally-inert ingredients such as cellulose. Since the diets used to test the main hypothesis of "extra-caloric effects" attributable to dietary fat incorporated cellulose, the effect of the

latter on the physiological parameters under study, was tested. At high levels of inclusion cellulose depressed body weight gain. Adverse effects of added dietary cellulose on food conversion efficiency and energy metabolisability were also evident. Another effect of added dietary cellulose which is particularly interesting is that it decreased abdominal adipose tissue.

Results of the above studies have shown significant differences among the different treatment groups in body weight gain, efficiency of food utilisation and metabolisability of energy within the first three weeks posthatching. The possibility that the residual yolk may influence the metabolic parameters in question was considered and tested. Absence of the yolk sac, excised surgically, did not influence the performance of birds on the basis of growth and energy utilisation as measured by body weight gain and metabolisable energy values, respectively. The residual yolk did not influence food conversion efficiency in the first and third weeks of the experimental period. However, depression of food conversion efficiency resulting from the removal of residual yolk was found to occur in the second week. It was noted that birds without residual yolk retained a greater amount of nitrogen compared to birds with residual yolk in the first week posthatching.

The residual yolk does not contribute significantly towards the nourishment of the chick in the first week posthatching as evidenced by the fact that abstinence from food resulted in the death of both the groups retaining yolk sacs and those without yolk sacs at approximately the same time.

The presence of a large bacterial population in the avian caeca

and extrapolation of the features associated with bacteria-host symbiosis in ruminants and other animals to the domestic chicken have led to speculation that the avian caeca perform some cellulolytic and proteolytic functions. The relevance of the concept of caeca-mediated nutrient utilisation to the topic under study prompted an experiment using intact and caecectomized chickens to investigate the effect of the excision of the caeca on the utilisation of dietary energy and protein. Caecectomized and intact control New Hampshire cockerels were fed diets used in the previous studies. Metabolisable energy values and uric acid excretion were used as the criteria for measuring dietary energy and protein utilisation. Caecectomy did not affect the metabolisability of the diets. Metabolisability of the diet incorporating corn starch was more variable and slightly lower with the caecectomized birds. Uric acid excretion was similar for the caecectomized and the intact birds.

Macroscopic and histological examination of sections of the caeca revealed that regeneration of the caeca had occurred in four caecectomized birds that survived until autopsy 85 weeks later. Although the onset of the regeneration of the caeca was not observed, it would appear that the degree (or the absence) of regeneration of the caeca in caecectomized birds may be responsible for the discrepancies in the findings reported with such birds.

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1. GENERAL INTRODUCTION

Energy utilisation has a central role in the efficiency of nutrient metabolism. Accumulating evidence indicates that the source and level of dietary energy influence the efficiency of utilisation of energy.

Carbohydrates and fats are the principal and most economic sources of dietary energy with carbohydrates being the dietary energy source used more extensively. This trend, however, is changing in the light of the widespread and consistent observation that it is possible to obtain excellent performance from chickens fed diets containing high fat levels. The indications are that the substitution of fat for glucose calories produces an energetic effect higher than can be accounted for by the caloric content of the energy-yielding components of the diet.

Nearly all of the significant data available on the "extra-caloric" effect attributable to the adjustment of nutrient ratios by means of dietary fat, have concerned turkeys and categories of chickens other than broilers. Since species, breed, strain and even individual differences are known to exert significant or marked differences on various physiological phenomena, our general understanding of the utilisation of energy by poultry may well be a very restricted one indeed.

The work to be reported herein was, therefore, carried out as a contribution towards the advancement of the state of knowledge of nutrition with regard to the effects of the adjustment of nutrient ratios on the efficient utilisation of energy by broiler chickens. The specific objectives of the research were:

1. To determine the effect of dietary fat on the performance of broiler chickens,

2. To determine the effect of added cellulose in diets incorporating varying levels of dietary fat on energy metabolism,

3. To determine whether the yolk sac influences energy metabolism in the early life of the chicken, and

4. To determine the role of the caeca on energy and protein metabolism.

2. LITERATURE REVIEW

2.1 The Utilisation of Energy from Alternate Sources

2.1.1 Historical perspective on energy utilisation

The central importance of energy metabolism in the economy of nutrient utilisation has been recognized for a long time, as has been the influence of the source of energy on the efficiency of metabolisable energy utilisation. Currently, metabolisable energy values are popular among the consulting nutritionists (Vohra, 1972), because where use is made of computer formulation of least cost poultry diets, the inclusion or rejection of a particular feeding stuff is greatly dependent on the metabolically useful energy values (De Groote et al., 1971).

2.1.2 Effect of dietary source of energy on the performance of poultry

2.1.2.1 Dietary source of energy

Carbohydrates and fats are the primary energy-containing macronutrients used in poultry formulations with the former being the dietary source more widely used for the purpose of supplying energy. It appears, however, that the body does not require carbohydrate or fat per se for the supply of energy but rather compounds such as glycerol and amino acids or precursors of compounds capable of being oxidized for energy. When soyabean oil fatty acids were included in a carbohydrate-free diet for chicks, growth rate and food consumption were severely depressed demonstrating that the glycerol moiety of the fat is essential for fatty acid uptake and utilisation in the absence of carbohydrate (Hill and Brambilla, 1965; Allred, 1969). This finding forms the basis

of the well-documented fact that the use of either carbohydrate or fat in the form of triglycerides as the exclusive source of non-protein energy does not result in depressed growth or impaired efficiency of feed utilisation.

Accumulating evidence in the literature shows that "carbohydrate-free" diets or diets in which the source of non-protein calories is predominantly fat, have produced favourable growth response. Donaldson et al. (1957) and Rand et al. (1958) showed that the chick can use high levels of fat as a source of energy. The latter workers reported that the substitution of fat calories for glucose calories resulted in improved weight gains and greater protein and energy utilisation. Evidence presented by Begin (1961) indicated that carbohydrate energy can be replaced calorie for calorie by fat. Similar results were obtained with growing turkeys by Yacowitz et al. (1956), Waibel (1958), Touchburn and Naber (1966), and Jensen et al. (1970). Forbes et al. (1946), French et al. (1948), and Swift and Black (1949) demonstrated similar physiological response in rats. No adverse effects were noted in the growth rate, feed conversion efficiency and nitrogen retention of chicks (Renner and Elcombe, 1964, Renner, 1964) and rats (Dror et al., 1973) when fat supplied practically all the non-protein calories.

Favourable growth response has been shown also in chicks fed diets in which all the non-protein calories were supplied by glucose (Donaldson, 1964). However, in the work cited above, chicks fed "fat-free" diets oxidized fatty acid maximally at one day of age with the ability to oxidize fatty acid declining with age.

While carbohydrates have been the dominant source of dietary energy and can effectively replace fats in this regard, it is evident that under

certain conditions at least, the energy needs can be more efficiently
met by supplying a part of the food energy in the more concentrated
form of fat. The interest being currently shown in the incorporation
of fat into the diets of poultry attests to the validity of the above
statement.

2.1.3 Fat as a dietary source of energy

The concept on quantitative use of fat as dietary source of energy
has undergone extensive revision. Recent advances in nutrient metabolism
have changed the view from one suggesting minimal use of dietary fat
on account of its reported interference in the digestion, absorption
and normal metabolism of other nutrients to that recommending the inclu-
sion of fat in the diet in substantial amounts for improved efficiency
of utilisation of other nutrients.

Vermeersch and Vanschoubroek (1968) carried out a comprehensive
review on the subject of fat supplementation to poultry diets in an
attempt to establish a quantitative effect of increasing levels of
various fats on the performance of chicks.

As a result of a detailed analysis of the data in the literature
these authors reported that the fats studied: soyabean oil, soyabean soap-
stock, maize oil, lard and tallow, were similar in their effects on food
consumption. The food consumption decreases significantly with rising
percentages of dietary fats according to a linear function. No differ-
ences were noted with regard to kinds of fat on food consumption. While
the incorporation of 2 to 20% of fats in the diets of growing chicks was
found to improve body weight gain, there was absence of a relationship

between body weight gain and the level of dietary fat.

A correlation was shown between efficiency of food conversion and the kind and level of fat: here the improvement is correlated with the level of fat added - the higher the level of fat, the better the efficiency of food conversion. Regarding the kind of fat, the degree of improvement in the efficiency of food conversion was, in an ascending order: tallow, lard, grease, maize oil, soyabean soapstock and soyabean oil.

The general conclusion from the review which covered 60 papers spanning the years 1954 to 1966 was that the incorporation of fat in poultry diets results in a decrease in food consumption and in an improvement in the efficiency of food conversion.

The review by Herstad (1970) encompassing 15 papers covering fat supplements in broiler diets confirmed the features established by Vermeersch and Vanschoubroek (1968). The various fats studied increased the rate of gain of broilers. The first 3% of soyabean oil or grease increased feed consumption; more than 3% fat in the diet decreased food consumption, although metabolisable energy consumption increased. The increase in consumption of food which incorporated certain fats was attributed to the poor digestibility of the particular fats.

Vanschoubroek et al., 1971, reported studies on the comparison of the effect of certain fat on the performance of broiler chicks. Soyabean oil included at a level of 4.5% of the diet improved feed conversion by 4.5% over lard to 4 weeks and by 3.3% to 8 weeks, in agreement with the results previously calculated by Vermeersch and Vanschoubroek (1968) using data from the literature.

2.1.3.1 Fat digestibility and absorbability

Poor digestibility and absorbability mainly account for the avoidance or the inclusion at a minimal level of fat in poultry diets in the early days. A change or reversal in the attitude of nutritionists occurred as a result of remarkable nutritional advances made in the ensuing years.

The metabolisable energy content of a fat is the product of its gross energy content and its absorbability (Whitehead and Fisher, 1975). Several factors are now known to affect the digestibility and absorbability of fats. These factors include the type, melting point, fatty acid profile, and the structure of the triglycerides (i.e. chemical characteristics) of fat; the number of fats in the diet (Young, 1961), the nature of the basal diet, the level of contamination of the environment by microorganisms, the level of intestinal bacteria and the age of the birds.

In general, vegetable oils with high levels of unsaturated fatty acids are more completely digested than animal fats. The difference in utilisation between fats which contain similar levels of fatty acids may be attributed to the difference in the distribution of fatty acids on the triglycerides of the fats concerned (Renner and Hill, 1960; Mattson, 1967).

Young et al. (1963) found that the absorption of lard fatty acids was greater when fed in a diet containing 28 or 30% protein as compared to a 24% protein diet. An improvement was observed in the digestibility of fat in four week old chicks fed antibiotics (Young et al., 1963). Supplee (1960) observed a 20% growth response when 13.3% corn oil was added to the diet in the presence of 50 mg of oleandomycin phosphate per kg of diet, but only a 10% increase in growth in its absence.

Results published by Mattson (1967) of a study on the effect of diet
on the bacteria found in the intestinal tract of rats showed that the
addition of antibiotics reduced caecal coliforms 50 times and total aerobes
approximately three times. Cleanliness of chick batteries (Donaldson,
1962) and laboratory (Young et al., 1963) has been mentioned as a
factor affecting the utilisation of fats. These reports suggest that
the utilisation of fat may be enhanced by controlling the level of con-
tamination of the environment by microorganisms or the balance of intes-
tinal microflora. Variations in these factors may account for some of
the variation in response to fat as reported in the literature (Salmon,
1972).

2.1.4 The specific effect of dietary fat on growth rate

The improvement in growth rate and efficiency of food utilisation
resulting from feeding high levels of fat to poultry has led to the
recognition of fat as having an "extra-caloric" effect (Touchburn and
Naber, 1966; Jensen et al., 1970). Donaldson (1966) explained that if
the total energy available for tissue synthesis were similar for chicks
fed both fat and "fat-free" diets, the fat-fed chicks would have the
advantage of not having to synthesize tissue fatty acids and thus might
have relatively more energy available for tissue protein synthesis.
Marion and Edwards (1963) stated a similar hypothesis and referred to
the amino-acid-sparing effect of dietary fat.

2.1.5 The importance of nutrient balance

The myriad of problems associated with feeding diets containing particular nutrients in excess of normal concentrations, could be attributed largely to improper balance resulting from such processes. Studies on the relationship of proportions of dietary nutrients to the overall efficiency of utilisation of nutrients have made it increasingly clear that nutrient metabolism is affected not only by the composition of individual feedingstuffs but also by the total composition of the diet.

Studies in this area have stressed the importance of balancing nutrients in relation to the energy level and amino acid balance. The work of Biely and March (1954), Munro and Wikramanayake (1954), Thomson and Munro (1955), Munro et al. (1959), contributed towards the development of the concepts that interaction existed between dietary protein, carbohydrate and fat and that dietary carbohydrate "spared" the protein of the diet by increasing the nitrogen balance of the animal in a positive direction.

Annison (1971) suggested imbalances in ratios between essential amino acids and energy, inadequate consumption of vitamins or trace elements, or the occurrence of toxic factors in fats as factors responsible for the poor results experienced by some investigators who fed diets, the energy of which was largely contributed by fat to poultry.

2.1.5.1 Calorie:protein ratio

The crucial role of the ratio existing between energy and protein in poultry nutrition was demonstrated by Biely and March (1954) who showed that supplementation with fat increased the level of protein

necessary for maximum growth of both chicks and poults. This finding
was confirmed by Waibel (1958). Donaldson et al. (1955.) showed that
the ratio of energy to protein in the diet influenced the caloric
intake, feed efficiency, growth rate and carcass fat and that further
widening of the calorie:protein ratio resulted in impaired growth and
increased fat deposition of broiler chickens.

March and Biely (1972) showed that the optimum dietary level of
effective protein is dependent upon the combined energy input from envir-
onmental temperature and dietary metabolisable energy and that increased
energy in the form of either heat or dietary metabolisable energy is
responsible for aggravating the depressing effect of dietary amino
acid imbalance on feed consumption and growth rate.

2.1.5.2 Calorie-nitrogen storage relationship

Ahrens et al. (1966) showed that for young rats fed two levels of
calorie intake, there were higher nitrogen gains when rats in the high
calorie group received the nitrogen as casein rather than as a mixture
of amino acids simulating casein. This effect was not shown in rats
of the same age fed diets providing similar nitrogen intakes at a
lower calorie level, thus indicating the dependence of nitrogen storage
on calorie intake rather than the source of nitrogen.

2.1.5.3 Implications of changing nutrient proportions

The substitution of one nutrient for another has its metabolic
complications. The lack of consistency in the findings reported in
the literature on the effect of dietary fat on body weight gain was soon
recognized to be due to restriction of nutrient consumption as a result

of reduced food intake when diets containing high fat levels were fed. The requirement for methionine (Baldini and Rosenberg, 1955), and lysine (Schwartz et al., 1958) has been shown to be dependent on the dietary energy level. Not only protein requirement is affected (Aitken et al., 1954; Slinger et al., 1955) but other dietary requirements also were found to increase when fat was added to the diet. The requirement for folic acid (March and Biely, 1955) and choline (March and Biely, 1956) was shown to increase in the presence of a high level of dietary fat.

Other studies have shown that the isocaloric substitution of fat for carbohydrate in the diet of the chick increases its requirement for vitamin B_{12} (Looi and Renner, 1974a) while it appears not to affect its requirement for methionine (Looi and Renner, 1974b).

2.1.6 Protein-carbohydrate interactions

The efficiency of protein utilisation is largely influenced by the extent to which the amino acids in the profile are available to the animal. Factors that affect or interfere with protein digestibility will also affect or interfere with amino acid availability and ipso facto, the efficiency of protein utilisation.

Lea and Hannon (1950) studied extensively reactions that occur between proteins and carbohydrates and reported that in the presence of a considerable amount of carbohydrates with reducing sugars, proteins containing amino acids with free amino groups such as lysine will react to form a protein-carbohydrate complex which may not be utilizable to

the animal. Nesheim (1965) discussed the fate of such a compound and suggested two possibilities. The compound could be degraded to yield products of little or no nutritional value to the animal or it could be completely destroyed.

Lack of a free amino group (on a protein containing an amino acid such as lysine) as a result of the linkage between it and the carbohydrate would make the protein resistant to hydrolysis by proteolytic enzymes. In such situations the protein-carbohydrate complex should be expected to appear in the excreta provided it had not been attacked by the microflora of the lower gut. Microbial degradation of the protein-carbohydrate compound may lead to the production and absorption of nitrogen in a form other than amino acids. Barnes and Kwong (1964) suggested that the nitrogen may be absorbed in the form of ammonia, a product of bacterial fermentation in the digestive tract.

2.1.7 Protein-fat interactions

Available evidence indicates interaction between protein and fat similar in nature to that occurring between proteins and carbohydrates. Lea et al. (1960) reported a drop in protein quality as a result of the reaction between fat oxidation products and amino acids, particuarly lysine. There was a fall of 8% and 4% respectively in the available lysine of untreated and antioxidant-treated herring meal stored at 20°C for 12 months compared to the available lysine content of fresh herring meal.

It is suggested (Nesheim, 1965) that under storage conditions which would permit oxidation or autooxidation of fat, carbonyl products

liberated during the oxidation of the fat could react with the free amino groups of lysine in proteins to produce bonds resistant to the actions of digestive enzymes or a compound not useful as a source of lysine.

2.1.8 Fish meal quality

Herring meal is widely used as a source of high quality protein. It contains a considerable quantity of highly unsaturated fatty acids and this accounts for its chemical and nutritional reactivity. Factors that affect the nutritive value of fish meal are well documented (El-Lakany, 1972). The biological value of herring meal has been reported to decline considerably as a result of processing and storage. During processing and storage, the poly-unsaturated fatty acids are subjected to oxidation. Depending upon the concentration of polyunsaturated fatty acids and the rate of oxidation, the fish meal may undergo spontaneous heating which could result in the destruction of amino acids (Laksevela, 1958; Lea et al., 1960), particularly lysine, trypsin, cysteine and histidine (Boge, 1960). Laksevela (1958) reported that the deterioration that resulted from spontaneous heating was of such magnitude as to cause a serious reduction in growth rate of chickens.

There are conflicting reports on the effect of storage on the nutritive quality of fish meal. Biely et al. (1951) and Miller (1955) did not find any adverse effect on the nutritive quality of fish meal stored under various temperatures for periods of three to twelve months. However, Stansby (1948), Almquist (1956) and Lea et al. (1958) showed that deterioration of the nutritive value of fish meal occurs under

various storage conditions. March et al. (1961) showed that low storage
temperature favoured the formation of protein-lipid complex which leads
to a decline in the nutritive quality of herring meal.

In general, fish meal quality varies with the methods of drying,
processing and storing of the meal. A marked decline in available lysine
occurs in diets in which fish meal of reduced nutritive quality is the
only source of protein.

2.1.9   Effects of dietary factors on body composition

The effects of dietary factors on body composition of chickens
were first described by Fraps (1943), who was able to produce chickens
with widely varying amounts of body fat by adjusting dietary components.
Subsequently, Donaldson et al. (1956, 1958), Rand et al. (1957), Spring
and Wilkinson (1957), Combs et al. (1964), Davidson et al. (1964),
Summers et al. (1965), Yoshida et al. (1966, 1970), Thomas and Combs
(1967), Yoshida and Morimoto (1970a, b), Thomas and Twinning (1971),
and Kubena et al. (1972), investigated the specific effects of dietary
protein, energy and calorie: protein ratio on the body composition of
chicks and poults. Through these studies, it was established that as
the dietary calorie:protein ratio widened, energy intake and carcass fat
deposition increased, while body water content decreased. Yoshida et al.
(1966, 1970) and Yoshida and Morimoto (1970a, b) have reported that the
effect of dietary protein concentration on carcass fat content is rapid
and reversible. Thomas and Twinning (1971) too, observed considerable
changes in carcass fat content, as early as 10 days after alterations

were made in protein concentrations.

The specific effect of dietary fat on body composition is not yet clear. While most of the reports reviewed above appear to establish that increasing the amount of dietary fat increased carcass fat while it decreased its protein content, Edwards and Hart (1971) failed to observe any change in total carcass composition when all the non-protein energy was derived from various oils. Bartov et al. (1974) reported that dietary oil supplementation per se did not increase the amount of carcass fat as long as the calorie: protein ratio was kept constant. If there existed any consistent trend at all, it appeared to act in the opposite direction: towards a decrease in carcass fat.

2.1.10 Effect of cellulose on metabolisability

The increased interest in energy nutrition of the chicken and progressive increase in the level of fat and, consequently, the density of diets used for poultry, has led to the present accepted practice of formulating experimental diets to contain varying levels of fibrous materials usually in the form of cellulose. There is conflicting evidence regarding the effect of cellulose on some physiological parameters of the chicken. Reports which indicate that growth and food utilisation are impaired when diets containing fibrous ingredients are fed to chickens, have been presented by Penquite (1936), Sheehy (1939), Heuser et al. (1945), Fraps (1946), Carrick and Roberts (1974a, b). Scott et al. (1947), Robertson et al. (1948), Panda and Combs (1950), Hill and Dansky (1954), Peterson et al. (1954), Mraz et al. (1956), and Richardson et al. (1956), have explained the

deleterious effect (attributable to fibre) on the basis of reduction in
energy intake mediated by the energy-diluting property of fibrous ingred-
ients. Halnan (1930), Robertson et al. (1948), and Wells (1963) attrib-
uted this effect to the imposition of physical limitation on the intake
of digestible nutrients.

There are, however, some reports which indicate that feeding moderate
amounts of fibrous materials may increase growth and improve the util-
isation of food above that obtained on the low fibre basal diet. Morris
et al. (1932), Wilcke and Hammond (1940), Record (1943), Davis and
Briggs (1947, 1948), Olsson (1948), and Saito et al. (1959) are among
those who are of the opinion that fibre may be of benefit in poultry
diets.

Sibbald and Slinger (1960) fed diets of which cellulose formed up
to 42% and obtained data which indicate that dilution of a chick starter
diet with cellulose does not change the metabolisable energy content.
This finding was substantially confirmed by Potter et al. (1960) who
showed that alpha-cellulose had zero or less metabolisable energy value.
Begin (1961) using isocaloric diets and a constant nutrient balance
technique demonstrated that the addition of woodpulp cellulose had
neither a growth-depressing nor a growth-stimulating effect when inclu-
ded in the diet of the chick. He explained that the major attribute
of cellulose when included in the diet without supplementary energy was
a depression in growth and feed utilisation and an overall decrease in
the utilisation of the diet as measured by the percentage of the gross
energy that was metabolised. According to Begin (1961), cellulose is
inert in respect of its effect on metabolisability or nitrogen retention.

2.1.11 Species, breed, strain and sex effect on energy metabolism

Differences occur in the response of different breeds (Gardiner, 1971) and strains of chickens to diets with the same (Nowland et al., 1971) or with different energy concentrations (Farrell, 1972). Wells (1963) noted differences in energy utilisation with respect to the sex of the bird.

There is evidence in the literature which points to species difference regarding metabolisability of energy. Slinger et al. (1964) showed that chicks metabolised more energy from a high-energy diet than turkey poults. Conversely, poults metabolised more energy from low-energy diet than chicks. Also, a slow-growing breed of chicks metabolised more energy from a high-energy diet than a fast-growing breed. Sudgen (1974) noted differences between the bantam chick and the blue-winged teal (duck) in respect of their ability to metabolise energy from various dietary sources. Slinger et al. (1964) and Sugden (1974) concluded that metabolisable energy values measured with one kind of bird cannot validly be applied to another kind.

Data presented by Leeson et al. (1974), do not support the above conclusion. The latter group of authors found no difference between turkeys and chickens in their ability to metabolise energy. Values obtained with the turkey for more fibrous materials, however, appeared to be substantially greater than have been found with the chick, suggesting turkeys with their larger digestive tracts might have a greater capacity for digesting fibrous foods.

2.2 The Avian Caeca and Efficiency of Utilisation of Dietary Protein and Energy

2.2.1 Overview

Very little is known about the physiological or nutritional role of the avian caeca. For many years there have been speculations as to whether the functions of the avian caeca are similar to those of other animals, particularly the horse. It has been suggested that the caecum may be a site for:

a) microbial digestion of cellulose;

b) digestion of carbohydrate and protein;

c) microbial synthesis and absorption of vitamins;

d) absorption of non-protein nitrogen

e) absorption of water, and/or

f) biosynthesis of antigens.

Various hypotheses have been advanced to support these suggestions and of these perhaps the most popular has been the one attributing a rumen-like function in the digestion of cellulose and protein and the biosynthesis and absorption of vitamins.

2.2.2 Carbohydrate and crude fibre digestibility

Kaupp and Ivey (1922) obtained crude fibre digestibility coefficients with poultry varying from 2.2 percent for extracted soybean meal to 11.7 percent for oats. Hunter et al. (1930) reported that fibre can be digested in the avian caecum. Maas (1934) using fowls with artificial anuses, reported digestibility coefficients of 2.4 percent for the crude

fibre of rye and 3.6 for that of wheat.

Halnan (1949) presented an excellent review embodying the work
of Radeff (1928) and others on crude fibre digestion. While the crude
fibre in barley was not digested by either normal or caecectomized fowls
that of wheat was better digested by the normal fowl (4.6-5.7 percent)
than the caecectomized fowl (1.4 percent). An even more remarkable
difference was shown with the crude fibre of maize of which the normal
fowl digested more (17.1 percent) than the caecectomized fowl which
showed zero percent digestibility. The source of fibre appears to be
of significance in relation to its degradation in the caeca. Variations
within the same food have been reported by Mangold (1934) who found
that the coefficients of digestibility of crude fibre for barley ranged
from 0 to 31.5 while those of oats ranged from 0 to 6.9 percent.

That the avian caeca possess some cellulolytic function is also
shown by Dukes (1955) and Nitsan and Alumot (1963). Thornburn and
Willcox (1965a) studied the significance of the caeca in the digestion
of dry matter, crude fibre, cellulose, pentosans, and starch by poultry
and reported a reduction in the overall digestibility of dry matter in
the food after caecectomy. Cellulose digestibility was reduced in indiv-
idual birds after caecectomy, but when they were compared with intact
birds of identical age, the reduction in digestibility was not always
evident. Variation in the caecal flora between birds was used to explain
the inconsistency of results between the intact and the caecectomized
birds (two in each case).

Not all evidence, however, is in accord with the above-mentioned
findings. The observation by Masson (1954) of the presence of potato
starch in the caeca makes the hypotheses of starch digestion in the

caeca less acceptable. Thornburn and Willcox (1965b) failed to produce conclusive evidence on the digestibility of carbohydrates in the intact caecum. Evidence presented by Scott (1955), Griminger (1957), Nelson and Norris (1961), McBee (1971), also disputes the claim of cellulolysis in the avian caeca. The repeated failure to find in the domestic birds caecal bacteria capable of hydrolysing cellulose must have prompted McNab (1973) to express doubt about the caeca as being an organ of significance in the digestion of cellulose or crude fibre.

2.2.3 Protein digestibility and utilisation

The role played by the avian caeca in the utilisation of protein is equally far from clear. Maumus and Launoy (1901) and Maumus (1902) both cited by McNab (1973) studied the action of different substrates of caecal juice from chicks, ducks and geese and reported the presence, in the caeca, of a proteolytic enzyme similar in action to trypsin. Nitsan and Alumot (1963) examined the caecal contents of chicks which had been fed diets based on raw and heated soyabean meals for proteolytic activity and noted high activity on both diets up to four weeks of age. Differences were noted in enzyme activity in the sixth week between birds fed the heated and those fed the raw beans - the former showing a marked decrease and the latter only a slight decrease in enzyme activity. Increased proteolysis was observed at eight weeks of age when the chickens were transferred from a heated to a raw soyabean based diet.

Fisher and Griminger (1966) tested the hypothesis of caecal proteolysis and failed to accept the suggestion of Nitsan and Alumot (1963) that the observed increase in proteolytic activity in the eight week old

chicken was attributable to compensatory proteolysis which occurred to obviate inhibited proteolysis in the small intestine. On the basis of good growth rate of the caecectomized chicks in comparison with that of unoperated controls, Fisher and Griminger (1966) concluded that caecal digestion of raw soyabean protein is of negligible consequence in the growing chicken.

Nesheim and Carpenter (1967) fed undamaged and heat-damaged fish meal to normal and caecectomized birds and reported that a significant proportion of the protein and peptides which escape hydrolysis and absorption in the small intestine enters the caeca and is fermented in such a way that the nitrogen is liberated as ammonia or some other substance of no nutritional value. This view is strengthened by the work of Salter and Coates (1971) who concluded that microbial activity did little to increase the availability of protein to the chick.

Payne et al. (1971) investigated the effect of caecectomy on apparent digestibility of protein and found that caecectomized birds had a protein digestibility coefficient that was slightly (though not significantly) smaller than that of normal intact birds. Despite the above findings, Payne et al. (1971) argued that the large experimental error coupled with the small number of observations per treatment (5 birds) accounted for the lack of statistical significance and concluded that proteins that are digested within the caecum are absorbed from the caecum and on that basis the caeca are involved in protein digestion.

2.2.4 Absorption of nutrients

The fact that microorganisms inhabiting the alimentary tract of

ruminants are responsible for activities of nutritional significance
to the host animals has given rise to considerable speculation on the
involvement of intestinal microorganisms in the digestion and/or absorp-
tion of nutrients by the domestic fowl.

The presence of a large population of microorganisms in the ali-
mentary tract, particularly the caeca, has been reported by Shapiro
and Sarles (1949), Barnes and Shrimpton (1957), and Barnes and Impey
(1970). Although the avian caecum is one of the areas of greatest micro-
bial proliferation and activity (Barnes and Impey, 1970), there is no
clear evidence that microbial activity is beneficial or detrimental to
the host.

One possible way in which the presence of microorganisms can be
regarded as beneficial to the domestic fowl is that carbohydrates or
proteins of dietary or endogenous origin that escape digestion in the
upper gut might be catabolized by microbial action in the lower gut with
subsequent absorption of the end products such as monosaccharides or
disaccharides in the case of carbohydrates, and amino acids or amino
acid degradatory products in the case of proteins. This would be in
agreement in part with the suggestions of Thornburn and Willcox (1965b)
and Nesheim and Carpenter (1967).

Alternatively, they might be of no nutritional value, if, for
                          the
instance, lactic acid is/end product of carbohydrate catabolism and
biologically unavailable peptides or excessive ammonia are the end pro-
ducts of protein breakdown.

2.2.5 Uric acid production

Since some protein hydrolytic function is suggested for the caeca

and uric acid is the main nitrogenous excretory substance in the bird the possibility exists that uric acid could be involved in the metabolism of the caecal microflora and that the microflora would contain a significant population of uric acid-utilizing bacteria.

Barnes and Impey (1972) found three isolates of usic acid-decomposing anaerobes and in subsequent study (Barnes et al., 1972) found that the uric acid degradatory organisms were always present at a minimal level of 10^8-10^9/g. Mead and Adams (1975) studied changes in the caecal flora of chicks aged between approximately 3 hours and 14 days and reported that during the 14-day period, approximately 100 percent of the organisms isolated through conventional anaerobic plating method utilized uric acid up to the third day but this activity declined with age to the extent that in one case it represented only four percent of the total flora. None of the isolates showed an absolute requirement for uric acid. Except with a few strains there has been little evidence for the utilisation of uric acid as a carbon source. However, Barnes (1972) found that a number of the uric acid utilising bacteria utilized ammonia as the main source of nitrogen. Barnes (1972) explains that the continual presence of a large population of uric acid recycling bacteria in the avian caeca suggests that a major function of the caeca could be the metabolism and reutilisation of the excretory products diverted into the caeca with the possible re-absorption of water and any other of the vitamins, volatile fatty acids or amino acids synthesized by the microorganisms. Akester et al, (1967) have reported that an unknown physiological mechanism, induced by the appropriate stimulus initiate contraction of the coprodeum which then results in the retrograde flow of urine and fine particles of digesta into the caeca

3. PART 1. THE EFFECT OF SUBSTITUTION OF FAT FOR STARCH ON THE
         PERFORMANCE OF BROILERS

3.1   Experiments 1 and 2

3.1.1   Introduction

The increasing world shortage of grains which, hitherto, have been the predominant dietary source of energy for poultry, has stimulated interest in the search for alternative dietary source(s) of energy for poultry.

A number of researchers have studied energy utilisation and have demonstrated the potential value of fat not only as an alternative, but also as an economic source of dietary energy. The attempts being made are in the direction of establishing a dietary energy concentration that would promote an efficient utilisation of nutrients, particularly protein.

Data published by Touchburn and Naber (1966) and Jensen et al. (1970) appear to establish a concept that supplemental dietary fat has an "extra-caloric" effect on the utilisation of metabolisable energy by turkey broilers. In a series of experiments these groups of workers showed that added dietary fat improved utilisation of metabolisable energy and that "a wider calorie:protein ratio could be tolerated when fat was added to the ration than when no fat was used".

There is little or no direct information on the broiler chicken regarding the effect of added dietary fat on the utilisation of metabolisable energy and tolerance of a wider calorie:protein ratio. A study has, therefore, been made of the effect of partial substitution of dietary fat for glucose calories on metabolisability of energy, body weight gain, efficiency of food conversion and carcass fat content of broiler chickens.

3.1.2   <u>Materials and Methods</u>

This phase of the study comprised two experiments conducted using broiler chicks. The same formulation of diets was used in both experiments. The composition of the diets is presented in Table 1. The basal diet contained 3% corn oil to keep down dustiness of the mash, and more importantly, to supply the dietary essential fatty acids, particularly linoleic acid, the lack of which would precipitate metabolic disorders which, consequently, would affect the expression of the parameters under study. There were four diets consisting of two levels of supplementary fat, 4% and 8% fed at two protein levels 18% and 22%.

Four hundred and sixteen chicks were housed in a thermostatically-controlled electrically-heated metal battery brooders with raised screen floors, and were fed a holding practical-type broiler starting diet for two days. The chicks were then wing-banded and distributed randomly into two major lots of stock for the two experiments. The two lots of chicks continued to be brooded in the manner described earlier, fed the same experimental diets, and kept in the same room except where it is otherwise specified. Food and water were provided <u>ad libitum</u> to all the chicks involved in the two experiments. One lot of chicks, consisting of one hundred and fifty six, was randomly redistributed into four groups according to the number of dietary treatments with three replications. The 13 chicks per replicate were assigned to one battery compartment. This constituted the stock for the first experiment.

Table 1. Composition of diets used in experiments 1 and 2.

Ingredient, or calculated analysis	Low Protein		High Protein	
	Low Fat	High Fat	Low Fat	High Fat
		Diet Number		
	1	2	3	4
	Percent			
Herring meal (72%)	13.0	13.0	21.3	21.3
Wheat (12.45)	70.9	70.9	53.0	53.0
Corn oil	3.0	7.0	3.0	11.0
Corn starch	9.6	-	19.2	-
Bone meal	1.5	1.5	1.5	1.5
Limestone	1.0	1.0	1.0	1.0
Iodized salt	0.5	0.5	0.5	0.5
Premix[1]	0.5	0.5	0.5	0.5
Cellulose	-	5.6	-	11.2
Protein	18.19	18.19	21.93	21.93
Fat	5.57	9.57	6.08	14.08
M.E. (kcal/kg)	3345	3347	3382	3385

[1]Micronutrients supplied per kg of diet: manganese sulphate, 132 mg; riboflavin, 3.12 mg; menadione, 0.48 mg; calcium pantothenate, 9.62 mg; folacin, 0.55 mg; vitamin B_{12}, 0.13 mcg; pyridoxine, 2.87 mg; biotin, 0.09 mg; choline chloride, 1.32 g; vitamin A, 4400 I.U., vitamin D_3, 440 I.C.U.; vitamin E, 18 I.U.; zinc bacitracin, 27 mg; chlorotetracycline, 124.9 mg; amprolium, 11 mg.

There was a slight modification in the replication of the dietary treatment groups of the stock used for the metabolisable energy study. There were five replicated lots of 13 chicks each. This was done in order to allow each chick the same floor space as in the first experiment. With 13 chicks in each replicate there were 65 chicks for each of the four dietary treatment groups, making a total of 260 chicks maintained under the same management conditions as the first experiment.

3.1.2.1
Experiment 1

This study was designed to investigate the effects of diets varying in fat and protein levels on the performance of broiler chickens using body weight gain, food conversion efficiency and efficiency of protein utilisation as the criteria for evaluating performance.

The chicks were individually weighed at weekly intervals throughout the experimental period which lasted seven weeks. Food consumption was determined on group basis and was done at the time of weighing the chicks. Spilled food was removed from the excreta by screening and added to the remaining feed in the troughs before the feed weigh-back. Data collected on body weight gain, food (conversion) efficiency and protein efficiency ratio values were treated by analysis of variance (Snedecor, 1956) and significant differences among treatment means were identified by Student-Newman-Keuls multiple range test.

3.1.2.2
Experiment 2

The second experiment involved 240 chicks. At 1, 2, 4 and 7 weeks of age, 60 chicks made up of three chicks from each quintuplicate lot

of the four dietary treatment groups respectively, were randomly removed from the second lot of chicks described earlier. The fifteen chicks removed from each dietary treatment group at each specified period were redistributed randomly into triplicate groups of five chicks and each group was assigned to an electrically-heated, thermostatically-controlled adjustable battery compartment with raised wire screen floors in a well-ventilated, temperature-controlled chicken room in the laboratory. The size of the compartments was adjusted at each housing period commensurate with floor space requirement.

All the chicks were individually weighed at the commencement and termination of each period lasting one week. Food consumption records were kept for each period. The chicks were continued on the same experimental diets for two and one half days. Food was withdrawn 18 hours prior to the commencement and termination of the collection of total excreta. Feathers, food and extraneous materials were carefully picked from the excreta and the three days' collections from each replicate group were pooled according to treatment and frozen. The frozen excreta was lyophilized, ground and stored in screw-cap sample jars and stored until required for analysis.

Moisture determination was carried out on all samples to permit calculations to be made on dry weight basis. Assay for energy content of both food and excreta was done using Parr Oxygen Bomb Plainjacket Calorimeter. Kjeldahl macro-method was followed in the determination of crude protein.

At the end of the experiment, all the chicks were killed and three chicks from each replicate group were selected at random for determination of the weight of the abdominal adipose tissue which included the abdominal fat pad and that associated with the viscera.

3.1.3

Experiment 1 - Results

Statistical analysis applied to the total body weight gains (summarized in Table 2) shows that the chickens were able to attain practically the same final weight to approximately seven weeks of age, regardless of the source of dietary energy/fat or protein level. The average body weight gains per bird fed diets 1, 2, 3 and 4 were 1653, 1665, 1646 and 1704 grams, respectively. Fig. 1 shows the closeness of body weight values throughout the experimental period. The data (Table 3) on weekly body weight gains subjected to statistical analysis, revealed no significant differences in this trait among the different dietary groups. In the first week, significant differences occurred among the dietary groups. Birds fed the low-protein diet in which fat was the source of supplementary energy (diet 2) made the poorest body weight gains. With the exception of the fourth week, there were no significant differences in weekly body weight gains among the various dietary groups from the third week to the termination of the experiment in the seventh week.

The food conversion efficiency values are presented in Table 4. With the exception of the second week in which the food conversion efficiency was best on the low-fat high-protein diet (diet 3), the best food conversion efficiency values were obtained with the high-fat high-protein diet (diet 4). Next in order of food conversion efficiency was the low-fat high-protein diet, indicating better food conversion efficiency on

Table 2. Effect of dietary fat and protein levels on body weight gains
in Experiment 1.

D I E T			Mean[1] Body Weights in Grams		
No.	Fat	Protein	Initial[2]	Final	Gain
1	Low	Low	68	1721	1653a
2	High	Low	68	1733	1665a
3	Low	High	67	1713	1646a
4	High	High	66	1770	1704a

[1]Means within a column followed by different letters differ significantly
(P ≤ 0.05)

[2]Birds were 2 days old at initiation.
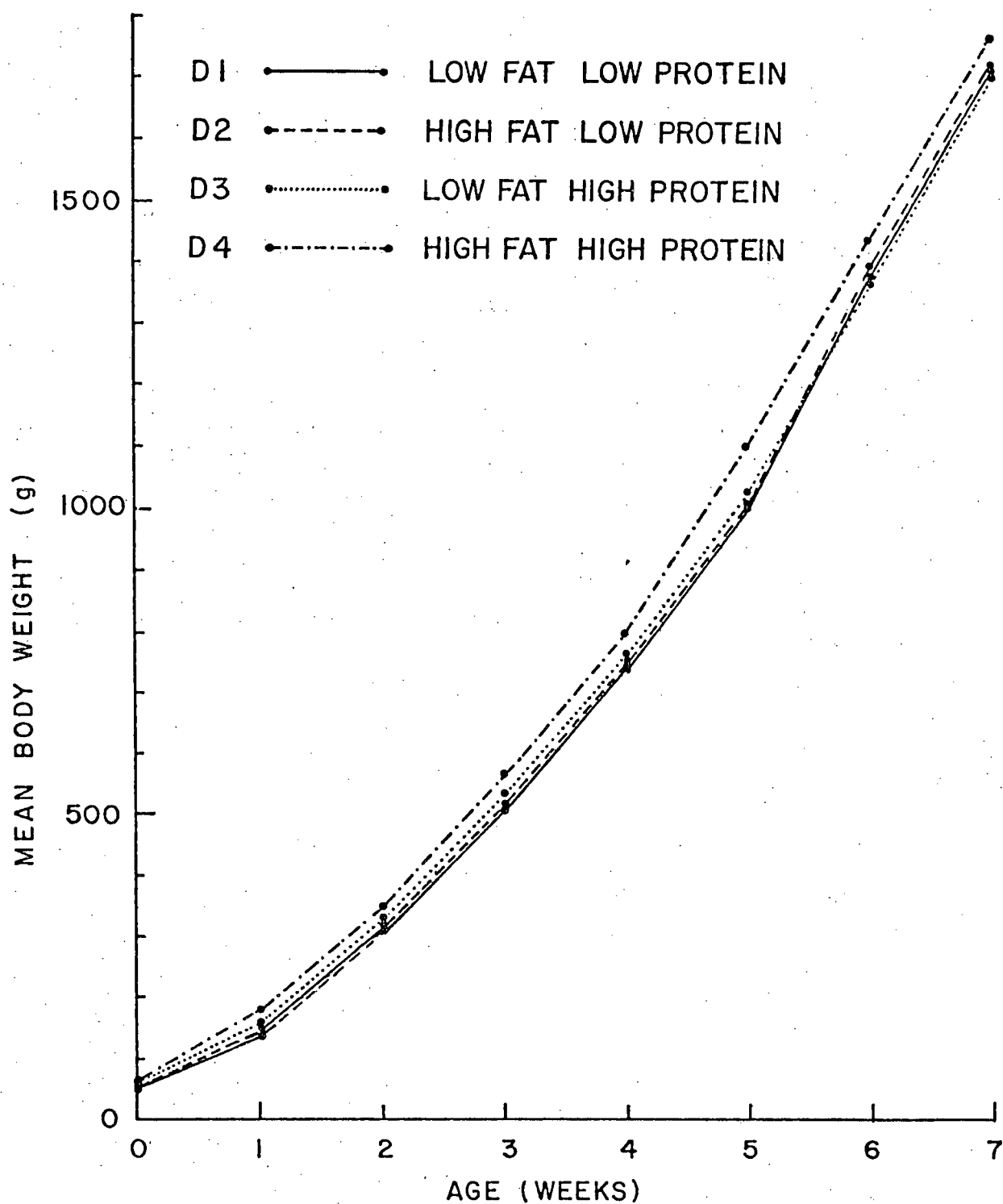
FIG. I: EFFECT OF DIETARY FAT AND PROTEIN LEVELS
ON BODY WEIGHT.

Table 3. Effect of dietary fat and protein levels on weekly body weight gain.

D I E T			Mean[1] Body Weight Gains in Grams						
						Weeks			
No.	Fat	Protein	1	2	3	4	5	6	7
1	Low	Low	93bc	162b	214a	225b	277a	344a	338a
2	High	Low	89c	167b	218a	224b	266a	360a	341a
3	Low	High	99b	169b	209a	222b	269a	344a	334a
4	High	High	107a	178a	221a	253a	272a	338a	334a

[1]Means within a column followed by different letters differ significantly (P ≤ 0.05).

Table 4. Effect of dietary fat and protein levels on food conversion efficiency[1], [2].

| D I E T | | | Weeks | | | | | | | |
No.	Fat	Protein	1	2	3	4	5	6	7	Overall
1	Low	Low	1.51	1.48	1.71	1.75	2.15	2.21	2.42a	1.89a
2	High	Low	1.53	1.46	1.73	1.74	2.16	2.16	2.45a	1.89a
3	Low	High	1.34	1.32	1.74	1.58	2.02	2.14	2.25a	1.77b
4	High	High	1.24	1.33	1.62	1.44	2.00	2.04	2.30a	1.71b

[1]Units of food consumed per unit of body weight gain.

[2]Values within a column followed by the same letters are not significantly different (P $\leq$ 0.05).

the high-protein diets. There was no difference in the overall food conversion efficiency between the birds fed the two low-protein diets. These birds gave consistently lower food conversion values during all weekly periods of the experiment.

There was a consistent decline with age in the efficiency of food conversion of birds fed diet 4 except during the fourth week when there was an improvement in this criterion. This trend was also shown by birds fed the other high-protein diet (diet 3) which had exhibited a similar tendency in the second experimental week. Birds fed the low-protein diets showed improvement in the second week after which they showed a consistent decline in efficiency of food conversion.

The level of dietary fat in low-protein diets does not appear to influence the efficiency of food conversion as evidenced by the fact that birds fed the basal dietary fat (diet 1) converted food with equal efficiency as those fed the additional fat (diet 2) in the low-protein category. Birds fed the basal fat, high-protein diet (diet 3) gave practically the same food conversion efficiency value as those fed the high-fat high-protein diet (diet 4). The trend for the cumulative food conversion efficiency values for the various dietary groups is shown in Fig. 2.

Table 5 shows that the protein conversion efficiency (body weight gain/protein consumed) by the birds fed the two low-protein diets, was significantly better than that obtained by birds fed the two high-protein diets. Birds fed diets containing the basal fat levels (diets 1 and 3) gave the greatest protein conversion efficiency values. As noted in the case of food conversion efficiency, the source of dietary energy or the level of dietary fat in the low-protein diets did not influence the
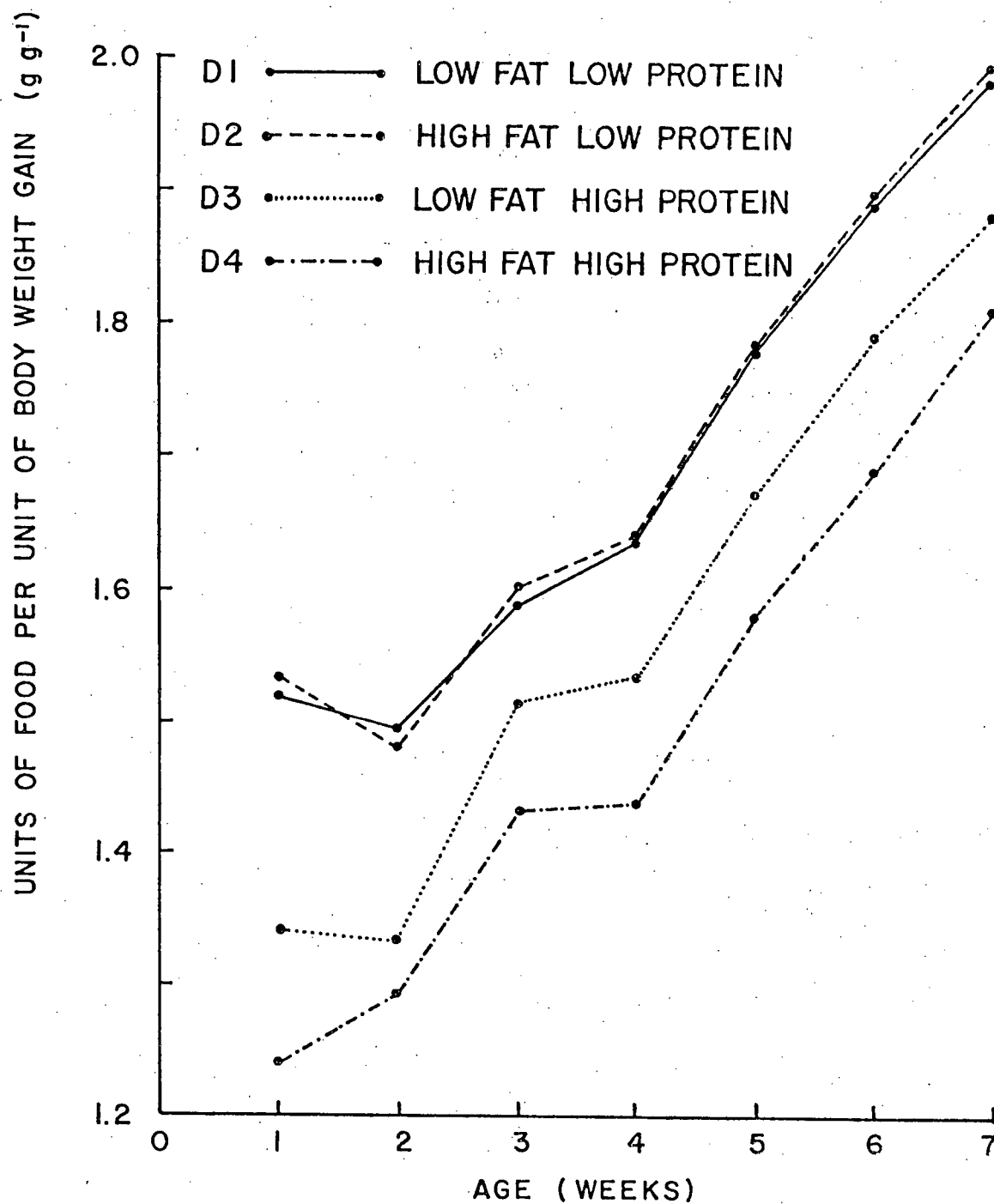
FIG. 2: EFFECT OF DIETARY FAT AND PROTEIN LEVELS ON FOOD CONVERSION EFFICIENCY (CUMULATIVE).

Table 5. Protein conversion efficiency

	D I E T		Body Weight Gains/Protein Consumed (g g^{-1})							
						Weeks				
No.	Fat	Protein	1	2	3	4	5	6	7	0-7
1	Low	Low	3.63	3.72	3.22	3.15	2.56	2.49	2.27	3.01
2	High	Low	3.59	3.77	3.18	3.15	2.55	2.54	2.24	3.00
3	Low	High	3.41	3.45	2.61	2.89	2.26	2.13	2.03	2.68
4	High	High	3.69	3.44	2.81	3.16	2.28	2.24	1.98	2.80

utilisation of dietary protein as reflected in the lack of difference between the two low-protein diets which differed only in the source of supplementary energy and fat level. It is interesting to note that a similar relationship existed between birds fed the two high-protein diets which differed also in the source of supplementary energy and dietary fat level.

3.1.4

Experiment 1   -   Discussion

Although chickens fed the high-fat high-protein diet grew signifi-
cantly heavier in the first, second and fourth weeks than those fed the
other experimental diets, the final body weight gain data (Table 2), the
weekly body weight gain data (Table 3), and the closeness of data on
overall growth rate (Fig. 1) do not demonstrate the concept that has been
established for turkeys that supplementary fat promotes superior growth.
The absence of a significant difference in later weeks in the final body
weights between chickens fed either fat-based or carbohydrate-based diets
indicates that the influence of dietary fat on growth rate would be
exhibited in early rather than late in the life of the bird. This obser-
vation is in close agreement with the finding of Touchburn and Naber
(1966) who reported that the beneficial effect of supplementary fat on
the performance of turkeys became less apparent in the final interval,
12 to 14.5 weeks of age and that of Salmon (1972) who did not obtain a
significant difference in the final weights between turkeys fed a high-
fat diet for the entire 24 week experimental period compared with others
fed a high-fat diet from 16 to 24 weeks.

The observation that no significant differences existed in the final
body weights and the overall body weight gains among the different diet-
ary groups could be reconciled with two well-established concepts. It
has been documented that as dietary fat increases, lipogenesis assumes
relatively less importance (Donaldson, 1966) and that dietary fat has a
sparing effect on amino acid conversion to fatty acids. As Donaldson
(1966) explains, "if the total energy available for tissue synthesis were

similar for chicks fed both fat and 'fat-free' diets, the fat-fed chicks would have the advantage of not having to synthesize tissue fatty acids and thus might have relatively more energy available for tissue protein synthesis". The level of dietary fat of six percent and ten percent in the low-protein diets may have been high enough to depress lipogenesis and induce tissue protein synthesis. In the other series, the dietary fat level of six percent may have similarly depressed lipogenesis while the protein levels may have been adequate.

The protein efficiency ratio data (Table 5) provide evidence which supports this view. Ratios of units of body weight gain per unit of protein ingested were higher for the low-protein diets than the high-protein diets. These results are in agreement with those of Biely and March (1954) and Waibel (1958) who found that growth promotion is achieved only if the concentration of dietary protein is increased in accordance with the dietary energy concentration. Since the dietary energy concentration within the protein series was the same and since there was no significant difference in growth between the dietary groups within the protein series, it appears energy to protein ratio is a factor of greater significance in the promotion of growth than the source of dietary energy. This observation supports the statement of Scott et al. (1969) that, "Diets containing as much as 35 to 40 percent fat and 45 to 50 percent protein, with little or no carbohydrate, and with energy values as high as 5000 kcal ME/kg, will support excellent growth in young chicks, as long as the protein and amino acid levels are maintained at the optimum ratios to the energy".

The lack of significant differences in overall body weight gain

among the different dietary groups seems to suggest also that there was a superfluous supply of protein and amino acids in the high-protein diets. The wider ratio (Kcal:percent protein), 186:1 having produced the same growth response as the narrower ratio, 154:1, could be considered as being more efficient as far as protein level is concerned.

Poults given a low level of added dietary fat required a narrower energy:protein ratio to four weeks of age and were more sensitive to energy protein imbalance than those given higher levels of added dietary fat (Salmon, 1974). Chickens involved in this study may have reacted in a similar manner to the different dietary energy:protein ratios, particularly the wider ratio in the first four weeks and this could account for the variation in growth in the period under reference.

The data on body weights of birds studied in this experiment confirm the finding of Vermeersch and Vanschoubroek (1968) that, while dietary fat incorporated at levels ranging from 2 to 20 percent improves body weight gain, there is no relationship between body weight and level of dietary fat.

The overall results relating to efficiency of food utilisation (Table 4) show that corn oil substituted isocalorically for corn starch does not improve the efficiency of food utilisation. The results rather show that protein level affects this trait. In interpreting these results which appear to contradict the findings of Touchburn and Naber, 1966; Vermeersch and Vanschoubroek, 1968; Herstad, 1970; Jensen et al., 1970 and Vanschoubroek et al., 1971, sight should not be lost of the fact that when fat replaces starch gravimetrically rather than isocalorically there is a change not only in calorie density but also in the ratio between energy and other nutrients.

The lack of significant differences in the efficiency of food conversion between the chickens fed on the low-fat low-protein diet (1) and those fed on the high-fat low-protein diet (2) throughout the duration of the experiment and the superiority of the group fed on the diet incorporating high-fat high-protein (4) over the group fed on the diet containing low-fat high-protein (3) in the overall statistical analysis demonstrate again the validity of the suggestion that diets incorporating fats should contain a concomitant level of protein in order to achieve a satisfactory food conversion efficiency value. A possible explanation for the better food conversion values obtained with chickens fed the high-fat high-protein diet is that this diet contained a more satisfactory metabolisable energy concentration associated with a favourable calorie: protein ratio. This is consistent with the reported low energy cost of fat hydrolysis in and the absorption of fat from the intestine, of triglyceride resynthesis in the epithelium and of transport and deposition relative to the efficiency with which fatty acids and carbohydrates supply acetyl CoA for energy requirement or fat synthesis (Annison, 1971).

3.2.1

Experiment 2   -   Results

The metabolisable energy values (ME) for the four experimental diets
are presented in Table 6. In the first week, birds which were fed the
low-fat high-protein diet (diet 3) metabolised energy significantly
better than birds fed all other experimental diets. The differences
between all other dietary treatments during the rest of the experimental
periods were not statistically significant. However, there was a sig-
nificant difference in the combined values for the entire experimental
period. The trend observed in the first week was repeated in the overall
metabolisability of the diets with the value for the basal-fat high-
protein diets being significantly higher than the two low-protein diets.
The added fat appeared to influence metabolisability of the diets incor-
porating the low protein levels as evidenced by the significantly higher
ME values for the low-protein diet (diet 2) which contained four percent
more fat than the other.

As shown in Table 7, no significant differences were observed in
adipose tissue among the four dietary groups. Birds fed the low-protein
diet in which fat replaced starch (diet 2) gave the highest adipose tissue
weights each week throughout the whole experimental period. Birds fed
the high-protein diet in which fat replaced starch (diet 4) gave the
second highest adipose tissue weights. The lowest adipose tissue weights
were obtained in birds fed the diet incorporating the basal level of
dietary fat and high level of protein (diet 3). There were observable
variations   within the dietary groups during each week.

Table 6. Effect of dietary fat and protein levels on metabolisability
of energy.

D I E T			Calories[1] per gram of food				
			Weeks				
No.	Fat	Protein	1	2	4	7	Overall
1	Low	Low	3343a	3460a	3568a	3560a	3483a
2	High	Low	3270a	3482a	3530a	3516a	3450a
3	Low	High	3429b	3532a	3604a	3533a	3525b
4	High	High	3280a	3469a	3618a	3560a	3482a

[1]Means within a column followed by different letters are significantly
different (P ≤ 0.05).

Table 7.   Effect of fat and protein levels on mean[1] abdominal adipose tissue weight.

D I E T			Grams			
No.	Fat	Protein	Weeks			
			1	2	4	7
1	Low	Low	1.57 ± 0.07[1]	4.87 ± 0.84	15.30 ± 0.72	22.76 ± 4.84
2	High	Low	2.10 ± 0.21	6.20 ± 0.03	17.67 ± 1.23	32.67 ± 2.70
3	Low	High	1.60 ± 0.06	4.80 ± 0.33	13.07 ± 1.39	19.03 ± 1.36
4	High	High	1.60 ± 0.17	6.17 ± 0.50	13.07 ± 0.83	27.00 ± 1.31

[1] Standard error of means.

The utilisation of metabolisable energy for body weight gain was essentially the same for chickens fed the low-protein diets (Table 8). A similar relationship was shown by chickens fed the higher protein diets for the second and the seventh weeks of the experiment. However, in the first week there was a difference between the two groups fed diets containing high levels of protein. Birds fed the low-fat high-protein diet utilised less metabolisable energy for a unit gain in body weight. Comparison of the metabolisable energy intake per gram of body weight gain revealed less intake for chickens fed the diets with high-protein levels up to the fourth week. This difference between the two protein-level groups did not exist in the seventh week. All groups of birds utilised metabolisable energy with the same efficiency in the first two weeks except the group that was fed the high-fat high-protein diet which utilised less metabolisable energy in the first week. An increase in metabolisable energy intake per gram of body weight gain was shown by all dietary groups in the fourth and subsequent weeks. Mortality among the dietary groups was slight and variable. The respective deaths were 4, 2, 1 and 3 for dietary groups 1, 2, 3 and 4. All the losses occurred between the fourth and sixth weeks and were attributable to perosis.

Table 8.　Metabolisable energy intake per bird per gram body
weight gain

D I E T				WEEKS[1]			
No.	Fat	Protein	Factor	1	2	4	7
1	Low	Low	ME (kcal/kg diet)	3343	3460	3568	3560
			Food intake (g)[2]	20.1	34.2	54.2	117.0
			ME intake (kcal)	67.3	118.5	193.5	416.4
			Weight gain (g)	13.3	23.2	31.1	48.3
			ME/Weight gain	5.1	5.1	6.2	8.6
2	High	Low	ME (kcal/kg diet)	3270	3482	3530	3516
			Food intake (g)	19.5	34.8	55.2	114.9
			ME intake (kcal)	63.6	121.1	194.8	404.0
			Weight gain (g)	12.7	23.9	31.6	46.8
			ME/Weight gain	5.0	5.1	6.2	8.6
3	Low	High	ME (kcal/kg diet)	3429	3532	3604	3533
			Food intake (g)	19.0	31.9	49.8	107.3
			ME intake (kcal)	65.0	112.7	176.6	379.0
			Weight gain (g)	14.2	24.1	31.5	47.7
			ME/Weight gain	4.6	4.7	5.7	7.9
4	High	High	ME (kcal/kg diet)	3280	3469	3618	3560
			Food intake (g)	19.4	32.6	50.6	110.3
			ME intake (kcal)	63.5	113.1	182.9	392.6
			Weight gain (g)	15.6	24.6	35.0	47.9
			ME/Weight gain	4.1	4.6	5.2	8.2

[1]The birds were 2 days old at the commencement of feeding experimental
diets.

[2]Food intake per bird.

3.2.2

Experiment 2   -   Discussion

The results of the metabolisable energy determinations (Table 6) suggest the need for dietary carbohydrate calories early in the life of the broiler chicken. The fact that the diets incorporating higher fat levels were more poorly metabolised makes it reasonable to assume that high dietary fat level depresses metabolisability of diets in young chicks to one week of age. It is known that fats and oils have normally a very high availability of metabolisable energy (Tasaki and Sakurai, 1969). However, the metabolisable energy content of a fat is the product of its gross energy content and its absorbability (Whitehead and Fisher, 1975). It has been established that corn oil is readily absorbed by chicks (Renner and Hill, 1960) and that the level of absorbability remains the same up to 8 weeks of age. More recent determinations by Carew et al. (1972) of absorbabilities of corn oil by chicks indicate that the newly hatched chick to 7 days of age does not have full physiological capacity for fat absorption. It is suspected that the chicks involved in this study must have absorbed fat at a sub-optimal efficiency and this could have resulted in a lowered metabolisable energy intake in the first week. It is difficult to explain the discrepancy between the observed higher body weight gains on the high-fat diets in the first week (Table 3) and the lower metabolisable energy values on the same diets in the same period. The higher adipose tissue content of the high fat diets may have contributed to the higher body weights. There is evidence that 10 to 15 percent more energy was deposited in the carcass of chickens

receiving diets containing 5 to 10 percent fat compared with similar
diets low in fat and that this phenomenon occurred even when metabolis-
able energy intake from the two diets was the same (Carew et al., 1964).
Forbes and Swift (1944) observed this phenomenon in rats and termed it
the associative dynamic action of fats. The improvement in energetic
efficiency can be attributed to a lower metabolic cost of utilising fats
in comparison to the other major source of dietary energy - carbohydrate.

The suggestion that poor absorbability may have contributed to the
observed depression in metabolisable energy values of the high-fat diets
seems valid in the light of the observed improvement in the metabolisa-
bility of diets incorporating high dietary fat in subsequent weeks when
they had developed their physiological capacity for fat absorption. The
lack of significant differences in the metabolisable energy values of the
diets from two through seven weeks is interesting from the point of view
of its economic implications. In terms of metabolic implication, it has
been reported that protein is not the only dietary factor that must be
adjusted commensurate with dietary fat level (Aitken et al., 1954; Slinger
et al., 1955). The levels of other nutrients, notably some vitamins,
require adjustment (March and Biely, 1955, 1956; Looi and Renner, 1974a).
It follows that the substitution of fat calories for starch calories
without changing the proportions of other dietary factors, particularly
the micronutrients, creates an imbalance among nutrients. The incidence
on the high-fat diets of perosis, a condition attributable to a deficiency
of manganese could have been precipitated by nutrient imbalance. Farrell
et al. (1973) observed small differences in metabolisable energy values
comparable to those being reported in this study and explained the poor

growth rate of broilers fed diets of varying energy concentrations on
the basis of nutrient imbalance or deficiency.

Wide variability occurred within the dietary groups and this could
have contributed to the lack of significant differences in adipose tissue
accumulation among the different treatment groups in the first two weeks
of the experimental period. Chickens fed the high-fat low-protein diet
(2) showed a significantly heavier adipose tissue weight in the fourth
and seventh weeks (Table 7). It is interesting to note that the periods
in which the birds fed the high-fat low-protein diets deposited signifi-
cantly more adipose tissue coincided with the periods in which the group
in question gave the lowest metabolisable energy values. Since the dif-
ferences in the latter response criterion did not reach statistical sig-
nificance (P ≤ 0.05) there was little or no basis to explore the possibility
of a statistical relationship. The reasons for the differences in fat
deposition among the treatment groups are not immediately obvious. Since
the highest deposition of fat occurred in birds fed the high-fat low-
protein diet, the possibility exists that the 18 percent protein level was
adequate in terms of amino acid levels and balance. With an adequate
supply of amino acids and preformed fatty acids, the magnitude of nutrient
interconversions would be comparatively less and this would result in a
saving in energy which would have been expended on biosynthesis of nutrients
that might be required. The "surplus" energy could have been converted
into fat. It is noteworthy that fat deposition in birds fed the high-fat
high-protein diet was less than that in birds fed the high-fat low-protein
diet. The possibility exists that the energy saved as a result of the
specific dynamic effect of fat was directed towards utilising more protein
for muscle tissues. This view becomes more attractive when it is considered

that birds fed the low-fat high-protein diet, which was isocaloric with the other diets, deposited the least amount of adipose tissue.

The results relating to the efficiency of metabolisable energy utilisation using the number of calories of metabolisable energy per a gram of body weight gain as a response criterion (Table 8) were the same for the diets containing the low protein level. A similar effect was shown between the high-protein diets. The lower ratios obtained on the diets incorporating higher protein levels and which contained a narrower calorie:protein ratio, again emphasize the importance of this principle with regard to the efficient metabolism of dietary energy and nutrients. The conclusions to be drawn on the results of this study agree essentially with those reported by Payne and Lewis (1964), Farrell et al. (1973), and Farrell (1974), in that there appears to be an optimum energy concentration in the diet beyond which performance of birds does not appear to improve and in some cases actually deteriorates. Payne and Lewis (1964) found that growth rate of broiler chickens did not increase at energy levels above 3.1 Mcal ME/kg and calories consumed per gram of gain were the same for diets above 3.2 Mcal ME/kg.

3.3 The Effect of Added Cellulose on the Performance of Broiler Chicks

3.3.1

<u>Experiment 3</u> -   <u>Introduction</u>

The domestic chicken has limited digestive capacity for fibrous foods.
Cellulose has been used frequently as an inert filler in many poultry experimen-
tal diets. In addition to increasing the bulk of food, cellulose is known
to accelerate the rate of passage which means a shortened time for sub-
strate-enzyme contact and a consequent reduction in digestion of food
and absorption of nutrients. The presence and level of added cellulose
in poultry diets, therefore, imposes a very important problem that has
not been investigated sufficiently. The results of Experiment 2 justify
an assumption that the presence of cellulose must have contributed to
the poorer metabolisability of the diets which included that ingredient
as compared with those devoid of added cellulose in the early life of the
chicken. Unfortunately, most of the papers published on metabolisability
of diets incorporating added cellulose have involved chicks which were
older than one week.

The paucity of information as indicated above prompted the following
experiment to be conducted with the objective of evaluating the effect
of added cellulose on growth rate, food conversion efficiency, metabol-
isability of energy and fat deposition.

3.3.2

Experiment 3   -   Materials and Methods

Day-old broiler chicks were randomly distributed into 12 groups of six chicks each. All groups were placed in a six-tier battery brooder equipped with wire floors and thermostatically-controlled heating units. The groups were assigned at random to four experimental treatments, three groups per treatment. The treatments were four diets designated, respectively, as diets 1, 2, 3 and 4. The composition of the diets are shown in Table 9. Diets 1 and 3 were devoid of added cellulose while 2 and 4 each contained 11.2 parts added cellulose Diets 1 and 2 differed from diets 3 and 4 in containing corn starch as the source of supplementary energy. The latter contained corn oil as the source of supplementary energy.

Each group of chickens was fed its experimental diet and water ad libitum for six weeks. Records were kept of weekly food consumption and individual body weights. Food conversion efficiency values were computed from the weekly food consumption and body weight gain data. Samples of excreta were collected at 24-hour intervals on the last three days of each experimental week. The daily collections were immediately frozen and the three-day collections for each group were pooled together, lyophilized, finely ground and kept in screw-capped glass jars for various analyses.

Moisture was determined according to A.O.A.C. method. Determination of nitrogen content of the diet and faecal samples was conducted by the Kjeldahl method and gross energy by bomb calorimetry using Parr plain jacket oxygen bomb calorimeter. The substance used as an index for

Table 9.　Composition of diets fed in Experiment 3.

| | | D I E T | | |
Ingredient	1	2	3	4
		weight		
Herring meal	21.3	21.3	21.3	21.3
Ground wheat	53.0	53.0	53.0	53.0
Corn starch	19.2	19.2	-	-
Corn oil	3.0	3.0	11.0	11.0
Calcium phosphate	1.5	1.5	1.5	1.5
Limestone	1.0	1.0	1.0	1.0
Salt	0.5	0.5	0.5	0.5
Premix[1]	0.5	0.5	0.5	0.5
Cellulose	-	11.2	-	11.2
Total weight	100.0	111.2	88.8	100.0
Calculated chemical analysis		%		
Protein	21.9	19.8	24.7	21.9
ME (kcal/kg)	3382	3046	3814	3385
ME:CP	154	154	154	154

[1]Micronutrients as in Table 1.

digestibility coefficient was 4N HCl insoluble ash. The method used is essentially the one described by Vogtmann et al. (1975). For food and excreta, approximately 10 and 5 grams respectively of dry samples were used. The samples were hydrolysed by means of boiling in 100 ml of 4N HCl for 30 minutes. The hydrolysates were filtered through ashless filter paper, and washed with distilled water until free of acid (final drops of filtrate tested with litmus paper). The filter papers with the hydrolysates were ashed at 600°C for a minimum of six hours.

The metabolisable energy values corrected to nitrogen equilibrium were determined using the following equation:

$$MEd = CEd - CEe \times \frac{Ad}{Ae} - 8.22 (Nd - Ne \times \frac{Ad}{Ae})$$

where,

MEd = Metabolisable energy in kilo-calories per gram of diet

CEd = Combustible energy per gram of diet

CEe = Combustible energy per gram of excreta

Ad = Ash per gram of diet

Ae = Ash per gram of excreta

Nd = Nitrogen per gram of excreta

8.22 = Combustible energy of uric acid (kcal/g of N)

The data were analysed statistically using the analysis of variance and the Student-Newman-Keuls multiple range tests were used to test means which are significantly different.

This experiment was originally designed to last three weeks but it was continued to six weeks before it was terminated. This necessitated the mixing of a second batch of diets at four weeks for the extended period of time.

3.3.3

Experiment 3   -   Results

A summary of the effect of the dietary treatments on total body
weight gain is presented in Table 10. Average body weight gain obtained
with the low-fat cellulose-added diet was significantly lower than that
obtained with the high-fat cellulose-excluded diet. On the basis of
source of dietary energy, higher total body weight gains were obtained
with the fat-based than with the starch-based diets. Within the set
relating to energy source, higher body weight gains were obtained with
the diets which did not incorporate cellulose. When the data on body
weight gain were analysed on weekly basis (Table 11), it was shown that
the birds fed the diets without added cellulose were generally slightly
heavier than those fed the diets incorporating added cellulose. The
progressive increases in body weight gain on the "cellulose-free" diets
were reflected in significant differences in mean weekly body weight gains
among the dietary groups in the third and sixth weeks of the experimental
period. Fig. 3 shows the trend of growth among the different dietary
groups.

The addition of fat resulted in improved efficiency of food conversion
in the first three weeks. Birds fed the diets incorporating added cel-
lulose made poorer conversion of food. The poorest food conversion
efficiency values were obtained consistently with the birds fed the low-
fat cellulose-included diet (Table 12). The relationship existing among
the determined food conversion efficiency values as plotted against each
weekly period of time is markedly altered when the adjusted food conver-
sion efficiency values are similarly plotted. As shown in Fig. 4, the

Table 10. Effect of source of supplementary dietary energy and cellulose on total body weight gain.

	D I E T			Mean body weight[1] in grams		
No.	Starch	Fat	Cellulose	Initial	Final	Gain
1	+[2]	Basal	-[2]	33	1227	1194ab
2	+	Basal	+	33	1170	1137b
3	-	+	-	32	1327	1295a
4	-	+	+	32	1286	1254ab

[1]Means within a column followed by different letters are significantly different (P $\leq$ 0.05).

[2](+), (-), signifies present, absent, respectively.

Table 11. <u>Effect of source of supplementary dietary energy and cellulose on weekly body weight gains</u>.

D I E T					Mean[1] body weight gains in grams					
No.	Starch	Fat	Cellulose	Initial	Weeks					
					1	2	3	4	5	6
1	+[2]	Basal	-[2]	(33)	55a	138a	203ab	233a	261a	306ab
2	+	Basal	+	(33)	55a	127a	188b	229a	272a	267b
3	-	+	-	(32)	61a	135a	221a	252a	295a	331a
4	-	+	+	(32)	64a	139a	221a	240a	292a	297ab

[1]Means in a column followed by different letters are significantly different ($P \leq 0.05$).

[2](+), (-), signifies, present, absent, respectively.
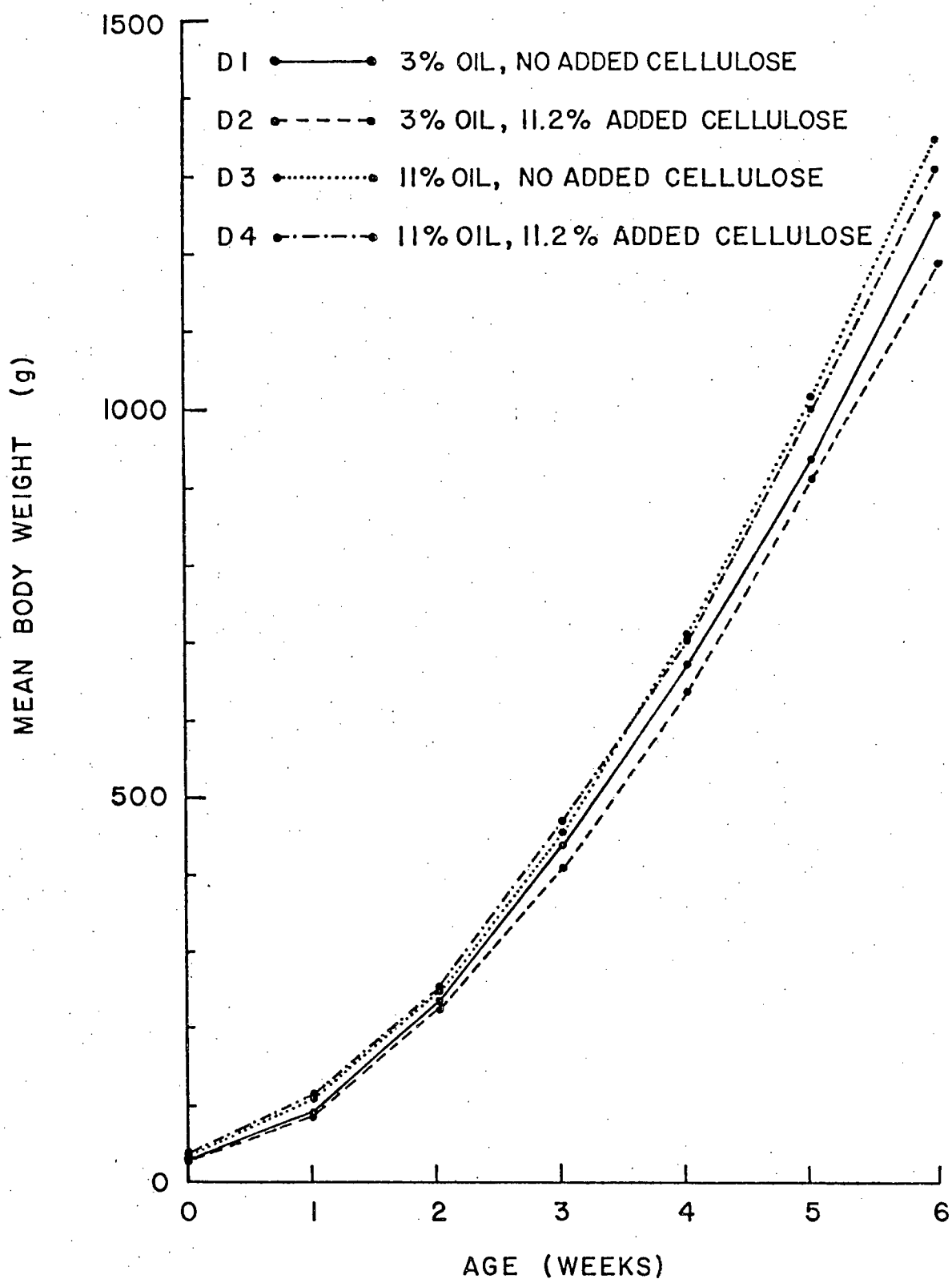
FIG.3: EFFECT OF SOURCE OF SUPPLEMENTARY DIETARY ENERGY AND CELLULOSE ON FOOD CONVERSION EFFICIECY.

differences among the treatment groups are virtually eliminated or non-existent in the adjusted values as compared to the determined food conversion efficiency values (Table 12a).

The results of the determinations of metabolisable energy values are presented in Table 13. Severe depression of metabolisability of energy was observed with the diets incorporating cellulose. The greatest depression occurred in the first week. For the first three weeks the metabolisable energy values were progressively higher for all diets. The introduction of a second mix of diet was attended with a decrease in metabolisable energy values in the fourth week. There was a rise in metabolisability of energy in the subsequent weeks.

A comparison between the determined metabolisable energy values (Table 13) and the corresponding adjusted metabolisable energy values (Table 14), shows clearly the effect of the added cellulose on the effic-iency of energy metabolism. The relationship existing among the deter-mined values is compared to that existing among the adjusted values (Fig. 5).

The mean adipose tissue weights are presented in Table 15. The dietary source of energy appeared to have no influence on fat deposition in this experiment. Although the birds fed diets with fat as the major source of energy laid down more fat than those fed diets with carbohydrate as the major source of energy, this difference becomes negligible when the values are compared on the basis of cellulose level. The birds which were fed diets which did not contain added cellulose had the heavier adipose tissue than those fed diets containing added cellulose.

Table 12. Effect of source of supplementary energy and cellulose on food conversion efficiency.

| | | | | Units[1] of food per unit of gain | | | | | | |
| | D I E T | | | Weeks | | | | | | |
No.	Starch	Fat	Cellulose	0-1	0-2	0-3	0-4	0-5	0-6	Overall
1	+	Basal	-	1.24	1.28	1.47	1.52	1.67	1.81	1.50 a
2	+	Basal	+2	1.50	1.55	1.61	1.74	1.90	2.01	1.72 c
3	-	+	-	1.18	1.23	1.24	1.36	1.50	1.58	1.35 b
4	-	+	+2	1.21	1.37	1.38	1.53	1.73	1.91	1.52 a

[1] Values within a column followed by the same letter do not differ significantly (P ≤ 0.05).

Table 12(a). Effect of source of supplementary dietary energy
component on food conversion efficiency calculated
on the basis of ingredients other than added cellulose.

| D I E T | | | | Adjusted units[1] of food per unit of gain | | | | | | |
| | | | | Weeks | | | | | | |
No.	Starch	Fat	Cellulose	0.1	0.2	0.3	0.4	0.5	0.6	Overall
1	+	Basal	-	1.24	1.28	1.47	1.52	1.67	1.81	1.50 a
2	+	Basal	+[2]	1.35	1.39	1.45	1.56	1.71	1.81	1.55 a
3	-	+	-	1.18	1.23	1.24	1.36	1.50	1.58	1.35 b
4	-	+	+[2]	1.07	1.22	1.23	1.37	1.54	1.71	1.36 b

[1] Values within a column followed by the same letter do not differ sig-
nificantly (P ≤ 0.05).

[2] The added cellulose was not used in calculation.

FIG. 4: EFFECT OF SOURCE OF SUPPLEMENTARY DIETARY ENERGY AND CELLULOSE ON FOOD CONVERSION EFFICIENCY.

Table 13. Effect of source of supplementary dietary energy and
cellulose on metabolisable energy values.

D I E T				Calories[1] per gram of diet				
No.	Starch	Fat	Cellulose	Weeks				
				1	2	3	4	6
1	+[2]	Basal[2]	-	3349	3652	3777	3608	3608 c
2	+	Basal	+	2966	3148	3444	3177	3264 a
3	-	+	-	3252	3867	3933	3651	3863 d
4	-	+	+	2591	3268	3556	2972	3349 a

[1]Means in a column followed by different letters are significantly
different ($P \leq 0.05$).

[2](+), (-), signifies present, absent, respectively.

Table 14. Effect of dietary source of supplementary dietary energy on metabolisable energy values calculated on the basis of ingredients other than added cellulose.

| | D I E T | | | Adjusted energy values[1] in calories/g of diet Weeks | | | | | |
No.	Starch	Fat	Cellulose	1	2	3	4	6	overall
1	+[2]	Basal	-[2]	3349	3652	3777	3608	3608	3596a
2	+	Basal	+	3298	3500	3830	3532	3630	3558a
3	-	+	-	3252	3867	3933	3651	3863	3713b
4	-	+	+	2917	3680	4004	3346	3771	3544a

[1]Means in a column followed by different letters are significantly different ($P \leq 0.05$).
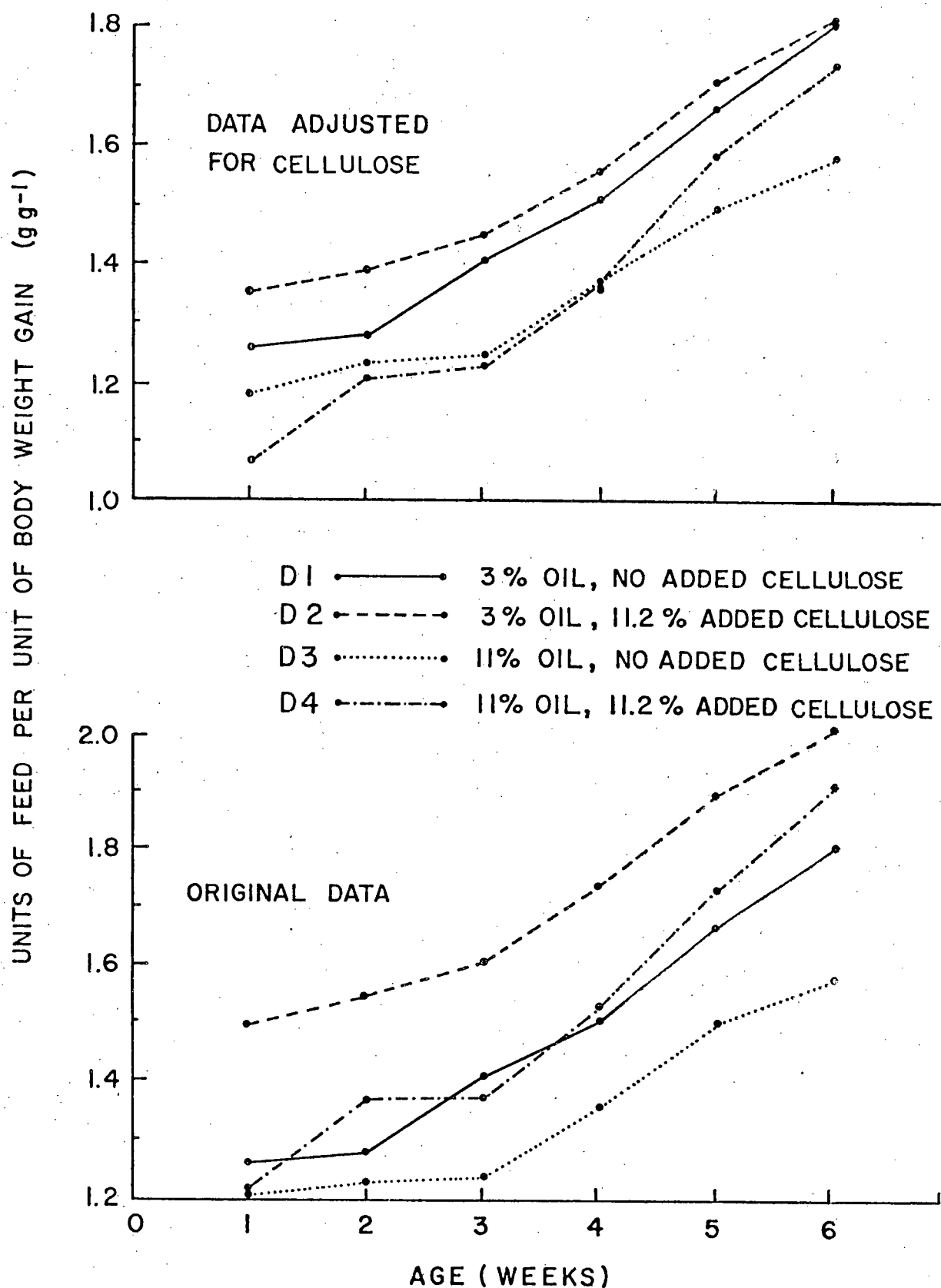
[2](+), (-), signifies present, absent, respectively.
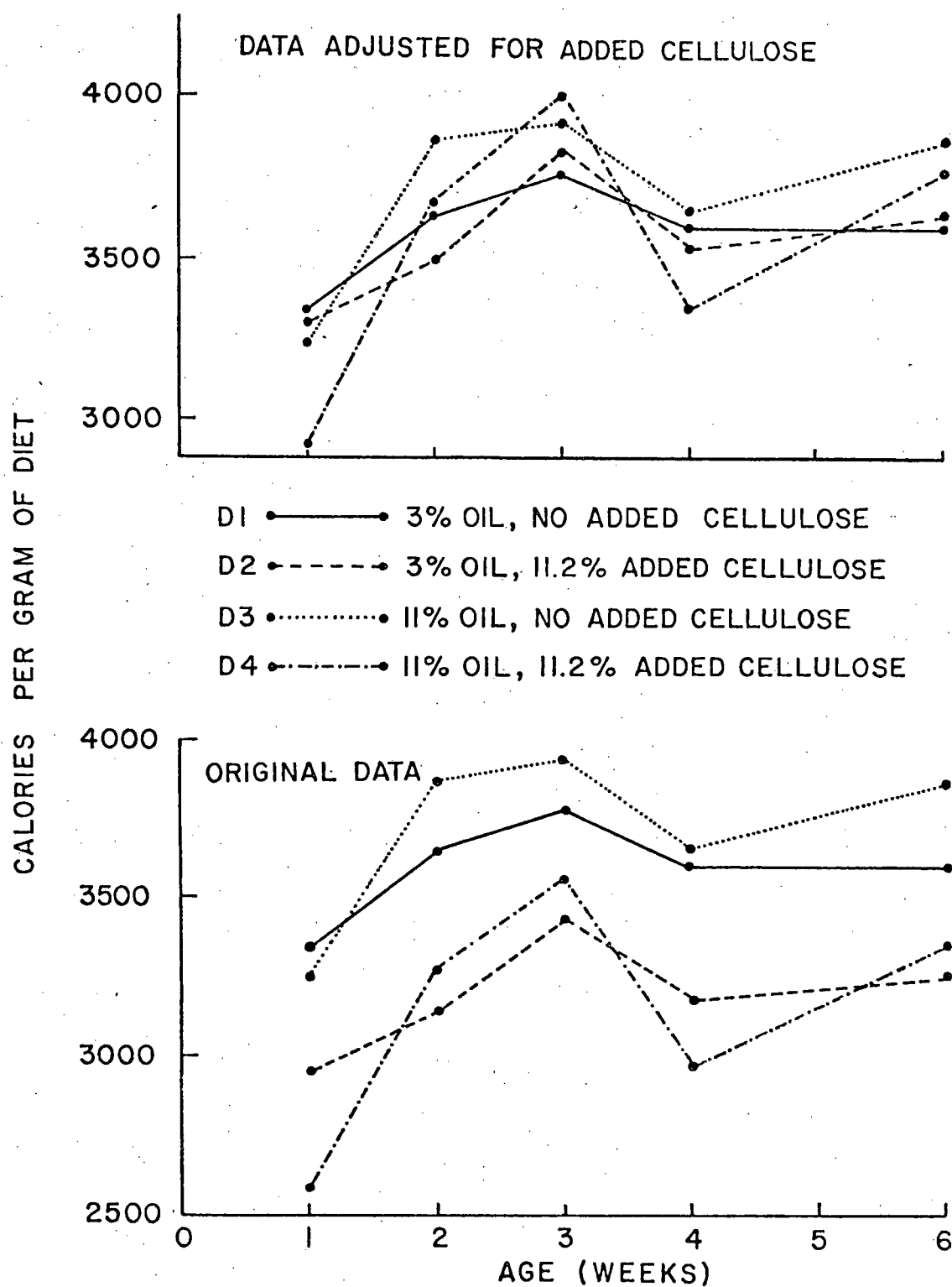
FIG.5 : EFFECT OF SOURCE OF SUPPLEMENTARY DIETARY ENERGY
AND CELLULOSE ON FOOD CONVERSION EFFICIENCY.

Table 15. Effect of source of supplementary dietary energy and cellulose on final (six-week) adipose tissue weights.

| D I E T | | | Grams of mean abdominal fat (six-week) |
No.	Starch	Fat	Cellulose	
1	$+$[2]	Basal	$-$[2]	25.72 ± 2.72[1]
2	$+$	Basal	$+$	18.33 ± 1.95
3	$-$	$+$	$-$	31.79 ± 4.55
4	$-$	$+$	$+$	19.68 ± 2.89

[1]Standard error of the mean.

[2](+), (-), signifies present, absent, respectively.

3.3.4

<u>Experiment 3</u>   -   <u>Discussion</u>

The higher body weight gains of chickens fed diets devoid of added cellulose in comparison to those fed diets incorporating added cellulose indicate that 11 percent added cellulose has adverse effects on body weight gain (Table 10). This finding is in accord with a large body of evidence in the literature. However, it is at variance with those of Morris <u>et al</u>. (1932), Davis and Briggs (1947, 1948), and Saito <u>et al</u>. (1959), that feeding moderate amounts of fibrous materials may increase growth and improve the utilisation of food above that obtained on the low fibre basal diet. The significant difference in total body weight gain between the chickens fed the high-fat cellulose-excluded diet and those fed the low-fat (carbohydrate-based), cellulose-added diet, appears to confirm in principle the statement made by Begin (1961) that the major effect of cellulose when included in the diet without supplementary energy was a depression in growth. This appears to suggest that diets high in fibrous ingredients should contain a high proportion of energy which could be utilised for growth or production. Corn oil is superior to starch in that it contains the much-needed fatty acids while starch does not. Therefore chickens fed the corn oil-rich diets had the advantage of utilising the energy which would have been expended in fatty acid biosynthesis for growth. Hence, increase in body weight of birds which were fed the fat-based cellulose-included diet over those fed the starch-based cellulose-included diet, is understandable. The data on food conversion efficiency (Table 12) are in line with the concept as mentioned earlier that the addition of high levels of fibrous ingredients to chicken diets depresses the

efficiency of food utilisation. The evidence shows that within the series relating to the source of dietary energy, the birds fed the diets incorporating added cellulose utilised more food for a unit of body weight gain in comparison with those fed the diets containing no added cellulose. The fact that the differences existed between the two mean weekly values within the starch-based or fat-based series, becomes markedly reduced or practically non-existent (Table 12a) when the values are calculated to remove the effects attributable to the added cellulose, demonstrates the influence of added cellulose (Fig. 4).

The mucosa of the gastrointestinal tract acts as a barrier against the entry into the body of large molecules, which, if absorbed, are not well utilised (White et al., 1973). Hallsworth and Coates (1962) reported that high fibre diets caused greater destruction of mucosal cells. This action may explain the observed severe depression of metabolisability of energy obtained with birds fed the diets incorporating added cellulose. As shown by Fig. 5, the reduction in magnitude or elimination of significant differences between the observed (Table 13) and the adjusted (Table 14) mean metabolisable energy values, provides additional support for the view that, at higher dietary levels added dietary cellulose depressed metabolisability of energy. This finding is contrary to those of Sibbald and Slinger (1960), Potter et al. (1960), and Begin (1961) who reported cellulose to be inert in respect of its effect on metabolisable energy values.

That added dietary cellulose has a depressing effect on adipose tissue deposition is shown by the data presented in Table 15. A possible explanation for the observed higher values of mean adipose tissue weight

obtained with birds fed diets devoid of added cellulose within the series relating to supplementary energy source, appears to be a possible lowered energy intake. Halnan (1930), Robertson et al. (1948), and Wells (1963) attributed a similar observation to the imposition of physical limitation on the intake of digestible nutrients.

3.4 The Effect of Residual Yolk on the Performance of Chicks

3.4.1   Experiments 4 and 5

3.4.1.1   Introduction

There is a wide variation among metabolisable energy values assayed
with chicks up to three weeks of age. Sibbald et al. (1960) considered
the influence of age on the metabolisable energy value of corn to be
small and negligible for practical purposes. Bayley et al. (1974)
reported the metabolisable energy values of ten samples of rapeseed meal
determined with both chicks and mature roosters to be equal.

On the other hand, there are reports that indicate that the metab-
olisable energy values for some feed ingredients and diets are higher
for mature birds than for chicks (Baldini, 1961; Young, 1961; Carew
et al., 1963; Zelenka, 1968; Lodhi et al., 1969; March et al., 1973).
An attractive theory used to explain the discrepancy among reported
metabolisable energy values of diets determined with chicks is the one
implicating the residual yolk. Available evidence indicates that absorp-
tion of the yolk sac continues until about the 14th day in the life of
the chick (Zelenka, 1968). Sibbald and Slinger (1963) suggested that
the residual yolk might furnish the chick with a significant supply of
nutrients for periods up to 10 days post-hatching. A significant supply
of nutrients from the residual yolk would indicate that the metabolisable
energy values determined during this period would be influenced in accor-
dance with the magnitude of contribution of nutrients by the residual
yolk. Zelenka (1968) tested this hypothesis and published results that
indicate changes in the metabolisable energy values of diets within the

first 14 days of the chick's life.

As the efficiency of utilisation of metabolisable energy is the prime concern of this phase of the study, two experiments were conducted to investigate the effect of residual yolk on the metabolisable energy values of a practical diet and on the survival of chickens.

3.4.1

<u>Experiment 4</u>   -   <u>Materials and Methods</u>

Day-old broilers were distributed at random into three groups of twelve chicks each according to treatments which were control, sham-operated and surgically-altered. The sham-operated chicks had their yolk sacs brought outside the body cavities, manipulated and returned to position intact while the surgically-altered chicks had their yolk sacs ablated through the following technique. Approximately 0.2 ml of pento-barbitone (nembutal at a concentration of 60 mg/ml) was injected intra-venously into each chick. The anaesthetized chick was placed back downwards with the vent towards the operated and was fastened to an oper-ating board by its legs and wings with elastic bands. After plucking the down on the abdomen, the chick was washed with an antiseptic solution. The yolk sac was reached through an incision made into the skin and the underlying muscles to the left of the centre line of the abdomen. The yolk sac was brought out with forceps and was ligated at the stalk before section. The yolk sacs of sham-operated chicks were brought out, handled and pushed back. The abdominal walls of both the yolk sac-ablated and sham-operated chicks were closed by cotton sutures each passing through the skin and the muscle layers. A topical antibiotic dressing was applied to the sutured area. The operated chicks were put in a battery brooder and no special treatment was necessary after complete recovery from the anaesthetic which lasted approximately two hours.

The three groups of intact and operated chicks were housed, accor-
ding to treatments, in electrically-heated, thermostatically-controlled
battery brooders with raised wire screen floors, in a well-ventilated,
temperature-controlled brooding room. One treatment group consisted of
two replicates of six chicks each. All were fed the same experimental
diet, the composition of which is shown in Table 16. Food and water
were provided ad libitum. Records were kept on body weight and food con-
sumption on weekly basis. Both food and excreta samples were analysed
for moisture, nitrogen and combustible energy according to methods as
described for Experiment 3.

Table 16. Composition of experimental diet - Experiment 4

Ingredients	Percent
Herring meal (72% CP; 3197 kcal ME/kg)	21.3
Ground wheat	53.0
Corn starch	19.2
Corn oil	3.0
Limestone	1.0
Calcium phosphate	1.5
Premix[1]	0.5
Iodized salt	0.5

[1]Microingredients as described in Table 1.

3.4.2

Experiment 4   -   Results

For the period of 1-21 days posthatching, there were no significant differences in body weight gains between the treatment groups. Table 17 shows that in the first week the chicks without yolk sacs gained slightly more weight than both chicks in the control and the sham-operated groups but this feature was not shown in the second week. The final body weights do not show any significant differences between treatment groups. Fig. 6 gives the graphical representation of the trends in growth rate.

There was a significant difference in the overall efficiency of food conversion between the control and sham-operated groups on the one hand and the group with yolk sacs removed on the other (Table 18). Throughout the experimental period, the chicks without residual yolk utilized more food per unit gain in body weight than either the control or the sham-operated chicks. Fig. 7 shows the trends relating to efficiency of food utilisation that existed among the three treatment groups. Data on the effect of treatment on the metabolisable energy values of the diet are presented in Table 19. The treatments employed had no apparent effect on metabolisability of the diet. The slightly higher metabolisable energy values obtained with birds without residual yolks compared with those obtained with the sham-operated birds provides clear evidence that the surgery per se did not affect the chicks ability to metabolise energy.

An interesting point brought out by the data (Fig. 8). is the higher apparent retention value (2.53 g/100 g of diet) obtained with the birds without residual yolk compared to the 2.18 and 2.13 g/100 g

Table 17. Effect of residual yolk on weekly body weights and total body weight gain.

Treatment	Initial	1	2	3		Total Gain
Control	33a	89a	225a	426a	:	393a
Sham-operated	34a	90a	226a	437a	:	404a
Yolk sac removed	32a	93a	224a	427a	:	396a

Mean[1] body weight and weight gains (g); Weeks

[1]Means within a column followed by the same letter do not differ significantly (P ≤ 0.05).
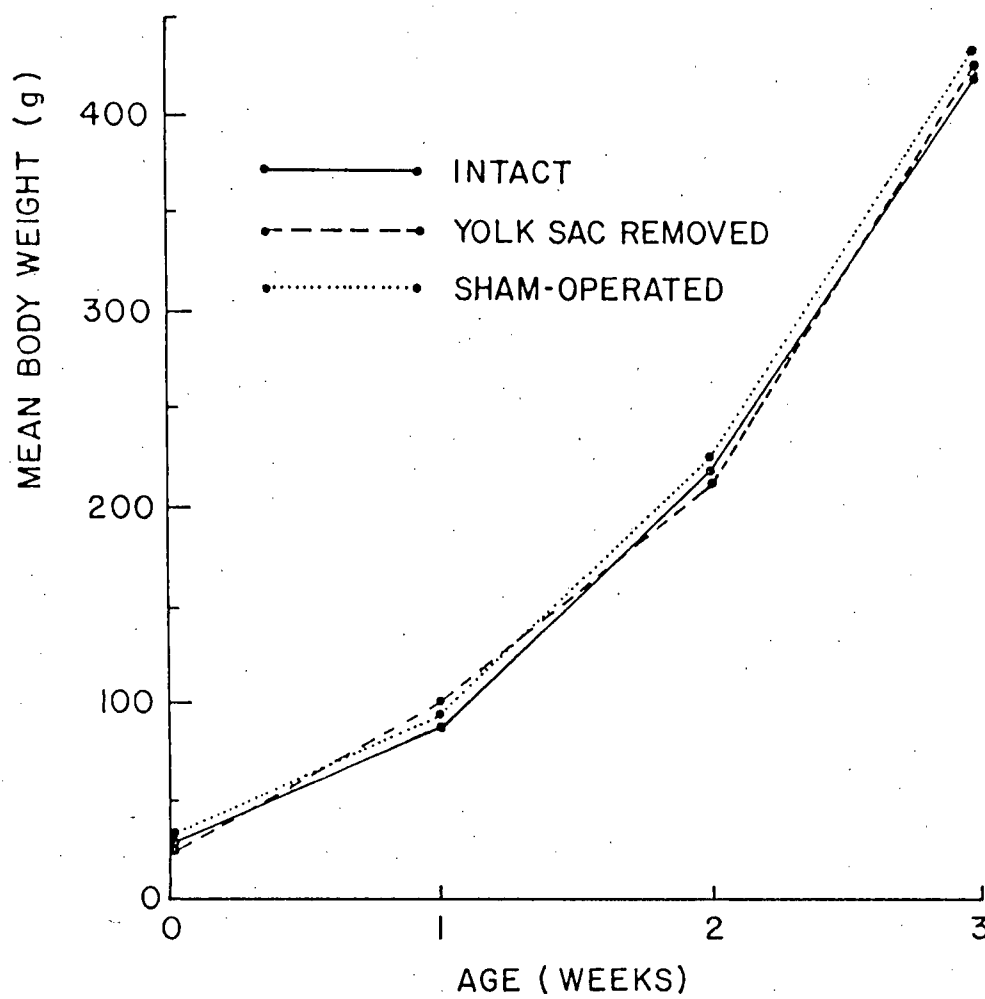
FIG. 6 : EFFECT OF RESIDUAL YOLK SAC ON TOTAL BODY WEIGHT.

Table 18. Effect of residual yolk on food conversion efficiency.

Treatment	Units[1] of food per unit of body weight gain			
	Weeks			
	1	2	3	Overall
Control	1.24a	1.28a	1.47a	1.33a
Sham-operated	1.18a	1.31a	1.40a	1.29a
Yolk sac removed	1.37a	1.49b	1.54a	1.46b

[1]Values followed by different letters are significantly different

(P ≤ 0.05).
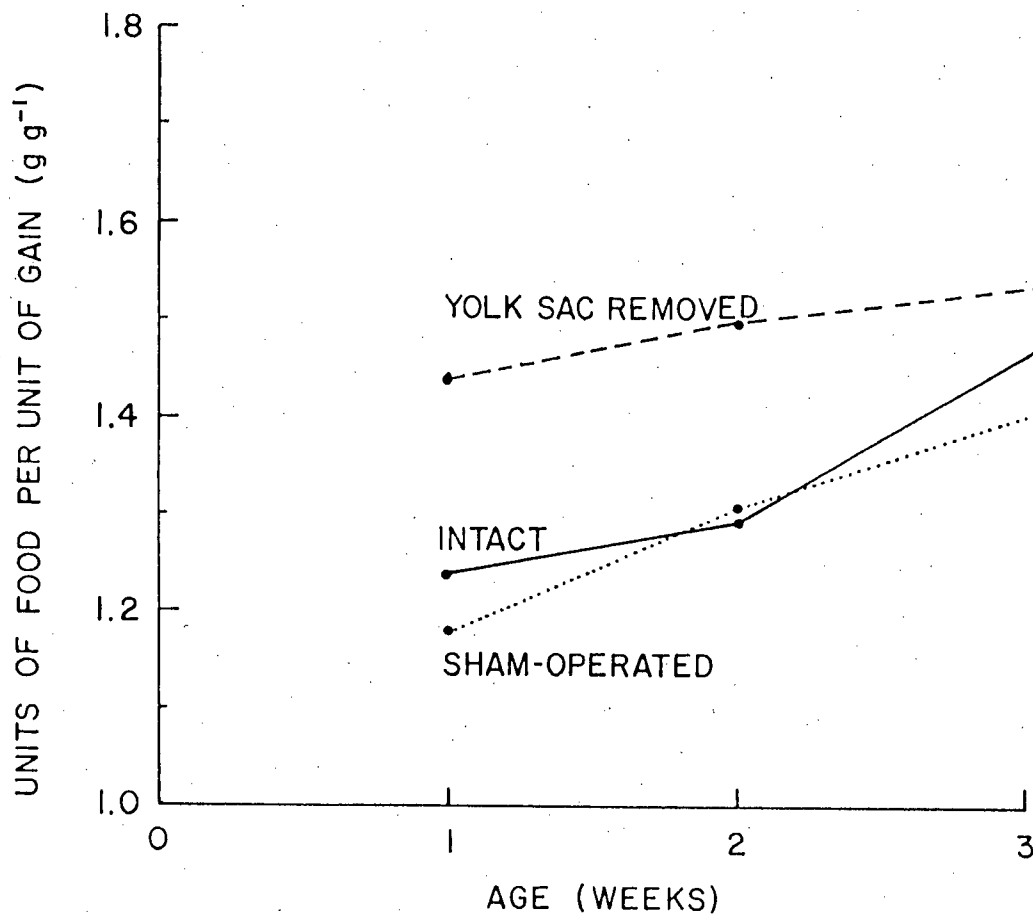
FIG. 7: EFFECT OF RESIDUAL YOLK ON CUMULATIVE FOOD CONVERSION EFFICIENCY.

Table 19. Effect of residual yolk on metabolisable energy values.

Treatment	Mean[1] ME[2] values (kcal/kg)		
	Weeks		
	1	2	3
Control	3402a	3673a	3788a
Sham-operated	3348a	3625a	3776a
Yolk sac removed	3396a	3635a	3776a

[1]Means within a column followed by the same letter are not significantly different (P ≤ 0.05).

[2]ME : Metabolisable energy.

with the sham-operated birds provides clear evidence that the surgery _per se_ did not affect the chicks ability to metabolise energy.

An interesting point brought out by the data on apparent nitrogen retention is the higher apparent retention value (2.53 g/100 g of diet) obtained with the birds without residual yolk compared to the 2.18 and 2.13 g/100 g obtained with the intact and the sham-operated birds, respectively, in the first week and the dramatic drop to practically the same level (2.39 g/100 g of diet) as that of the sham-operated birds in the second week (Fig. 8). The value for the birds without residual yolks rose as sharply as it had dipped reaching a level of 2.68 g/100 g of diet, the highest of the three values in the third week. Both the intact and the sham-operated birds showed a gradual rise in apparent nitrogen retention from the second week and by the third week, both groups had reached the same level of apparent nitrogen retention.
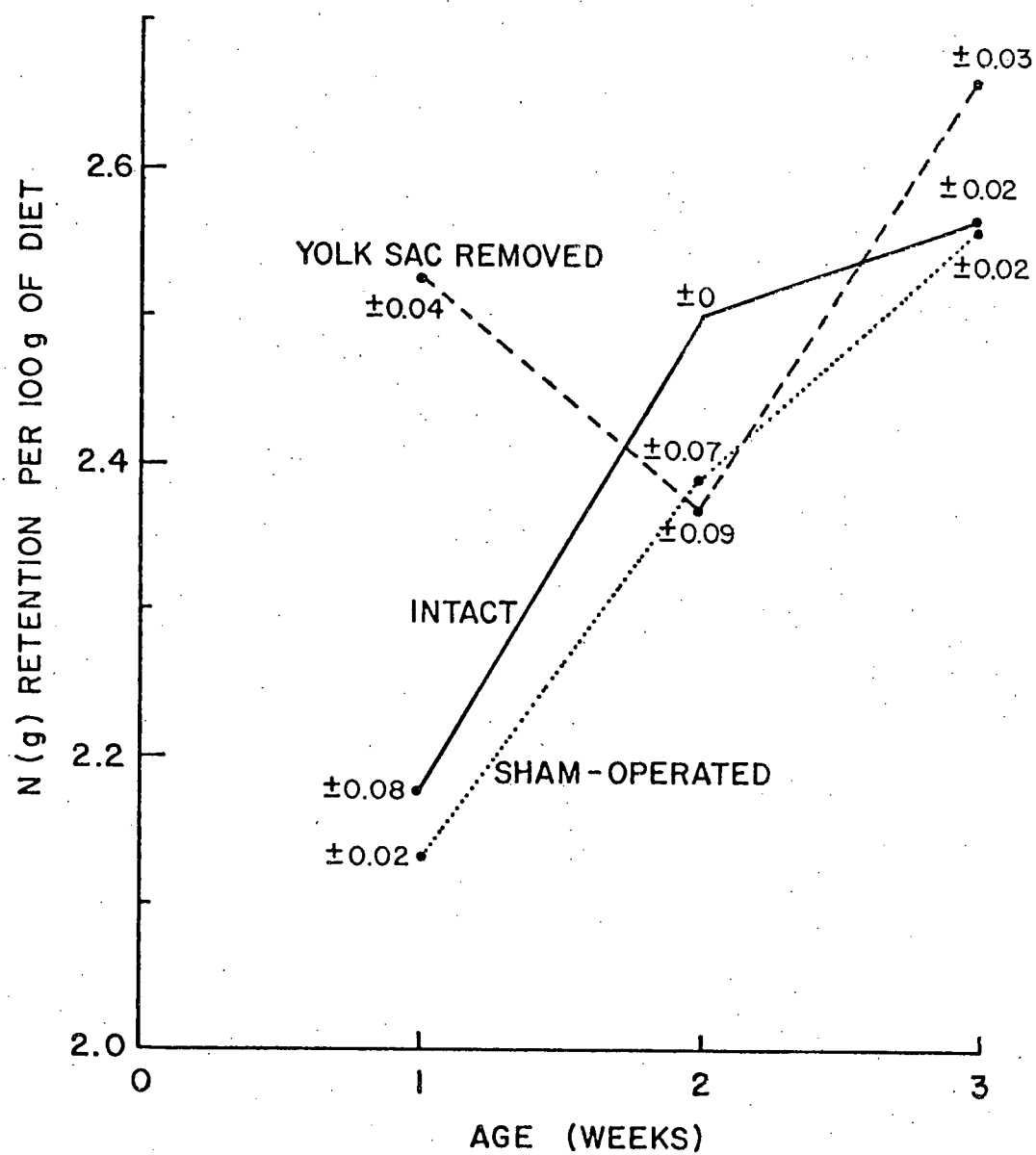
FIG. 8 : EFFECT OF RESIDUAL YOLK ON APPARENT NITROGEN RETENTION.

3.4.3

Experiment 4   -   Discussion

The data on body weight gain reported here (Table 17) indicate clearly that residual yolk has no effect on the growth rate of chickens to 21 days of age. Since the higher mean body weight gain of the chicks without yolk sacs did not differ significantly from the mean body weight gains of the other treatments in the first week and since the lead in weight gain was lost in subsequent weeks, further discussion on this observation does not appear warranted. The lack of significant differences in mean overall body weight gain justifies the above conclusion. The closeness of the mean body weight values of each of the three treatment groups is illustrated in Fig. 6. Residual yolk appears to have effect on the efficiency of food conversion as demonstrated by the consistently poorer food conversion values obtained with birds without residual yolks and the consistent lack of significant differences between the intact and the sham-operated birds, the yolk sacs of which groups were not removed. It is surprising that the differences in food conversion efficiency among the treatment groups in the first week did not reach the five percent statistical significance level. There is no obvious explanation for the better food conversion efficiency values obtained with the sham-operated chickens over those of the intact groups. However, it appears the surgical treatment must have stimulated some growth in the first week. Evidence to support this suggestion is provided by the fact that the birds which had undergone surgical treatment gained a slightly higher average weight than the intact birds (Table 17).

This stimulated growth which can logically be expected to be compensatory in nature must have been accompanied by a rapid turnover of nutrients in the first week. The sham-operated, without loss of tissue compared to those with yolk sacs removed, under such stimulation may have utilised food more efficiently. A similar response could have been shown by the birds with yolk sacs removed but the loss of tissue would militate against achieving the same ratio obtained by the sham-operated group. The narrowing of the gap in food conversion ratios between the birds with yolk sacs removed and the intact birds (Fig. 7) appears to indicate a trend towards "normalisation" of physiological processes.

The observed higher apparent nitrogen retention value (Fig. 8) obtained with the group of chicks without residual yolks and which also had the highest body weight gain in the first week is consistent with the fact that there is a positive correlation between rapid growth rate and nitrogen retention. The difference in the apparent nitrogen retention between the intact birds and those with yolk sacs removed could probably be explained on the following basis. There is evidence that although the yolk sac is connected directly with the intestine, there is little or no movement of material via this route even after hatching and that the residual yolk is absorbed through the yolk sac membrane and transported to the tissues by the omphalomesenteric vessels (Fritz, 1961). The residual yolk is rapidly utilised by the bird within five days (Freeman, 1965). In the absence of information on the utilisation of nutrients derivable from the residual yolk qualitatively and quantitatively, the possibility should be considered that the end-products may

be highly nitrogenous in nature and this could add to the normal nitrogenous excretion to bring down the value of apparent nitrogen retention.

Zelenka (1968) found the metabolisable energy values of the diet to increase rapidly during the first days after hatching, stabilise about one week of age and increase again until two weeks of age; a finding which the data of this experiment (Table 19) would generally tend to support. However, it does not agree with the observation of Sibbald et al. (1960) who, after a series of experiments designed to provide further information on the age of birds on metabolisable energy values of corn, concluded that there were no significant differences between ages (2 weeks to 16 months) within diets and suggested that if age differences exist, they are negligible for all practical purposes. It is worthy of note that their determinations did not cover the metabolisable energy values for one week post-hatching. Removal at hatching of the residual yolk did not have any significant effect on the chicks ability to metabolize energy, an important observation in view of the fact that discrepancies in metabolisable energy values in the first seven to ten days post-hatching have been explained on the assumption that the residual yolk supplies nutrients in amounts significant enough to affect metabolisable energy values (Sibbald and Slinger, 1963; and Zelenka, 1968).

3.5 Effect of Residual Yolk on Survival of Chicks

3.5.1

Experiment 5   -   Introduction

The purpose of this experiment was to test the hypothesis that the residual yolk furnishes chicks with a significant amount of nutrients for a period as much as 10 days after hatching. If this assumption were true, chicks whose yolk sacs had been removed within a day of hatching and without access to food, would be expected to die in a significantly shorter time as compared to those with intact yolk sacs but also deprived food.

3.5.2

Materials and Methods

The experimental procedure was the same as in Experiment 4. The only differences were that White Leghorn males were used and that the chicks were not fed throughout the test which lasted eight days. All the chicks had access to water at all times.

3.5.3

Results

Table 20 summarizes the results of the effect of yolk sac on the livability of starved chicks. There was no mortality in the intact control group in the first five days of the experimental period. Two-thirds of the control group died on the seventh day. The rest died on the eighth day. Most of the mortality among the sham-operated group occurred on the sixth day when 23 out of a total of 32 died. The longest period reached by chicks for this group was 8 days as it occurred in the

Table 20. Effect of yolk sac on the survival of chicks.

Treatment[1]		Days mortality occurred							
		1	2	3	4	5	6	7	8
Control	no. of birds	-	-	-	-	-	3	16	5
Sham-operated	no. of birds	-	-	-	1	2	23	5	1
Yolk sac removed	no. of birds	2	2	2	-	3	17	2	-

[1]Total number of chicks on each treatment:

    Control - 24
    Sham-operated - 32
    Yolk sac removed - 28

case of the control chicks. With the exception of the fourth day, mortality occurred on each day for the seven days that was the duration for the group without yolk sacs. Seventeen of the total of 28 chicks without yolk sacs died on the sixth day.

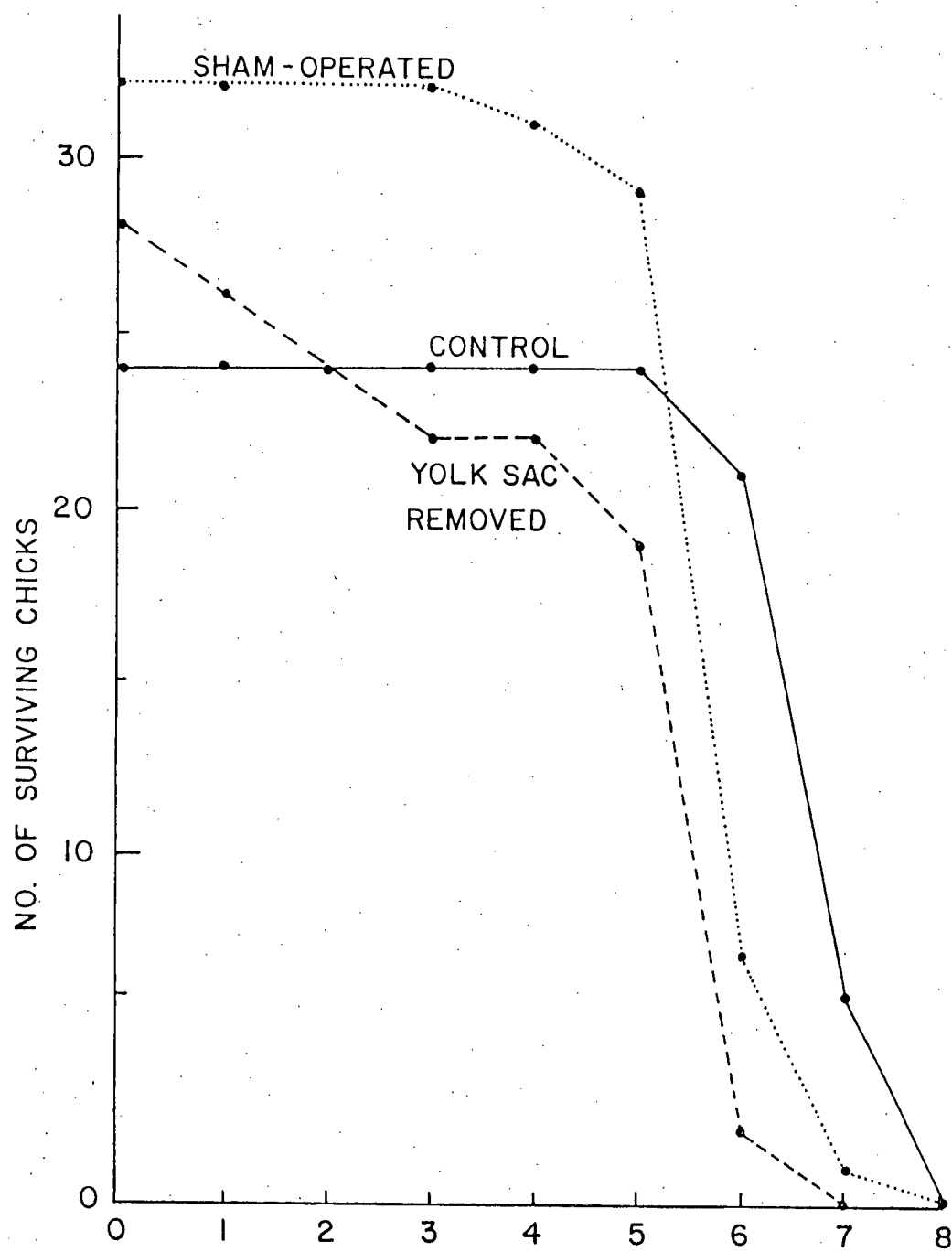Fig. 9 represents the trend of mortality among the three treatment groups.

FIG. 9: EFFECT OF RESIDUAL YOLK ON THE LIVABILITY
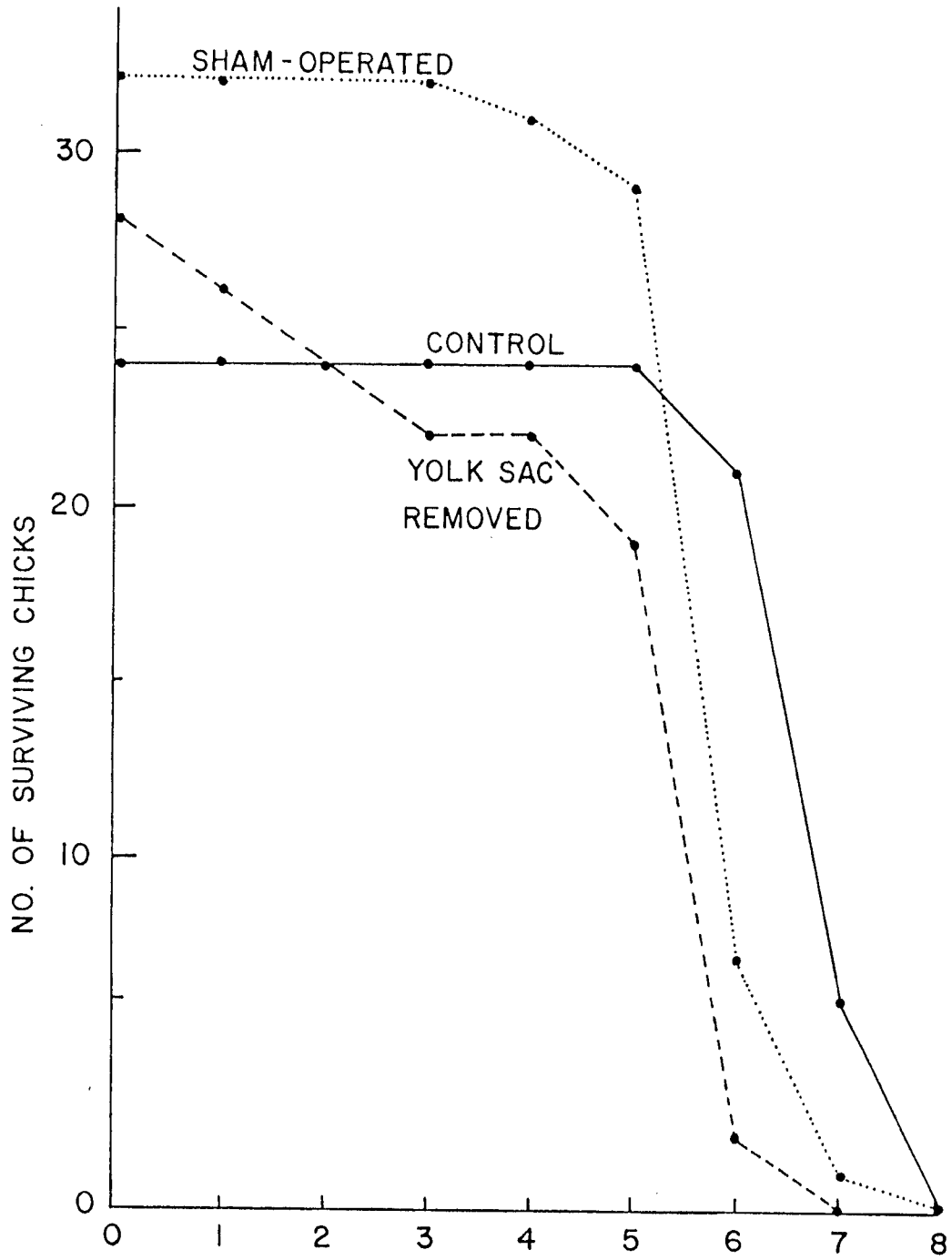OF STARVED CHICKS.

FIG. 9: EFFECT OF RESIDUAL YOLK ON THE LIVABILITY OF STARVED CHICKS.

3.5.4

Experiment 4   -   Discussion

The observation that mortality was severest on the sixth and seventh days for the surgically-manipulated and the intact birds respectively argues against a major role for the residual yolk in supplying significant amounts of nutrients in the first few days after hatching. The observed heaviest mortality occurring on the same day (the fifth day) for the surgically-altered birds (Fig. 9) might be associated with the effect of surgery. It is difficult to reconcile the finding in the present paper that residual yolk does not furnish chicks with a significant amount of nutrients during the first week after hatching to the observation of Zelenka (1968) that by the fifth day post-hatching the yolk sac had lost 13.1 kcal representing about 85 percent of its 15.4 kcal of energy at hatch. The concept that the residual yolk supplies significant amounts of nutrients during the early days has been based upon an observed fluctuation in metabolisable energy values in the first week. Interpretation of results of studies on nutrient utilisation in the newly-hatched chick has to take into account the fact that at hatch the chicks ability to digest food is not fully developed and that subsequent development of the ability to digest food and absorb nutrients is largely accountable for the rise and stabilisation of nutrient utilisation from the second week onwards.

3. PART 2 THE AVIAN CAECA AND EFFICIENCY OF UTILISATION OF

DIETARY ENERGY AND PROTEIN

3.6 The Role of the Caeca in Energy and Protein Metabolism

3.6.1

Experiment 6   -   Introduction

The presence of a large bacterial population in the avian caeca and extrapolation of the features associated with bacteria-host symbiosis in ruminants and other animals to the domestic chicken continue to prompt sporadic investigations into the role of the avian caeca in the utilisation of dietary nutrients. These investigations have failed to establish a characteristic function for the caeca of the domestic chicken. There is stronger evidence to support the hypothesis of cellulolytic or proteolytic functions for wild birds than there is for domestic chickens. Recent studies by Thompson and Boag (1975) of the utilisation of dietary energy by intact and caecectomized Japanese quail showed that the caeca contributed 5.7% of the daily energy requirement. In a previous study, Fenna and Boag (1974) concluded that the major function of the caeca is to retain nutrient-rich ingesta for further digestion and absorption while allowing the bulkier cellulose material to be excreted more rapidly from the gut.

The theory which suggests that microorganisms in the caeca of the domestic chicken are a source of cellulolytic enzymes which would enable the chicken to obtain some nutritional value from dietary fibre (Nitsan and Alumot, 1963; Thornburn and Willcox, 1964) has not gained wide

acceptance. McNab (1973) doubts whether such a process, if it occurs, would be of any nutritional significance to the chicken. Nitsan and Alumot (1963) reported that caecal proteolysis compensated in some degree for inhibited proteolysis in the small intestine when raw soybean meal was fed to intact and caecectomized birds. There was no difference, however, in nitrogen utilisation when heated soybean meal was fed. Caecectomy did not appear to affect the nitrogen excreted in the experiments of Nitsan and Alumot (1963). Barnes and Impey (1972, 1974) have reported that many different types of caecal anaerobes are capable of breaking down uric acid. What this may have on the nitrogen economy of the bird is unknown.

The absence of a well-established function for the caeca of the domestic chicken underlines the need for research in this area as it is absurd, from the teleological viewpoint, for the domestic chicken to possess an organ of this size that has no characteristic function. This view supports Mattocks' (1971) contention that selection pressure against possession of an organ with no function might be expected to cause the organ's extinction and that an organ with a blind end such as the caecum would be particularly susceptible to parasitic invasion resulting in a fatal peritonitis.

The paucity of information as indicated above and the relevance of the concept of caeca-mediated nutrient utilisation to the topic under investigation prompted the following experiment using intact and caecectomized chickens to investigate the effect of the excision of the caeca on the utilisation of dietary energy and protein.

3.6.1

Experiment 6   -   Materials and Methods

Nine-week-old New Hampshire chickens each weighing approximately 800 g were caecectomized. Food was withdrawn from them at least 18 hours before the operation. The chicken was tied to the operation board with elastic straps so that its ventral part was up and toward the operator. Surgical anaesthesia was induced with pentobarbitol sodium (Nembutal) and ether. An average of 0.4 ml of Nembutal (60 mg/ml) was slowly injected into the wing vein until the chicken lost consciousness. The 18-gauge needle used was pointed toward the body and nearly parallel to the wing as it was inserted. The operation lasted about twenty minutes per chicken and in some cases the amount of Nembutal administered was inadequate for this length of time, therefore ether was used as a standby anaesthetic. A bottle containing ether-soaked cotton wool was placed around the head of the chicken for a few seconds until the chicken showed signs of sedation.

The caeca were reached through a 2.5 cm-long longitudinal incision made into a deplumed area (about 5 cm^2) of the skin and into the abdominal wall muscles in the left ventral-lateral (postventer) region 2.5 cm from the midline and 2.5 cm anterior to the vent. The peritoneum was torn with forceps and the distal portion of the intestine with the caeca was carefully brought outside the body cavity with a blunt probe whereupon the cervix of each caecum was ligated and held with a haemostat before excision was made with scissors at the ileo-colic junction leaving

a 5 mm stump for suturing. One caecum was excised and the stump sutured before the other was touched.

A modified purse-string suture was used to close the circular opening of the stump using a surgical silk (No. 4/0) and a 3/8 circle round body surgical needle. The suture was passed in and out around the circular opening and the two ends of the suture was drawn tight. The needle was then drawn back through the stump and the thread was wrapped a few times around it before the needle was driven through once more for a surgical square knot to be made. The caecal part of the intestine was then put back in place and the wound was sprayed with an antibiotic preparation, V-Sporin* (trade name for a topical antibiotic manufactured by Wellcome Division of Agrco Pharmacy Ltd., Lasalle, P.Q.).

The layers of muscles were stitched by a method similar to the mattress suture using a 1/2 circle cutting surgical needle. The suture was continuously applied back and forth through both edges of the wound. The modification was necessitated by an observation made previously that the straight purse-string suture tore off as a result of pressure exerted by the digesta. The two edges of the skin were brought together and clipped with 18 mm wound clips. The wound of the muscle and skin was sprayed with V-Sporin* before the chickens were put back in their cages and given the necessary post-operative care. The suture clips were removed seven days after the operation, except in two cases where removal was effected ten days after the operation.

Caecectomized and intact control birds were maintained on a 17% protein diet for the ensuing 11 weeks. The ability of the birds to

utilize nutrients from two different diets was then determined. The composition of the diets is shown in Table 21. Diet 1 contained 19.2% corn starch. Diet 2 contained 8% corn oil and 11.2% ground cellulose in place of corn starch and was isocaloric and isonitrogenous with Diet 1. Each diet was fed to six intact and six caecectomized birds during successive three-week periods. Feed consumption and total excreta voided by the individual birds were measured during the last three days of weeks 1, 3, 4, 5 and 6. Metabolisability of the diets was determined for each week. The method used is the one of quantitative feeding and collection of excreta and bomb calorimetry. Protein utilisation was evaluated by measuring nitrogen retention, apparent nitrogen absorption and uric acid excretion.

Total nitrogen was determined by the macro-Kjeldahl method. The procedure for uric acid determination was a modification of the method described by Pudelkiewicz et al. (1968). Samples of finely ground excreta were extracted with 50 ml of 0.5% lithium carbonate, in a 250 ml volumetric flask for 30 minutes at room temperature with constant shaking of the flasks. The flasks were then made to 250 ml with distilled water and mixed thoroughly. Approximately 10 ml of the extract was centrifuged for about ten minutes and 0.25 ml of the supernatant was analyzed for uric acid concentration using a modification of the procedure described by Practorious (1965). Faecal extract obtained as described above was used instead of plasma, 0.25 ml of supernatant of the extract was added to 2.75 ml, 0.1 M glycine buffer (8.06 g glycine + 14.2 g sodium hydroxide per liter, pH9.3). A uric acid standard was included to check accuracy. Uric acid concentration was read at 292 mμ on an ultraviolet spectrophotometer (Unicam model SP 1800).

Table 21. Composition of diets fed to intact and cacecectomized chickens.

	DIET	
Ingredient	1	2
	%	
Herring meal	21.3	21.3
Ground wheat	53.0	53.0
Corn oil	3.0	11.0
Corn starch	19.2	-
Ground cellulose	-	11.2
Bonemeal	1.5	1.5
Limestone	1.0	1.0
Iodized salt	0.5	0.5
Micronutrients[1]	0.5	0.5
	100.0	100.0
% Protein	24.0	24.0

[1]Micronutrients as listed in Table 1.

Considering the fact that the caeca are areas of high micro-
bial activity, it was of interest to ascertain whether there was
any difference between the intact and the caecectomized chickens in
the proportion of the excreta due to bacteria. To achieve this objec-
tive, the bacteria were separated mechanically using the following
procedure. Freshly voided excreta from individual birds was collected,
thoroughly mixed, and an average of 0.5 g of sample was weighed and
placed in a 50 ml centrifuge tube. To this 49.5 ml of distilled water
was added and the sample was thoroughly mixed and spun in an MSE
Angle Centrifuge at maximum speed for ten minutes. The supernatant
was removed and the sediment was placed in a dilution bottle containing
about 60 ml distilled water. Glass beads were added and the bottles
were shaken for 1 hour on an agitator. The mixture was filtered
through four layers of cheesecloth onto a 50 ml centrifuge tube. The
filtrate (about 40 ml) was spun as mentioned earlier. The supernatant
was removed and the remaining solids which constitute a crude bacteria
content of the excreta were weighed and dried in a vacuum dryer. The
bacteria content as a percentage of a pre-dried excreta sample was
then calculated.

3.6.2   Results

The metabolisable energy values obtained for the diets when they were fed to the intact and caecectomized birds are given in Table 22. These values have been corrected for nitrogen retention. Diet 1 was utilized with practically the same efficiency by both groups of birds. A similar picture emerges for Diet 2 which contained added cellulose, higher fat level and no corn starch. Significant differences in metabolisable energy values between Diet 1 and Diet 2 were noted. Higher metabolisable energy values were obtained on Diet 2. The ME values obtained with intact chickens were always slightly higher than those of caecectomized chickens on both diets but the differences were not statistically significant.

Table 23 summarizes the result of uric acid excretion (as measured by uric acid concentration) in the faeces. The results in respect of Diet 1 were variable. In the first week the intact birds excreted more uric acid than the caecectomized birds but this situation changed in the third week. The results for Diet 2 were more consistent. The intact birds excreted more uric acid than the caecectomized birds. The differences, however, were not statistically significant. The percentage of ingested nitrogen as uric acid (Table 23) also followed a pattern similar to that of the uric acid concentration.

The nitrogen balances of the chickens for the period over which collection was made are presented in Table 24. With the exception of the third week, the nitrogen retention in the caecectomized chicken was slightly higher than that of the intact chickens as was the case for uric

Table 22. Metabolisable energy values[1] of diets.

(corrected for nitrogen-retention).

Diet	Age of chickens in weeks	Intact kcal/kg	Caecectomized kcal/kg
1 (Cornstarch)	21	3345a	3325a
	23	3350a	3305a
2 (Corn oil & Cellulose)	24	3535b	3530b
	25	3520b	3515b
	26	3520b	3510b

[1]Values not followed by the same letters differ significantly ($P \leq 0.05$)

Table 23. Uric acid concentration in excreta by intact and caecectomized chickens.

Diet	Age of chickens in weeks	Intact		Caecectomized	
		$\%^1$	$\%^2$	$\%^1$	$\%^2$
1 (Cornstarch)	21	8.4	22.0a	7.7	20.0a
	23	13.7	36.2b	14.3	38.0b
2 (Corn oil & Cellulose)	24	8.4	28.8c	7.8	25.0c
	25	10.3	33.7d	10.0	32.6d
	26	10.7	34.9d	9.5	31.1d

[1] % in excreta, dry matter basis.

[2] % of ingested N excreted as uric acid.

[3] comparisons are between intact and caecectomized groups within diets and values followed by the same letters do not differ significantly ($P \leq 0.05$)

Table 24.   Apparent Nitrogen absorption (expressed as a percentage
of nitrogen ingested) by intact and caecectomized chickens.

Diet	Age of chickens in weeks	Intact % absorption	Caecectomized % absorption
1 (Cornstarch)	21	64.3 ± 3.42[1]	63.5 ± 2.13
	23	66.9 ± 1.89	65.6 ± 1.17
2 (Corn oil & Cellulose)	24	70.2 ± 0.47	69.0 ± 3.14
	25	65.9 ± 2.63	68.4 ± 5.90
	26	70.9 ± 3.24	69.2 ± 0.81

[1]Standard error of the means.

showed no clear trend as Table 24 shows. It is interesting to point out that the birds were still gaining weight (Table 25).

The intact birds voided faeces which contained significantly ($P \leq 0.01$) more bacterial residue than did the caecectomized birds. As can be seen from Table 26, the range was from 15.6 to 30.5 (mean:22.5) among the intact birds, while the values for the birds without caeca ranged from 9.87 to 19.00 (mean:13.6).

Table 25. Body weight gains of individual chickens.

Intact		Caecectomized	
g	% gain [1]	g	% gain
551	19.3	398	16.8
11	0.4	408	16.3
739	32.1	531	24.0
310	11.2	424	17.7
187	7.4	388	14.6
264	10.5	368	17.2
Mean 344	13.7	420	17.7

[1] Differences between body weights at 21 and 26 weeks of age.

Table 26. Bacterial content of excreta of individual chickens, percent on a dry matter basis.

Intact	Caecectomized
%	%
17.9	13.7
22.8	9.9
30.5	19.0
25.9	11.2
15.6	14.3
Mean[1] 22.5a	13.6b

[1]Mean value followed by different letters differ significantly (P≤ 0.05)

3.6.3   Discussion

The metabolisable energy values (Table 22) show that metabolisability of neither diet was altered by caecectomy. The energy required by the chicken is derived from carbohydrate (mainly amylose and amylopectin), lipid and protein components of the ingested food. The digestive tract without the caeca is anatomically endowed to carry out the processes of digestion and absorption which means that the absence of the caeca will not significantly alter this attribute. The absence of the caeca may cause an abnormal proliferation and increase of microorganisms in the small intestine. Jayne-Williams and Fuller (1971) suggested that the presence of microorganisms and/or their metabolic products causes increased thickness of the intestinal wall and a reduction in the absorptive efficiency of the small intestine. On this premise one would expect the caecectomized chickens to utilise nutrients less efficiently. However, the results of this investigation do not show that. The lack of significant difference between intact and caecectomized chickens in respect of their ability to metabolize dietary energy is an experimental evidence which provides an indirect support to the finding that the presence of a microflora has little effect on amylase activities in different sites in the fowl's alimentary tract (Lepkovsky et al., 1964).

The results of this experiment are not in agreement with those obtained by Radeff (1928), Henning (1929) and Thornburn and Willcox (1965) that there is microbial digestion of fibre in the caecum of the domestic chicken. Even if some bacterial digestion occurs in the caecum, it probably plays an

insignificant part in the metabolism of the host chicken compared to

that occurring in the caeca of the wild bird where it represents 5.7% of

the daily energy requirement (Thompson and Boag, 1975).

The higher metabolisable energy values obtained for the diet which

contained corn oil as the major source of dietary energy (Diet 2) agree

with values reported by other workers who substituted corn oil for carbo-

hydrate (Donaldson, 1964, 1966; Donaldson et al., 1957; Rand et al., 1958;

Carew and Hill, 1964; Dror et al., 1973). The observed higher values for

Diet 2 can also be explained on the basis that by the time this diet was

fed, the age of the chickens had increased and that their digestive tracts

had been more developed to cope with bulky digesta.

Many of the types of bacteria inhabiting the caeca utilize uric acid

and since uric acid is the primary nitrogenous excretory product formed

in the avian species, the possibility was considered that removal of the

caeca might increase the amount of nitrogen excreted as uric acid. The

data shown in Table 23 show that there was no appreciable effect of the

removal of the caeca on the amount of uric acid excreted. This was true

whether the amount excreted was calculated as a percentage of the excreta

or relative to the amount of nitrogen ingested. The values of the excreta

nitrogen expressed as a percentage of the nitrogen consumed by the control

group in this study (20-36%, mean 31%) are analogous to those (20-25%,

mean 23%) reported by Featherston and Scholz (1968) who fed a diet containing

a similar level of protein to chicks from day-old to 10 days of age. The

percentage of ingested nitrogen excreted as uric acid increases with age

(Featherston and Scholz, 1968) and this may explain the difference between

the two means. In Table 24 the apparent absorption of nitrogen has been

estimated as the sum of uric acid nitrogen and retained nitrogen. It will be seen that there was no difference between the intact and the caecectomized chickens in the apparent absorption of dietary nitrogen. Although the chickens were 20 weeks of age, they gained weight during the test (Table 25). The significantly reduced average percentage of bacteria in the excreta from the caecectomized chickens (Table 26) appears to be of consequence. Since there was less loss of nutrients via excreted bacteria in the caecectomized, it was logical to expect some compensatory increase in the loss of nutrients via other route. Similar results have been obtained with germ-free compared with conventional animals. It might be expected that germ-free animals would show less excretion of faecal nitrogen than do conventional animals. The reverse situation, however, has been shown to occur. Under the dietary conditions of the present experiment, the caeca did not appear to be essential for maximum utilisation of energy and protein. If there are advantages associated with the presence of the caeca, they must have been counter-balanced with some disadvantages. It is tentatively suggested that the balance is between bacterial and endogenous protein and amino acids with little effect on absorption of ingested nutrients.

3.7 REGROWTH OF THE AVIAN CAECA FOLLOWING CAECECTOMY

3.7.1
Experiment 7 - Introduction

Caecectomy has been employed extensively as a means of studying the role the caeca may play in the nutrition and physiology of birds, particularly the domestic chicken (Sunde et al., 1950; Beattie and Shrimpton, 1958; Nelson and Norris, 1961; Nitsan and Alumot, 1963; Fisher and Griminger, 1966; Barnes, 1972; Kese and March, 1975). Although several articles appear in the literature concerning the measurement of various physiological parameters after caecectomy, relatively few discuss operative procedure and post-mortem observations. Surgical ablation of the avian caeca is attended by some problems not the least of which is that of certainty of completeness of the extirpative procedure. The omission of descriptive of the surgical process, particularly the completeness of caecectomy does not allow one a common base for valid comparison of surgical treatment and data.

Internal organs react differently to removal of different amounts of their tissue (Liozner, 1974). Studies on adult developmental processes point to a remarkable ability of animals to replace portions of tissues or organs removed by surgery. There are no tissues in the bodies of warm-blooded vertebrates which are not capable of repairing localized injuries and in some cases (e.g. fracture healing, feather and hair regeneration, or the restitution of the urinary bladder), the response may involve high degrees of histological morphogenesis (Goss, 1965). Adaptive morphological and functional changes following resection of parts

of the alimentary tract are well documented in surgical and medical literature (Wickborn et al., 1975; McDermott and Roudnew, 1976).

The findings, cited previously, underline the need for studies involving biopsy and autopsy of caecectomized birds. This section of the study is concerned with the major gross and microscopic anatomy observed on autopsy.

3.7.2   <u>Materials and Methods</u>

The materials and methods are essentially as described for experiment 6 because the chickens involved in this study are the same chickens used to study the role of the avian caeca in the utilisation of dietary energy and protein.

3.7.3   <u>Results</u>

The birds were autopsied 85 weeks after caecectomy and the alimentary tract was examined. As shown in Figs. 10 and 11, the four surviving caecectomized birds had regrown their caeca to varying lengths. The regrowth ranged from 17 to over 40 percent of the length of the caeca in the unoperated chickens (Table 27). Trunk sections from the midzone of each caecum of both the caecectomized and unoperated chickens showed, on histological examination, that regeneration of the caeca had occurred as evidenced by the presence of most of the elements that constitute the basic structure of the caecum, namely, the serosa, the muscularis externa, the submucosa, the muscularis mucosae, and some glands (Fig. 12).
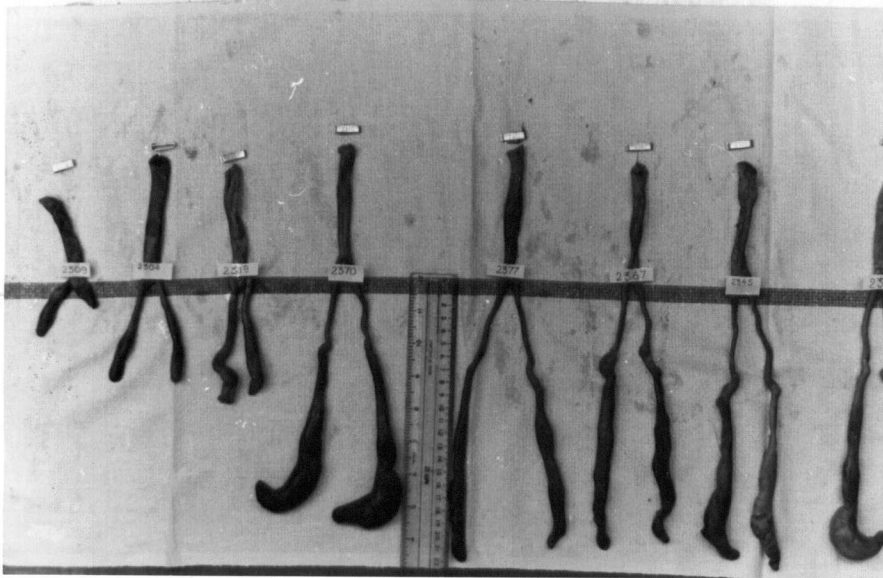
Fig. 10. Regrown caeca from 85-week-old chickens caecectomized at 9
          weeks of age and caeca from unoperated chickens of the same
          age. First three on the left - caecectomized; the next five
          - unoperated.

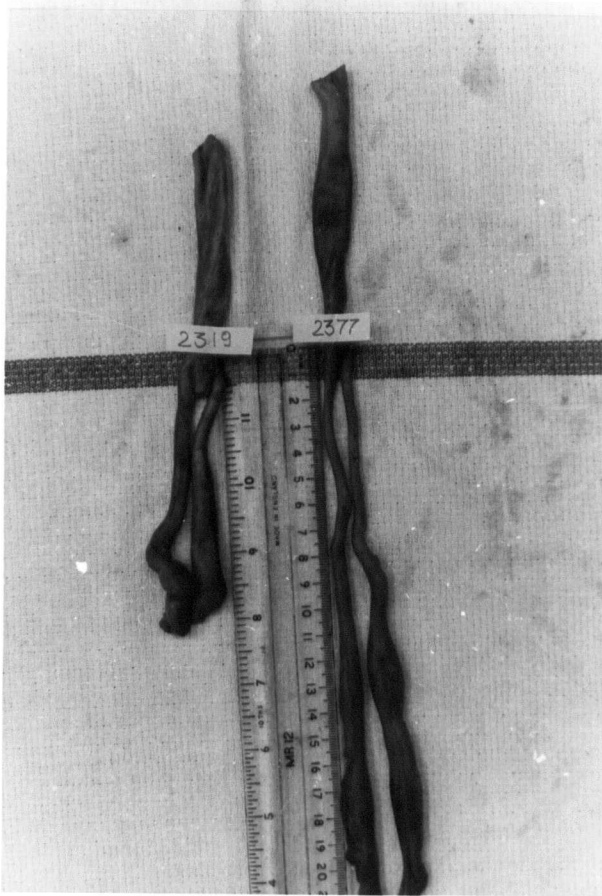Fig. 11. (Left) Regrown caecum from caecectomized chicken, and (right) caecum from unoperated chicken.

Table 27. Length of intact and regrown caeca.

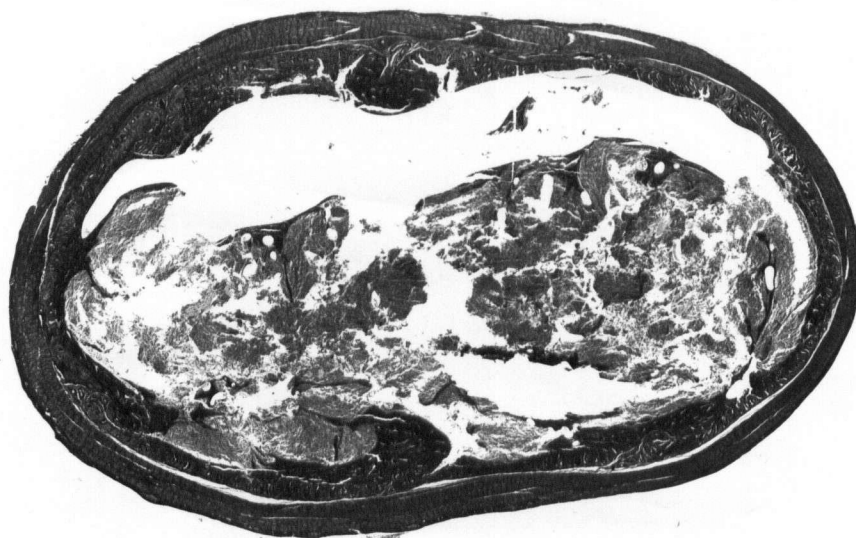| Bird	Control	Caecectomized
	cm	
1	21.6	4.0
2	23.4	4.1
3	23.7	8.6
4	24.1	10.5
5	24.5	–

Fig. 12.   Transverse section through the mid-caecum.
top: regrown caecum;   bottom: intact caecum.

3.7.4   Discussion

Studies on the role of the caeca in avian nutrition or physiology have, so far, failed to establish a function for this organ. In the light of the fact that regeneration of tissues or organs is not a rare phenomenon, it is pertinent to make the following comments in an attempt to explain what could cause some of the discrepancies existing in the literature on the performance of caecectomized chickens. The absence of precise descriptions of excision methods in experiments involving caecectomy allows for variation in methods, particularly with regard to the amount of residual tissue. The presence or absence of residual tissue is likely to influence the healing of the surgical wound or the regeneration of the organ. The observed regrowth of the five millimeters stump in this study (Table 27) underlines the importance of this point. Figs. 10 and 11 indicate clearly that a piece of tissue or organ inadvertently or purposely left in situ is likely to stimulate some form of regrowth or reparative regeneration. Such a situation is likely to distort results.

Ability to regenerate lost organs has been reported to decline with age. Compensatory regrowth or regeneration of an organ, if they do occur, will be faster in younger than in older chickens. Adaptive morphological and functional changes will be quicker in younger chickens than in older ones. This raises the question regarding the age at which the occlusion of an organ will make the most significant impact. When an organ is removed very early in life, probably before it begins to function effectively, it is likely that its (possible) function will be

taken over by an organ of homologous tissues. If, on the other hand, the organ is removed later in life, it is probable that a different result would be produced. Comparing physiologic indices of birds caecectomized at different ages in life appears therefore to be a probable source of variation in the results. It is important to bear in mind the rapidity with which hypertrophy and/or hyperplasia which characterize the phenomenon of tissue repair or regeneration takes place. In the chicken, regeneration and restoration of functionality may be complete in one month (Beattie and Shrimpton, 1958). Nine weeks, the age at which the chickens involved in this study were caecectomized, represents a stage at which the birds are in active growth (Table 25) and their cells were still very versatile to undergo all the developmental processes associated with tissue regrowth. Even in the adult stage, the avian caeca may undergo developmental adjustment to meet functional requirements. In the Japanese quail, for example, it has been well documented (Fenna and Boag, 1974) that changes in some physical attributes of food and in the rates of food consumption resulted in changes of the morphology of the caeca. Larger volumes of food ingested per day produced significant increases in caecal lengths.

It is unfortunate that the design of the experiment being reported did not offer the opportunity of observing the onset and the rate of regrowth of the caeca. Such information would help elucidate similarities or differences in response criteria existing between the intact and caecectomized chickens of this study.

In conclusion, it must be restated that proof of a physiological role(s) for the caeca of the domestic chicken has been elusive for the

following reasons:

a) Difference in experimental methods - variability in excision methods; failure to ascertain occurrence or absence of regrowth,

b) Possibility of restoration of function - sharing of functional load; functional shifts to cells of homologous tissues, and

c) Variation in age of birds involved in the different studies.

4.   GENERAL SUMMARY AND CONCLUSIONS

The research which forms the subject of this dissertation has considered many implications of the use of dietary fat as a supplementary source of energy for broiler chickens. The level of dietary fat and the substitution of fat for carbohydrate calories at varying protein levels, have been evaluated in terms of growth performance, food conversion efficiency, metabolisable energy and nutrient utilisation and abdominal fat deposition. Hypotheses considered pertinent to an in-depth treatment of the topic under investigation were developed and/or tested.

The first seven weeks in the life of a broiler chicken represent a period in which the requirements for balanced protein and other nutrients are most critical (Scott et al., 1969). It is reasonable to expect that responses to stimuli induced by dietary treatments would be maximal during this period. These results show that the incorporation of fat in the diet did not have any special effect on the growth of, or the utilisation of energy by, broiler chickens. This finding is in agreement with a number of other reports on chickens (Begin, 1969; Velu and Baker, 1974). Begin (1969) reported that chickens of the three breeds which he studied used fat and carbohydrate calories with equal efficiency and that no beneficial or deleterious effect was associated with the replacement of carbohydrate by fat calories. However, the finding of this study differs from others in which dietary fat per se was found to improve the efficiency of energy utilisation by turkeys. (Touchburn and Naber, 1966; Halloran et al., 1972). Breed differences have been noted among chickens in the

efficiency of nitrogen and energy utilisation regardless of the source of calories (Begin, 1969) and, as Salmon (1972) pointed out, a species difference in the relative efficiency of utilisation of carbohydrate and fat energy is conceivable.

Summers et al. (1964) consider energy as one of the most important factors to consider in the evaluation of nutrients on account of its influence on food intake. Factors such as dietary energy concentration and balance between amino acids are probably in the forefront as far as food intake-limiting factors are concerned. The importance of considering not only the level of energy but also the calorie to protein ratio of a diet has been emphasized by Biely and March (1954), Donaldson et al. (1955), Scott et al. (1969). Another factor, other than the level of energy or protein or the ratio between them, is the balance between amino acids. It has been demonstrated that an imbalance (Harper and Kumta, 1959; Fisher and Shapiro, 1961); excess (Almquist, 1954) or deficiency (March and Walker, 1970; March and Biely, 1972) in amino acids results in marked depression in food intake. An earlier observation that the detrimental effect of incorrect energy:protein relationship could be alleviated by improving the balance of amino acids in the diet (Hill and Dansky, 1950) established the importance of energy and amino acid balance in the evaluation of nutrients or diets.

It is important to point out that in interpreting the results of the present study congnizance should be taken of the fact that fish meal was the principal source of protein. As such it was possible not only to provide a good supply of essential amino acids but also to maintain a constant balance between amino acids as the protein level increased.

Lipogenesis in the domestic chicken involves the conversion of acetyl CoA to fatty acids in the cytoplasm (Annison, 1971), but the pyruvate formed from glucose, a major fat precursor in the bird, gives rise to acetyl CoA in the mitochondria. Acetyl CoA cannot diffuse into the cytoplasm at a rate commensurate with requirement for lipogenesis and has to be transported through the mitochondrial membrane as citrate where it is converted to oxaloacetate and acetyl CoA (Pearce, 1974). The shunting of this substrate from the mitochondria to the cytoplasm necessitates the expenditure of energy. Under conditions of increased biosynthetic activity, this energy expenditure may reach significant proportions. Quite apart from the fact that the so-called extra-caloric effect of fat has been observed mostly with turkeys, the beneficial effect attributable to added dietary fat is largely a consequence of the fact that diets without added fat may not be adequate in terms of the supply of essential fatty acids. It is doubtful whether the diets without added dietary fat used in the studies of Touchburn and Naber (1966) and Jensen et al. (1970) were adequate in meeting the essential fatty acids requirement by turkey broilers.

The data presented in Experiment 3 demonstate that added dietary cellulose has a deleterious effect on metabolisability of diets and efficiency of food utilisation. This observation is in agreement with several others reported in the literature (Penquite, 1976, Wells, 1963). However, inclusion of cellulose in the diet at a level higher than that used in the present study did not interfere with the birds' ability to consume sufficient energy for their requirements (Sibbald et al., 1960).

The difference between the finding of the present experiment and the one under reference may be explained on the basis of differences in strain and growth rate of the birds involved in the two studies. Under normal physiological conditions, high dietary fibre may shorten ingesta transit time. The increased bulk of non-assimilable material in the alimentary tract of the chicken may precipitate physico-chemical reactions which may affect processes such as enzyme-substrate binding and water-facilitated movement of nutrients towards and through the absorbing mucosal surface. As Southgate (1973) explained, losses of endogenous material which will undoubtedly affect the results of balance studies may occur as a result of mechanical erosion of the mucosal surface. Piekarska (1964) and Rao and Sunderavalli (1970) observed increased faecal nitrogen excretion and consequently decreased apparent protein digestibility in rats fed semi-purified casein diets containing 10-20 percent fibre or crystalline cellulose. Similar findings have been obtained with chickens fed diets containing high levels of fibre (Kibe et al., 1964; Vlcek, 1968; Vlcek and Pazourek, 1970).

Contrary to popular belief, the yolk sac does not influence metabolisable energy values of nutrients in the early days posthatching. If the residual yolk influences the performance of the chick in the first few days posthatching, it must be a parameter(s) other than growth as measured by body weights and metabolisability of nutrients. During incubation, the embryo utilizes all nutrients, with the exception of protein, to a near depletion level. Through some unknown mechanism, there is a

noticeable increase in the concentration of total proteins in the yolk (Romanoff and Romanoff, 1967) and the yolk sac (Rol'nick, 1970) compared to the amount at the midpoint of embryo development. In addition, several nitrogenous compounds including ribonucleic acid and some twenty amino acids are present (Romanoff and Romanoff, 1967). The increased amount of nitrogenous compounds imposes additional physiological load on the baby chick. The implication seems to be a stepping up of the rate of nitrogen excretion. This hypothesis would explain the observed lower apparent nitrogen retention values obtained with chicks with intact yolk sac compared to those obtained with chicks without residual yolk. Under the conditions of this experiment, it has been shown that not only does the residual yolk not provide nutrients in significant amounts, but its presence may interfere with the utilisation or the excretion of the waste products of nutrients, particularly those of protein.

The data presented in Part 2 indicate that energy utilisation as measured by metabolisable energy values is not influenced by the presence or absence of the caeca. The data support the observations of Scott (1955), McBee (1971) and McNab (1973) among others, who dispute the claim of cellulolysis in the avian caeca. The data also tend to support the finding of Fisher and Griminger (1966) that the avian caeca do not play a significant role in protein utilisation. The assimilation of proteins is the concerted process closely regulated by neural and hormonal mechanisms rather than a result of clearly defined individual steps (Gitler, 1964). The use of nitrogen balance method as a criterion for the estimation of nitrogen retention in the body is a sensitive method, so sensitive that

the balance will vary very rapidly with shifts in physiological states, responding to alterations in diets, endocrine secretions and abnormalities of various kinds. One or more of the above-mentioned factors could be responsible for the observed variations in the apparent nitrogen retention values within treatment groups and the fluctuations within periods. Costa (1960), Allison and Bird (1964) have reported losses of sizeable amounts of dietary nitrogen through some unsuspected route, possibly as gaseous nitrogen from the lungs. Nesheim and Carpenter (1967) reported fermentation of protein and peptides which escape breakdown and enter the caeca resulting in the loss of nitrogen in the form of ammonia. The fact that uric acid nitrogen was used as a component for the estimation of the apparent nitrogen absorption and the fact that uric acid determination underestimates the total nitrogen excreted should be considered in arriving at a conclusion on the protein utilisation as measured by apparent nitrogen absorption or retention.

The view is held by some researchers that the caeca may function actively in trapping protein of endogenous origin or dietary protein which has escaped digestion and/or absorption in the upper gut. If this is true, it is logical to expect this mechanism to be fully operational in situations of protein inadequacy or deficiency. Recycling may reduce the amount of protein excretory products and this may affect the balance of nitrogen in the body. The level of protein used in this study was not low enough to evoke such a mechanism. The testing of this hypothesis - that the caeca may recycle protein in cases of inadequate dietary protein level - will yield valuable information.

Finally, in view of the integrated nature of the nutritional factors influencing the expression of any physiologic response, further research should involve the investigation of the broad implications of as many related factors as possible. The study described herein represents an attempt to achieve such an objective.

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