A STUDY OF THE PROTEIN NEEDS OF GROWING PIGS FED RATIONS CONTAINING WHEY

A thesis presented in partial fulfilment of the requirements for the degree of Master of Agricultural Science in Animal Science

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'Comrades!' he cried. 'You do not imagine, I hope, that we pigs are doing this in a spirit of selfishness and privilege? Many of us actually dislike milk and apples. I dislike them myself. Our sole object in taking these things is to preserve our health.'

George Orwell.

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CHAPTER 1

INTRODUCTION

Pig production in New Zealand has been traditionally linked with dairy farming, utilizing the liquid by-products from butter, cheese and more recently casein manufacture, as the basic sources of food. However recent changes within the dairy industry have resulted in an alteration in the availability of these by-products. Table 1/1 gives some indication of the nature of these changes.

Table 1/1: Annual manufacture of some milk products (Tons) (from the New Zealand Dairy Board, Fifth Annual report 1966).

Year	Cheese	Skim-Milk Powder	Butter Milk Powder	Casein	
				Lactic	Rennet
1961-62	99,889	41,755	17,393	26,531	8,862
1965-66	105,593	85,936	24,637	50,756	2,245

Over the 5 year period shown, the twofold increase in the manufacture of skim-milk powder has resulted in a marked reduction in the supply of skim-milk available for pig feeding. At the same time, the increased output of casein and to a lesser extent cheese, has made available to the pig producer an increasing volume of whey. With whey playing an ascending role and skim-milk a declining role in the production of pig meat, consideration of the protein adequacy of the diet becomes of greater necessity, in view of the relatively low protein content of whey. This point is emphasised by reference to the effect of the level of dietary protein on carcass lean content, particularly when market demand discriminates against a product containing a high proportion of fat.

Little or no positive information could be found throughout the literature on the need for supplementary protein in diets based on whey. Under New Zealand conditions where the choice of protein concentrates is limited and where those that are available command high prices in relation to their protein content, e.g. buttermilk powder, or to the quality of the protein, e.g. meat meals, information on this matter would seem particularly relevant.

The work to be described was designed to assess the need for protein concentrates in diets based on whey and the extent to which this is influenced by the level of meal fed in conjunction with whey.

CHAPTER 2

REVIEW OF LITERATURE

A. THE PROTEIN REQUIREMENT OF THE GROWING PIG:

1. General -

It was recognized in the F.A.O. report on protein requirements (1957) that the nutritive value of the protein in food depends on the quantity of protein and its quality (amino acid balance); the energy content of the food (calorie to protein ratio); the calorie intake (plane of nutrition); the nature and proportions in the diet of many essential accessory ingredients; and the dietary regimen e.g. the timing of meals and the distribution of protein between various meals during the day.

Although the report was directed towards problems in human nutrition, it may be extended, in principle, to include protein nutrition of mammalian species in general. The factors outlined above which influence the value of protein consumed are covered in detail in the double-volume publication "Mammalian Protein Metabolism" (1964). A full review is beyond the scope of this thesis.

Recognition of these principles implies that the adequacy of diets with regard to protein, cannot be evaluated on the basis of absolute or percentage content alone. Apart from the influence of accessory ingredients and dietary regimen, assessment must be made in terms of the absolute and relative content of amino acids and energy, and in reference to the rate at which the diet as a whole is consumed.

As the nutritive status of a diet can only be established in terms of biological performance, it follows that any estimate of the absolute requirement of an animal for protein will be influenced by the quality of the protein - how closely its amino acid pattern meets the needs of the animal for different amino acids - and by the concomitant intake of energy.

Traditional systems of describing the nutritive value of proteins, or the protein adequacy of diets, have disregarded the interdependence of the two dietary factors, protein and energy (re Platt, Heard and Stewart 1964). However the procedure introduced by Platt, Miller and Payne (1961) for the measurement of the protein value of the diet consumed, does recognise the influence of energy intake on protein metabolism, and serves to classify diets on a protein-calorie basis. The value used in such nomenclature is Net Dietary-protein Calories per cent. (NDp Cal.%), which is a measure of the calories which could be derived from the protein if it were all utilized for energy purposes, calculated as a percentage of the total metabolizable energy in the diet.

Just as traditional systems of evaluating protein quality failed to recognise the importance of energy intake, so conventional methods of estimating the protein requirements of animals disregarded the influence of calorie intake.

The historical background to current concepts on the significance of nutrient to calorie ratios in animal nutrition, with particular reference to protein-calorie ratios, is outlined by Crampton (1964).

The basic studies on the interrelationship of dietary energy and protein were performed using laboratory animals. They have resulted in a system of defining diets and animal requirement in terms of NDp Cal.%, and stimulated Miller and Payne (1963) to propound a theory on the "mechanics" of protein metabolism in relation to energy intake, and to construct a growth equation based on NDp Cal.%.

The importance of this aspect of nutrition to feeding farm animals has shown itself over recent years by the amount of research work directed towards evaluation of the significance of protein to calorie ratios on the performance of meat producing animals. Combs (1962) reviewed the work which has eventuated

in the establishment and adoption of optimum energy to protein ratios in poultry meat production, and drew attention to the need to express requirements on the basis of calorie to amino acid ratios rather than to protein as such.

The early work designed to assess the protein requirement of the pig, perhaps because of the failure to recognize the influence of both energy intake and protein quality, resulted in quite variable recommendations. The review by Morgan and Robinson (1962) shows that the protein allowance of the growing pig (40 - 100 lb) has been variously estimated as between 13 and 21% of the diet.

2. Protein Quality -

The following brief account of the significance of protein quality in mammalian nutrition, with particular reference to the pig, was obtained from the comprehensive reviews by Almquist (1957), Allison (1964), Harper (1964 and from the review of Homb (1963) on amino acids in pig nutrition.

It is now generally recognized that protein nutrition is synonymous with amino acid nutrition, and consequently that the nutritive value of a protein is dependent upon its amino acid composition, in the light of animal requirement. Protein quality is a reflection of the amino acid pattern of the protein and how closely this pattern conforms to the relative requirement of the animal for different amino acids, after correcting for digestibility. If the correlation is high, then the protein is of high quality and has a high Protein Efficiency Ratio, Biological Value, Chemical Score or Net Protein Utilization rating. These values however are by no means constant for a given protein and will vary with level of intake, with the physiological status and age of the animal and with productive function.

Amino acids may be classified as dispensable or indispensable. Those appearing in the former grouping can be manufactured in the body at an adequate rate, from the indispensable amino acids which must be provided in the diet. The addition of dispensable amino acids to the ration may however induce an increase in nitrogen balance, through liberation of limiting or marginal indispensable amino acids from transamination.

It will be appreciated that it is extremely unlikely that any diet will exactly meet the animal's requirement for all amino acids. Although not conclusive, it is generally accepted that amino acids presented in relatively supra-optimal amounts, are preferentially catabolized and used as a source of energy, in order to maintain a "preferred" plasma amino acid pattern. (Harper 1964: Yoshida, Levng, Rogers and Harper 1966).

Amino acid imbalances, toxicities and antagonisms have been demonstrated in animal nutrition. Harper (1964) defines these phenomena as follows:

"Imbalance applies to dietary amino acid patterns causing growth depression which is completely prevented by a small supplement of the limiting amino acid(s)."

"Antagonism applies to dietary amino acid patterns causing growth depression which is largely or completely prevented by a small supplement of a structurally similar amino acid or acids not originally limiting in the diet."

The effects of excessive intakes of individual amino acids that do not fit the above categories, he groups under the general term toxicities "until some more meaningful basis for grouping them in another way is developed."

Under practical pig feeding conditions, imbalance or degrees of deficiency of amino acids, is probably the most likely "abnormaility" to arise.

Considering a dietary regime where energy intake is not restrictive to growth e.g. ad libitum systems of feeding, the rates of body protein synthesis achieved, may be considered a function of the absolute and relative intake of

amino acids - both dispensable and indispensable - up to a genetically determined maximum. If a single indispensable amino acid is absent from the diet, then protein deposition ceases, the animal entering a phase of negative nitrogen balance, with an associated cessation of growth, accompanied by reduced food intake and an eventual loss in body weight. As the dietary intake of the deficient amino acid is increased, then the synthesis of body protein increases in direct proportion. Such response is accompanied by increased nitrogen balance, being a reflection of a decline in de-amination, as amino acids are used to an increasing extent for protein biosynthesis. In general, at constant calorie intake, the higher the quality of protein, the greater the amount of nitrogen retained and consequently the higher the rate of growth, carcass lean content and feed efficiency.

Conflicting evidence exists on the interrelationships between dietary protein and amino acid levels. Some information suggests that amino acid requirements increase with increasing dietary protein, other that the relationship is fixed; and yet other that the amino acid requirement decreases when expressed as a percentage of the protein. Harper (1964) mentioned some factors which could contribute to such inconsistency. Almquist (1957) stated that if amino acid requirement is expressed as a percentage of protein, this percentage will decrease as the protein level of the diet is increased. This appears to be the current view held in the fields of both chick and pig nutrition. It is possible that as protein intake increases, so protein efficiency decreases, more being metabolized for energy purposes and that this fraction comprises largely dispensable amino acids. Consequently proportionally less of the indispensable amino acids are required.

It was mentioned earlier that the quality of a protein depends on its amino acid pattern after correcting for digestibility, i.e. upon the "amino acid pattern" actually absorbed from the intestine. Factors affecting the digestibility or availability of amino acids are thus of real importance. As there is little scope for control of factors of animal origin affecting digestibility, those associated with food processing methods are of greater significance. The classic example is that pertaining to raw soya beans, which contains a trypsin inhibitor having a deletrious effect on the liberation of all amino acids. The inhibitor is however heat labile, such that heat treatment renders it ineffective, resulting in a product of higher nutritional value. Overheating, on the other hand, may result in a permanent loss of amino acids. This is particularly so for protein sources such as soyabean meal and other vegetable proteins containing high levels of free carbohydrate, which forms stable complexes with amino acids on overheating. Overheating of protein meals containing little free carbohydrate, e.g. fish and meat meal, casein etc. results in an acid-reversible, therefore non-permanent complexing of amino acids. A more general effect of overheating is to slow down the rate of liberation of amino acids from protein, this effect being non-selective, and which could thus effectively alter the sequence of rate-limiting amino acids,

Under practical feeding conditions there are three ways in which amino acid deficiencies or imbalances may be rectified. Firstly by direct supplementation with synthetic amino acids - Homb (1963) provides information on the value of D- and L- isomers. Secondly by feeding greater quantities of the protein so that intake of the most limiting amino acid is adequate to meet the animal's requirement. This method is costly both in economic and biochemical terms. Thirdly, and the method most frequently adopted in practice, by feeding combinations of proteins, such that deficiencies in one are offset by excesses in another. For maximum

economy, the selection of protein should meet the amino acid requirements of the animal at the lowest possible protein percentage, as excesses will be broken down and excreted, used as a direct source of energy or stored as fat.

The majority of studies relating specifically to the pig have involved the addition of one or more amino acids to both synthetic and practical diets. From these experiments a list of requirements has been drawn up in the NRC publication on the nutritional requirements of the pig (1964). Reference to the literature (Morgan and Robinson 1962: Homb 1963) shows the results of such work display wide variation, which in view of the diversity of secondary effects which will influence requirement and associated with experimental control and terminology, is not particularly surprising.

The relative quality of various sources of protein for pig feeding has been studied by Woodman and Evans (1951); Evans (1952, 1958, 1960a); Carpenter, Duckworth, Lucas and Shrimpton (1956); Jones, Hepburn, Cadenhead and Boyne (1962). It is generally recognised that proteins of animal origin, particularly those of milk, are of higher quality than vegetable proteins. Furthermore, the young pig is more sensitive to differences in protein quality, requiring protein of higher quality than the older pig. For this reason it is standard practice that where barley meal forms the major portion of the diet, a protein source of animal origin is incorporated in the ration of pigs weighing up to about 100 lbs. (Evans 1960b), subsequent to which it may be replaced by a lower quality and less expensive vegetable protein. It may be that because the young pig is capable of laying down proportionally more protein than the older pig (Oslage and Fleigel 1965), deficiencies in protein quality are of relatively greater significance.

3. Interrelationships of dietary energy and protein -

In the light of existing knowledge, Miller and Payne (1963) and Munro (1964) clarified the complex interrelationship between dietary energy and protein

in reference to mammalian protein metabolism.

They pointed out that as protein biosynthesis is an energy dependent process, then either energy or protein may be rate-limiting, or more specifically energy or amino acids. When either is limiting to protein synthesis then addition of the other to the diet will have no, or little effect, on tissue protein synthesis. They presented in diagramatic form the likely effects on nitrogen balance of protein and energy intake under different nutritional conditions, and indicated that dependent upon the relative intakes of energy and protein, their effects on nitrogen balance may be independent or interdependent of each other.

Although the desirability of maintaining a constant level of dietary energy for any comparative nutrition study was emphasised by Woodman and Evans (1951), it is only in recent years that attention has been directed specifically to the possible, if not probable, significance of dietary energy on the protein requirement of the pig, in relation to standards of performance.

The work is reviewed below under two headings, viz. experiments involving either unrestricted or restricted systems of feeding. As the review is largely descriptive, the results have been brought together in tabulated form and are presented in Appendix 2/1.

(a) Unrestricted systems of feeding

Abernathy, Sewell and Tarpley (1958) found that over the growth period of 40 - 110 lb. pigs fed diets containing 18% protein grew significantly faster than animals receiving diets of 14% protein. The addition of tallow at 0, 5 or 10% produced a significant linear increase in growth rate, but there was no significant fat x protein interaction.

Feeding diets containing from 14 to 20% protein combined with 0 to 20% fat to pigs of 35 to 125 lbs. Kennington, Perry and Beeson (1958)

observed that increases in fat content of the diet resulted in significant increases in growth rate. High fat levels also led to decreased food consumption, improved feed efficiency and increased back fat thickness. Dietary protein content was without effect on rate of gain, food consumption, feed efficiency or depth of backfat. The interaction between fat and protein levels proved non-significant as did that between sex and treatment.

Baird, McCampbell and Neville (1958) fed diets of 13 and 19% protein in combination with 0, 5 and 10% tallow to pigs from 40 to 200 lb. Increased caloric density of diets resulted in improved feed efficiency but had no effect on rate of gain or carcass quality. There was a significant negative correlation between energy to protein ratio and daily gain, indicating that pigs receiving diets with narrower ratios grew faster,

Lowrey, Pond and Maner (1958) described an experiment conducted with pigs of 20 lb. and continuing for 35 days. The dietary treatments, arranged in factorial design, incorporated three levels of protein (13, 16 and 19%) and two of fat (0 and 10%). Although the results of statistical analysis were not presented, examination of the data suggests an energy x protein interaction, in that the inclusion of 10% fat in the high protein diet promoted an increase in daily gain, but reduced growth rate at the low level of protein. Raising either the level of fat or protein appeared to stimulate faster growth, while increases in caloric density resulted in improvements in feed efficiency.

By manipulation of the amount of fat in the ration, Clawson, Blumer, Smith and Barrick (1959) formulated diets having calorie to protein ratios of 27, 32 or 41 (Gross Cals/gm protein), which were fed to pigs from 40 lb. liveweight. Again the results of statistical analysis were not presented, but the data indicate that increases in energy content were accompanied by

increases in rate of gain and feed efficiency with no apparent effect on carcass composition. Narrower calorie to protein ratios promoted faster growth and higher food conversion but again had no obvious influence on carcass quality.

Noland and Scott (1960) studied the interrelationships of dietary energy and protein, over the growth period 40 - 200 lb. Three protein levels (12, 16 and 20%) were combined with three levels of productive energy (950, 1050 and 1200 Cals/lb.)

From 40 to 75 lb. liveweight, higher levels of protein resulted in significantly faster rates of gain, but energy over the range studied was without effect. Over this stage of growth a significant energy x protein interaction was isolated whereby at the low level of protein, increased energy resulted in reduced rate of gain, but significantly improved growth performance at the high protein level.

Over the final stages of growth (125 - 200 lb.) the diet with the widest calorie to protein ratio (1200 Cals. prod. energy/lb : 12% protein) promoted the fastest daily gain. However higher levels of energy resulted in carcasses containing significantly more fat, but induced higher feed efficiency.

Clawson, Blumer, Smart and Barrick (1962) fed diets having calorie to protein ratios (gross Cals/gm. protein) of 26, 31 or 38 in conjunction with fat contents of 0, 5 and 10%, to pigs from 40 to 200 lb. Over the first 28 days of the growth period, rate of gain was significantly influenced by the energy to protein ratio - diets having the narrowest ratio promoting the fastest growth. However over the entire experimental period this effect proved non-significant.

Over the range studied, the level of protein was without effect on any index of performance, while gross energy intake was influenced by neither

caloric density nor calorie to protein ratio. The efficiency of energy utilization was similar for all diets.

Increasing the level of fat resulted in significantly faster growth, but the existence of a significant fat x calorie to protein ratio indicated that this effect was greatest for pigs fed diets having the narrowest ratio. The addition of fat to diets having wide calorie to protein ratios significantly reduced food consumption and rate of gain. The efficiency of protein utilization was influenced by the energy to protein ratio, being significantly greater for diets of narrow ratio.

No differences were found in the composition of carcasses.

Diets containing 13, 19 or 25% protein, in combination with productive energy levels of 950 and 1170 Cals/lb. or 1310 and 1640 Cals/lb. metabolizable energy, were formulated by Wagner, Clark, Hays and Speer (1963) and fed to pigs of 40 to 150 or 200 lb. liveweight.

As the level of dietary protein increased so daily gain increased with improvement in feed efficiency. Carcasses from pigs fed high protein diets contained significantly more lean.

Increased energy level resulted in faster growth in one experiment but not in the other. Increases in caloric density were accompanied by greater efficiency of food utilization and higher fat content of the carcass.

Greeley, Meade and Hanson (1964) fed pigs for 42 days, commencing when the animals weighed 45 lb. on diets containing from 13 to 19% protein and from 0 to 12% tallow. Subsequent to this period pigs received diets containing the same levels of fat, but the protein content of all rations was standardized at 13%.

Increased caloric density resulted in increased daily gain, decreased food consumption and higher feed efficiency. Daily intake of digestible

energy was not influenced by percent tallow, but digestible energy was utilized more efficiently by pigs receiving diets containing high levels of tallow.

Increases in dietary energy level produced carcasses containing significantly greater amounts of fat, but dietary level of protein was without effect on any index of pig performance.

Feeding diets containing 12.5% and 14.5% protein in association with 0, 4 and 8% yellow grease, Seerley, Poley and Wahlstrom (1964) found daily gain to be significantly greater for pigs fed the high protein diets. Food consumption was lower for animals receiving high energy diets at both levels of protein, but feed efficiency was significantly higher. The efficiency of energy utilization was lowered, as the fat content of low protein diets increased.

High protein diets resulted in leaner carcasses, while increases in dietary fat were accompanied by increases in carcass fat content.

Bowland and Berg (1959) described rather more detailed experiments designed to investigate the relationship of protein to energy in the rations of growing and finishing pigs. The diets fed over the growing period incorporated combinations of high and low energy (approx. 79 and 65% TDN) and high and medium protein (approx. 21 and 17%), and the investigation involved pigs of two strains and two sexes (gilts and castrates).

In the period up to 110 lb. pigs fed high energy rations consumed more feed per day than pigs receiving low energy diets, but differences in rate of gain failed to reach significance. High energy/high protein diets promoted the fastest growth and the highest food intake. Energy level was without effect on the efficiency of food utilization, but pigs fed diets high in protein exhibited higher food conversion efficiences than those receiving diets containing the medium level of protein.

Although carcass composition would obviously have been influenced by food consumed over the finishing period, diets high in energy were found to result in carcasses of high fat and low lean content, as indicated by the measurements recorded. The changes in the level of dietary protein had no effect on carcass composition, although there were non-significant trends indicating some increase in the lean content of carcasses from pigs fed diets high in protein.

Over the growing period significant ration x strain and sex x strain interactions were observed. In the words of the authors "These results suggest that in the growing period up to 110 lb. of weight not only absolute differences may exist between strains and sexes but that the magnitude of such differences may vary with a particular protein and energy level."

A nitrogen balance experiment involving two levels of dietary energy (64 and 80% TDN) and protein (14 and 18%), is described by Likuski, Bowland and Berg (1961). A total of sixteen castrated male pigs were involved in the experiment, i.e. four per treatment and nitrogen balance was determined at liveweights of 8, 20 and 50 kg. Unfortunately nitrogen retention was expressed only in percentage terms, which was complicated by differential nitrogen intakes of pigs receiving the same level of dietary protein (due to differences in energy content and the fact that pigs were fed to appetite). Interaction between energy and protein occurred at the 8 kg. balance period but not at the other two. The interaction showed high energy to have a beneficial effect on the percentage of nitrogen retained at the high level of dietary protein, but little or no effect at the lower. Differences in rate of gain and carcass composition in response to dietary energy and protein agreed, the authors stated, with those found by Bowland and Berg (1959).

Three levels of dietary fat (0, 15, 30%) and protein (14, 18, 22%) were fed in combination by Kuryvial, Bowland and Berg (1962) to pigs weighing 15

to 195 lb. All pigs involved were castrated males. Increases in both dietary fat and protein resulted in improvements in rate of gain, feed efficiency and carcass leanness. There was however a significant energy x protein interaction effect on daily gain and food consumption, indicating that high dietary energy "permitted full expression" of high levels of protein.

Kuryvial and Bowland (1962) fed the same diets as those used by Kuryvial et. al. (1962) to castrated male pigs and conducted nitrogen balances when the pigs weighed 7 and 45 kg. There was a non-significant increase in the percentage of nitrogen retained by 7 kg. pigs as dietary protein increased. In the case of 45 kg. pigs, nitrogen retention decreased as dietary protein increased. Rate of gain, feed efficiency and carcass composition followed the same pattern as outlined by Kuryvial et. al. (1962) but in each case the energy x protein interaction proved significant.

(b) Restricted systems of feeding

Comparatively little information is available on the significance of calorie to protein ratios to growing pigs fed restricted amounts of food.

Costain and Morgain (1961) described a 2x2x2 factorially designed experiment involving two energy levels (66 and 78% TDN); two levels of protein (15.5 to 18.5%); and two sexes (gilts and castrates).

Over the growing period (50 - 100 lb) there was a significant interaction between protein and energy, in that at the high level of protein, pigs receiving the low energy ration grew significantly faster than those fed the high energy diet, while there was no difference in growth performance between pigs fed low protein diets containing either high or low levels of energy. From the text it appears that the interaction is partly explainable

in terms of differences in protein quality (percent lysine) between the four diets. Differences in food consumption data followed the same pattern as those for growth.

Pigs fed diets high in energy produced carcasses containing significantly more fat than those from pigs fed low energy diets. There was a non-significant trend indicating that at each level of energy pigs receiving diets with narrower calorie to protein ratios (high protein) produced leaner carcasses.

Despite the fact that the experiment was designed to test sex effects no mention was made throughout the test of the influence of sex on any index of performance.

The authors tentatively concluded that it might be justifiably postulated that the dietary balance of energy and protein is of some significance in determining pig performance, particularly in so far as carcass composition is concerned.

More recently (Robinson, Morgan and Lewis 1964) a large scale experiment was carried out to investigate more fully the interrelationships between dietary energy and protein over the growing period. The experimental diets fed over the growing period were arranged as a 4x4 factorial, the factors being energy and protein, and the study was conducted using castrates and gilts. Diets were formulated to avoid the use of such materials as starch, sugar or fats and an attempt was made to standardize the amino acid composition of diets within protein groups. The four energy levels were 3260, 3120, 2860 and 2640 k. cals. D.E./kg. and the four levels of protein, 20, 18, 16 and 14% of the diet. The rations were fed in accordance with a scale based on liveweight to pigs from 23 to 55 kg. subsequent to which all animals received a common "finisher" ration to slaughter at 90 kg. when assessment of carcass composition was made. Nitrogen balance studies were carried out with pigs

fed the four extreme diets.

Before outlining the results it should be noted that some differences termed significant in the text appear as non-significant in the tables. These will be followed by question marks in the following account.

With each increase in protein to 18% there was a significant? improvement in rate of gain over the period 23 to 55 kg. but a further increase to 20% resulted in significantly? slower growth at all levels of energy except that of 2860 k.cals.D.E./kg. Food conversion efficiences followed the same pattern but in this case the differences reached significance at $p < 0.001$.

For the growth period 23 to 55 kg. increases in dietary energy from 2640 to 3120 k.cals.D.E./kg. resulted in a non-significant improvement in rate of gain but a significant ($p < 0.001$) improvement in feed efficiency. Increasing the level of energy to 3260 k.cals.D.E./kg. resulted in a non-significant and significant ($p < 0.001$) depression in rate of gain and feed efficiency respectively.

Any differences in carcass composition cannot be attributed solely to the sixteen experimental diets as they would also have been a reflection of the common finisher ration (containing 13.5% protein and 3,000 k.cals.D.E./kg) and the compensatory growth shown by pigs fed diets promoting the slowest rates of gain over the growing period.

Dietary energy level was without effect on carcass composition. Although the authors stated that there was a consistent rise in the lean content of carcasses with each rise in protein from 14 to 18% followed by a decline at the 20% level, this is not apparent from the data presented. There was however a consistent and significant improvement in eye muscle area with each rise in dietary protein. The authors concluded that the inclusion of 18% protein in diets containing 3260, 3120 or 2630 k.cals.D.E./kg.

resulted in maximum rate of gain and efficiency of food utilization, while 20% protein promoted maximum performance for diets containing 2860 k.cals.D.E./kg. They attempted to explain this phenomenon on the basis of the lysine content of the different diets. Because diets containing from 2860 to 3260 k.cal.D.E./kg. were without effect upon growth rate, food conversion and carcass quality, and in view of the absence of any significant protein x energy interactions, it was suggested that energy per se. above "a certain minimum level", and calorie to protein ratio in growing pig diets are of minor significance compared with protein, particularly with regard to carcass quality.

As all differences between rates of gain of pigs, resulting from dietary energy level, are shown and referred to as non-significant, it is difficult to comprehend how a certain minimum level of energy was regarded as critical. Furthermore reference to the relevant data does not support the contention that the level of protein was of relatively major importance in determining rate of gain and carcass quality in comparison with calorie intake. In general the validity of the conclusions reached by the authors seems subject to considerable doubt. However supposing the differences in performance upon which the conclusions were based did exist, there is still some doubt as to whether the inferences made were entirely correct. The major defect in the experiment was that data pertaining to carcass composition could not be related directly to dietary treatment, in view of the standard finishing period. There was some indication that there was an interaction between diets consumed over the growing and finishing periods. It is unlikely that higher energy intake was without effect on any index of performance, and assuming there was no influence on rate of gain or feed efficiency, then it is probable that differences occurred in the relative

rates of deposition of lean and fat which were obliterated or modified during the course of the finishing period. On this basis therefore it would have been more appropriate to conclude that the level of dietary protein had a more "permanent" effect on carcass composition than energy intake, rather than a greater influence in absolute terms. Alternatively, in the light of the standard ration fed over the later stages of growth, it would have been legitimate to conclude that energy intake over the growing period was of less significance than protein intake. For the same reasons criticism may be levelled at the conclusion suggesting the calorie to protein ratio of the diet fed over the growing period, to be of minor influence on performance.

It is perhaps worth noting the results of an experiment conducted by Robinson and Lewis (1964). These workers found that although dietary protein and energy level over the finishing period were without effect on growth rate or feed efficiency, both resulted in highly significant differences in carcass composition. From the results the authors realised the possibility of defining appropriate energy to protein ratios for finishing pigs. As the biochemical processes involved in the synthesis of body protein are likely to be similar irrespective of stage of growth, it seems improbable that if calorie to protein ratios are considered important over on arbitrarily classified growth period, they can be considered of little significance throughout some other equally arbitrary stage of growth.

From the results obtained by Robinson and Lewis (1964), cited by Lewis (1963), Lucas (1963) emphasised the limitations of the conclusions reached by Robinson et. al. (1964), in relation to the probable effect the common finisher ration would have had on performance.

(c) Conclusion

It will be apparent that from the work cited involving both ad libitum and restricted systems of feeding it is not possible to reach any firm conclusions on the significance of calorie to protein ratios in pig nutrition or to define optimum ratios in relation to "desired" criteria of production. This is due in part to a general lack of standardised terminology, but the interplay of several factors specific to each experiment must also be of significance, e.g. the breed, strain and sex of pigs used, in relation to the genetic capability for lean meat production; the source of energy (F.A.O. Nutr. Studies No.16. 1957); Donaldson, Combs and Romoser (1956); the source and quality of protein.

There does however seem to have been little attempt, particularly by North American workers, to interpret results in terms of calorie to protein ratios, rather than in terms of energy or protein. This presumably has resulted from the absence, in the majority of cases, of a significant protein x energy interaction, indicating that dietary energy and protein act independently of each other in any effects they may have on performance.

It is worth nothing that where significant calorie x protein interactions have been isolated, or are suggested by the data presented, (Lowrey et. al. 1958; Noland and Scot 1960; Costain and Morgan 1961; Clawson et. al. 1962) they apply only to comparatively early stages of growth - from 20 - 100 lb. of weight. It is possible that the apparent absence of any such interactions over later growth periods may be a reflection of the range of protein levels selected in formulation of the experimental diets. Thus from current recommendations, and in view of the declining relative requirement of the pig for protein on ageing, the younger animals involved in the experiments would have been more likely to experience protein deficiency. Where energy x protein interactions were found, increases in caloric density

depressed the growth of pigs fed low protein, wide ratio diets, but improved the performance of animals fed high protein, narrow ratio diets.

In general, response to increased energy intake results in faster growth and fatter carcasses, under both ad libitum or restricted feeding regimes (re App. 2/1). One should therefore be able to define an optimum level of dietary energy in order to achieve an acceptable rate of gain and composition of carcass, within which the protein level could be so adjusted to give maximum efficiency of energy utilization. This procedure has, in principle, been followed in the establishment of optimum ratios in poultry meat production (Combs 1962), and implies that similar ratios could be defined for the most economic production of pigmeats. As the "mechanics" of protein synthesis are likely to be similar irrespective of the morphological environment in which they proceed, it is theoretically probable that optimum calorie to protein ratios do exist in pig nutrition.

The necessity to measure response in terms of rate of gain, feed efficiency, energetic efficiency and carcass composition is stressed by Combs (1962). Only by following this procedure and ensuring that the response can be truly related to the treatment imposed, will any progress be made towards the evaluation of protein requirements in relation to energy intake in pig nutrition.

As it is not yet possible to define optimum calorie to protein ratios for various classes of pig, one must turn to the more conventional studies in order to gain information on protein requirements.

Due to the declining relative requirement of the pig for protein on ageing (Lucas 1958; Braude 1958c), standard recommendations show that diets fed to animals over the finishing period may contain a lower percentage of protein than those fed to younger stock. (N.R.C. 1964; Morgan and Robinson 1962). This implies that as the pig ages the calorie:protein

ratio of the diet fed may be widened without serious detrimental effects on performance. However the extent to which the ratio should be widened appears to be dependent upon the parameter of optimum performance. Thus evidence exists that increasing the level of protein beyond that required for maximum rate of gain results in further improvement in carcass quality (Wallace, Milicevic, Pearson, Cunha and Kojer 1954; Ashton, Kastelic, Acker, Jensen, Maddock, Kline and Catron 1955; Wenninger 1955; Beacom 1959; Robinson and Lewis 1964). Irrespective of this point it will be apparent that current recommendations for the protein requirement of the pig expressed either as a percentage of the diet or in absolute terms, represent crude and approximate estimates of optimum protein to calorie ratios, arrived at by manipulation of the protein content of the diets fed.

In view of the different planes of feeding adopted by various workers and variations in the quality of the protein used, recommendations for the protein requirement of the growing pig, expressed on a percentage of the diet, cover quite a wide range (re Morgan and Robinson 1962). However from the work cited by these authors and in reference to the NRC publication No. 1192 (1964) the protein requirement of the growing pig (approx. 50 - 100 lb.), whether fed to appetite or to a restricted scale, appears to fall at approximately 15 - 18% of the diet. It should be borne in mind that the recommendations have been established in experiments involving pigs fed all-meal diets, which have a TDN content usually in the range of 65 to 75%.

B. WHEY COMPOSITION:

Whey is the liquid by-product resulting from the precipitation of casein from skim-milk or from the manufacture of cheese from whole milk. As such it must be considered an energy rich as opposed to a protein rich food. Due to day to day fluctuations, seasonal variations and differences arising from manufacturing processes, whey quality is highly variable, both in terms of dry matter content and dry matter composition.

In reference to the literature (Wegelin 1952; Schneider 1954; Morrison 1956; McDowall and Thomas 1961; Evans 1960b; Mitchell 1963), Table 2/1 has been compiled, showing the approximate gross composition of lactic casein and cheese whey. Rennet casein whey has a composition intermediate to those shown in the table.

Table 2/1: The approximate gross composition of lactic casein and cheese wheys (percent).

	Lactic Casein	Cheese
Total Dry Matter	5.8	6.5
Protein	0.8	1.1
Lactose	3.9	4.8
Fat	0.04	0.04
Salts	0.60	0.56
Acidity (Lactic Acid %)	0.60	0.12

A full analysis of whey or serum protein is given by Wegelin (1952) and Jenness and Patton (1959). The major points of interest to this thesis are that in acid wheys approximately 25% of the total nitrogen present is in non-protein form, and of the protein, about 80% is represented in the classical lactalbumin fraction. Whether or nor allowance is made for non-protein nitrogen in published figures of the protein content of wheys is not known. It is

somewhat confusing to find on recalculation of Wegelin's (1952) data, that the values for total nitrogen content of whey powders were used in determination of the protein content of the experimental diets, although original analysis of the whey powders themselves was conducted on a total nitrogen and non-protein nitrogen basis. Presumably this must be based on an assumption that non-protein and protein nitrogen are equally utilizable by the pig. It is of interest to note that Riggs, Beaty and Mallon (1955) found whey protein extracts gave inferior performance to lactalbumin when incorporated in diets fed to rats. The non-protein and/or the lactalbumin-free protein fractions may be implicated as causes of the difference.

From this brief description it will be apparent that whey in general and lactic casein whey in particular, has a very low dry matter content (or conversely a very high water content) a relatively high soluble salt content; and low and extremely high protein and lactose contents respectively, when expressed as percentages of the dry matter.

The following sections cover the utilization and physiological effects of the major constituents of whey, viz. water, lactose, protein and salts, in pig nutrition.

C. PHYSIOLOGICAL ASPECTS OF WHEY FRACTIONS:

1. Water -

The commonly termed "bulk effect" of whey is attributable to its high water content, but the relevance of this with regard to the limitations of whey as a food for pigs has not been definitely established. It is possible that the high water intake associated with the consumption of whey, may influence animal performance in three ways: firstly through an effect on rate of passage and absorption from the intestine; secondly through a cooling effect and associated

demands on available energy; thirdly through a physical limitation to intake related to gut capacity. Whether any one, or all of these factors are of significance under practical systems of whey-feeding is difficult to determine, due to a lack of published data from experiments specifically designed to investigate this matter.

Castle and Castle (1956: 1957) found that the rate of passage of food through the pig's intestine was positively correlated with the total amount of ingesta, i.e. meal plus water, irrespective of the type of ingesta. However they found no significant effect of rate of passage on the digestibility of dry matter, although there was some indication that the faster the rate of passage the lower the digestibility of protein. Whether digestibility would be effected to a greater extent on feeding higher levels of water than those employed by Castle and Castle is not known.

Work by Dunkin (pers. comm) on the dilution of condensed whey at two planes of feeding, suggested a deterioration in animal performance at the higher level of dilution (giving a d.m.% of approx. 6) and that this was most severe at the higher plane of feeding, i.e. where absolute intake was greater. In addition, Dunkin and Carr (1965 unpub.) found that at low levels of meal supplementation ($1\frac{1}{2}$ - $\frac{1}{2}$ lb/pig/day), pigs were unable to consume enough whey of approximately 4% dry matter to support a rate of gain comparable with that of animals receiving whey of 6% dry matter. Furthermore, the growth rate of pigs receiving the most dilute whey, was somewhat lower than that of pigs fed the 6% dry matter whey, even in the earlier stages when the total daily dry matter intake of both groups was similar.

These studies suggest that the high water intake associated with whey-feeding may have detrimental effects on animal performance, in any one or all of the forementioned ways.

It cannot be assumed however that the inferior growth rates often observed when high levels of whey are fed in association with low levels of meal (see 2D) are attributable solely to the high intake of water or the low energy density of whey. Qualitative aspects of whey solids, when consumed in large amounts, may also be implicated.

It is of interest to note that both Palmer (1961) and Dunkin (1963b) found voluntary water intake to increase as whey dry matter (supplied as whey powder) intake increased, and in the latter case that this appeared to be a function of the soluble salt content of the diet. The high water intake associated with fresh whey-feeding may paradoxically therefore be beneficial, through its function in eliminations of the unavoidably high intake of soluble salts. However there is some information (Dunkin pers. comm) that the amount of water associated with dry matter in fresh whey, may exceed the requirement for elimination of salts. Thus pigs receiving whey containing 30% dry matter, diluted it by voluntary water intake to approximately the equivalent of a 9% dry matter whey.

2. Lactose -

(a) General

The following short account of the physiological effects and utilization of dietary lactose in mammalin species was complied from reviews by Fischer 1957; Atkinson, Kratzer and Stewart 1957; Herzenberg and Herzenberg 1959. More detail is available by reference to this literature.

Lactose is a reducing disaccharide found only in milk and its by-products, which on hydrolysis yields equal quantities of glucose and galactose.. Hydrolytic breakdown of lactose occurs during its passage through the intestinal mucosa of the upper small intestine, but some unhydrolysed lactose is also absorbed. Due to either difficulty of

absorption and/or hydrolysis, lactose remains in the digestive tract for a comparatively long time, and consequently appears lower in the intestine than the majority of digestible food substances. At these lower regions, lactose hydrolysis may be induced through lactase of bacterial origin - a fact of possible importance in adaption to prolonged intake of high levels of lactose. Thus in illustration, adaptive enlargement of rat (Lawrence, Fischer, Sutton and Weiser 1956) and pig (Shearer 1967) caeca in response to increases in dietary lactose has been reported, suggesting increases in the activity of the floral population of the caecum.

The fate of lactose per se. and galactose entering the blood stream is not well understood, although neither is utilized as well as glucose by the adult mammal as a source of energy (Verzar and McDougall 1936). There is evidence that galactose is better utilized in the presence of glucose than when consumed on its own (Carleton, Misler and Roberts 1955). This may possibly be a reflection of the inhibitory effect of glucose on galactose absorption (Crane 1960), thus effectively reducing the systemic concentration of galactose and in view of the low renal galactose tolerance (Folin and Bergland 1922) minimizing the loss of galactose via the urine.

Apart from phosphorylation and inversion of galactose to glucose for energy yielding purposes - presumably of greater significance the higher the level of dietary galactose - galactose also plays a "structural" role, through its incorporation in mucopolysaccharides and cerebrosides. (Muir 1961: Maurice 1962). Although high levels of systemic galactose have been reported to induce cataract formation in rats and chicks and convulsions and subsequent death in chicks, no such effects have been reported in the case of the pig (Atkinson et. al. 1957).

Certain dietary ingredients, e.g. fat, sugars, calcium salts may enhance lactose utilization, while the lower pH and induced aciduric floral type of

the intestinal contents of lactose-fed animals may reduce the dietary requirement for particular nutrients, e.g. B-group vitamins, calcium and phosphorus.

Fischer and Sutton (1949a) discussed at length the observation that apart from reduced food consumption and rate of gain, animals receiving diets high in lactose often display a high incidence of diarrhoea. In explanation they considered the hydragogue concept, involving the osmotic movement of water into the gut lumen in response to hypertonic lactose solution, the most plausible.

In conclusion it may be said that at the animal level the overall response to dietary lactose may be considered a combination of responses to unhydrolysed lactose present in the gut and to lactose and its hydrolytic products absorbed from the intestine. As the value of lactose as a source of energy depends largely upon its hydrolysis to glucose and galactose, the "ability" of the animal to achieve such hydrolysis is of prime importance.

(b) Development of lactase activity in the pig

The pattern of development of lactase activity in the baby pig has been studied by several workers (Bailey, Kitts and Wood 1956; Walker 1959; Catron, Baker and Hartman 1957; De Groot and Hoogendoorn 1957; Hartman, Baker, Neagle and Catron 1961). Although some discrepancy exists between results, which may possibly be associated with the different methods used in expressing activity, the general pattern of development is quite well established. At birth, lactase activity, expressed per unit intestinal weight, is high, but declines to reach a minimum but thereafter (to 8 weeks of age at least) constant level at 4 - 6 weeks of age. This basal level approximates to 10% of that at birth. There is evidence that the characteristic pattern of changing activity may be modified somewhat by the type of diet consumed.

Although intestinal lactase activity, expressed on the basis of unit intestinal weight, diminishes over the first 4 - 6 weeks of life, it is probable that total activity remains at least constant, or even increases with age, due to the natural increase in intestinal size. The data presented by Bailey et. al. (1956) suggested total lactase activity to be approximately the same at 8 weeks of age as at birth, while the results of Walker (1959) showed constant total activity, or slightly increasing activity, over the first 5 weeks of life. Walker (1959) concluded that total activity remains constant as the pig ages. However this conclusion is not entirely supported by the data presented and in any case is only applicable to the first 5 weeks of life at the end of which the experiment terminated. No positive information could be found relating to total lactase activity in pigs subsequent to 8 weeks of age. If activity per unit weight of intestine reaches a basal but constant level at 4 - 6 weeks of age, then total activity might be expected to rise subsequently, although changes in mucosal cell numbers and the secretory activity of individual cells would also be of significance.

The literature to be reviewed in following sections indicates that the pig is able to utilize greater quantities of lactose on ageing, despite the fact that the amount it can utilize expressed as a percentage of total food intake decreases. This suggests that total lactase activity increases with the age of the pig.

An important aspect of lactose utilization concerns adaptation to prolonged intake of high levels of the sugar, typified by cessation of diarrhoea. Studies with laboratory animals have led to current views on the physiological processes involved (Fischer and Sutton 1949, 1953; Fischer, Sutton, Lawrence, Weiser and Stahly 1949; Lawrence et. al. 1956; Dalqvist and Thompson 1964) which favour both an increase in intestinal

lactase output through adaptive increases in mucosal tissue and an increase in bacterial fermentation involving enlargement of the caecum. In relation to the pig, Shearer (1967) found increases in caecal size as the lactose content of the diet increased, which in association with observed changes on the prevalence of diarrhoea suggested that the pig is also capable of adaptation to high levels of dietary lactose. It seems likely therefore that the total lactase activity (mucosal plus bacterial) of pigs older than 8 weeks, is not simply a function of age but also of the diet previously consumed. Consequently pigs of the same age, but fed diets containing different amounts of lactose, would be expected to show different total lactase activities. This conclusion emphasises the importance of the gradual introduction of milk by-products into the diets of pigs, to avoid excessive scouring often accompanying abrupt and drastic introduction.

(c) Lactose in pig nutrition

Becker, Ullrey and Terrill (1954) reported that the baby pig (7 - 35 days of age) is capable of utilizing a dietary level of at least 57% lactose with no adverse effects upon health, growth performance or food utilization. However Becker and Terrill (1954) found that a diet containing 50% lactose fed to pigs of 9 weeks of age for 39 days, significantly depressed growth rate and food intake and caused a moderate level of scouring. Pigs of 16 weeks of age were found capable of tolerating 25% of dietary lactose without any adverse effect on performance, but incorporation at 50% induced slower growth, lower feed intake and a low level of scouring. It is worth noting that the diets fed in the experiments cited were of a semi-synthetic nature and that the pre-experimental diets used in the 9 and 16 weeks of age studies were devoid of lactose.

Dunkin (1957) reported an experiment involving diets containing 4 levels of crude lactose (increasing in amount as the pigs aged), fed in

conjunction with a fixed daily allowance of meal to weaner pigs. The highest level exceeded the estimated lactose intake of pigs on high levels of whey feeding. With successive increases in lactose intake growth was significantly depressed and persistent scouring and unthriftiness developed in pigs receiving the highest level. It should be mentioned that the observations may have been complicated by qualitative deficiences in the diets of high lactose content.

Wegelin (1952), from work designed primarily to evaluate the nutritive value of whey powder protein, concluded that the adverse effects of feeding high levels of dried whey to growing and finishing pigs, could be attributed to the lactose and/or salt content. He found reduced rates of gain and feed efficiency in animals receiving diets containing 60 and 75% whey powder, providing 23 and 29% of lactose.

Shearer (1967) fed pigs over the weight range from 50 to 120 lb. on diets containing from 0 to 45% lactose. In one experiment, involving 7 replicates per treatment, sequential increases in dietary lactose were accompanied by significantly inferior rates of gain and feed efficiency, with a higher incidence of scouring and a general increase in variability of performance. However in a second experiment, involving 4 pigs per treatment fed diets similar to those of the first experiment, the level of dietary lactose was without significant ($p < 0.05$) effect on either growth rate or efficiency of food utilization. Examination of the relevant data suggests that the discrepancy between the results of the two experiments was in fact a true difference in the response of treatment groups, rather than a difference in significance resulting from variability in within-treatment variation. Thus in general, pigs in the second experiment fed the lowest level of dietary lactose (0%) performed poorly compared with their counter-

parts in the first experiment, while the opposite situation appeared true for pigs fed the highest (45%) lactose diets.

3. Whey Protein -

No reference could be found concerning the utilization of protein in fresh whey. As whey protein is predominantly lactalbumin, of high biological value (Jenness and Patton 1959), it is generally assumed that whey protein per se. is of high value.

Riggs et. al. (1955) fed a variety of dried whey protein extracts to rats and obtained biological values of 91.0 - 93.9% and 81.8 - 83.5% for spray and roller-dried samples respectively. The former promoted significantly faster growth than the latter, but were inferior to lactalbumin. Similar differences between spray and roller-dried whey powder were reported by Baker, Becker, Notzold, Jensen and Norton (1962) and Baker et. al. (1963). It was suggested that heating during roller drying in the presence of sugars renders the whey protein resistant to enzymic hydrolysis. In contrast, Becker, Terrill, Jensen and Hanson (1957) found that pigs fed roller-dried whey samples grew significantly faster and utilized their food more efficiently than pigs receiving diets containing spray-dried whey. Despite this controversy, it is probable that as fresh-whey protein is not exposed to heat treatment, its "potential" biological value is on a par with that of protein in spray-dried whey powders, i.e. approximately 90%.

Wegelin (1952) found that whey powder protein could totally replace traditional sources of animal protein (fish meal and tankage) without any significant deterioration in the performance of growing/finishing pigs. He concluded by saying "..... whey proteins are an excellent form of animal protein".

In conclusion therefore, studies with rats and pigs have shown that the protein contained in whey powders is of high quality, although it may be influenced

to some extent by processing technique. However extension of this premiseto include the protein of fresh whey, is not entirely justifiable, in that factors specific to fresh whey may influence protein quality.

4. Salts -

Daniel and Harvey (1947) reported that dialysis of whey solids had a beneficial effect on their nutritive value for rats and that whey ash reduced the rates of gain of rats fed dried whole milk and dialysed whey as the source of protein. Wegelin (1952) concluded that either lactose and/or salts were responsible for the detrimental effects of diets containing high proportions of whey powder fed to growing/finishing pigs. Dunkin (1963b) found reduced performance of pigs, from 50 to 140 lb. liveweight, fed a diet containing 50% neutralized whey powder. Neutralization was achieved by treatment with sodium hydroxide, giving an increase of approximately 3% by weight of sodium and resulting in reduced acidity. As Dunkin (1959) could find no effect of the acidity of fresh whey on pig performance, it may be tentatively concluded that the deletrious effect of neutralization was associated with the increase in salt (sodium) content. Baker et. al. (1962) found the phosphorus content of dried wheys fed to rats, to be significantly negatively correlated with the incidence of diarrhoea.

From the literature cited it is apparent that the high salt content of whey powder may have deletrious effects on animal performance, but the evidence is far from strong. For this reason, it is not possible to evaluate with confidence, the significance of the concomitant intake of salts by pigs fed fresh whey.

5. Summary -

(a) Very limited information exists to support the contention that the high water content of whey is a limiting factor in its value as a food for pigs.

(b) The value of lactose as a source of energy is dependent largely upon the ability of the animal to hydrolyse it to glucose and galactose. When fed at levels in excess of tolerance, growth depression, lowered feed intake and efficiency, diarrhoea, and maybe death ensue. Although the absolute amount of lactose which the animal can utilize increases with age, the percentage which it is able to tolerate in the diet decreases with age. The level of tolerance may be influenced by adaptive processes. Limited evidence suggests that the baby pig is capable of tolerating at least 57% of dietary lactose, while proportions in excess of 15% have been found to adversely effect the performance of growing/finishing pigs.

(c) From experiments with dried whey protein, the "potential" biological value of fresh whey protein is very high. However its "actual" value may possibly be influenced by characteristics specific to fresh whey.

(d) Very limited information suggests that the relatively high content of salts in whey has a detrimental effect on anaimal performance.

D. THE UTILIZATION OF WHEY AND WHEY PRODUCTS BY THE PIG:

1. Percent. whey dry matter intake increasing with age or liveweight -

(a) Fresh Whey

Braude, Clarke, Mitchell, Cray, Franke and Sedgwick (1957) found that under ad. libitum systems of whey-feeding (group-feeding under large-scale commercial conditions), a daily meal allowance of 3 lbs/pig supported growth rates from weaning to baconweight equal to those achieved on an all-meal diet,

fed to a maximum daily allowance of 6½ lbs/pig. The efficiency of dry matter utilization was significantly greater for the pigs receiving whey. Reduction of the daily allowance of meal/pig from 3 to 2 lbs, at either 13 or 17 weeks of age, resulted in significantly poorer rates of gain. In the latter case, but not the former, food conversion efficiency was also significantly poorer. Pigs fed diets containing whey had, in general, less back-fat than pigs receiving all-meal diets, and as the daily meal allowance fed in conjunction with whey decreased, so back-fat measurements decreased (this may have been partly attributable to the associated slower growth rate).

Reference by Braude, Mitchell, Cray, Franke and Sedgwick (1959) to unpublished data (Braude et al.) showed that reduction of the daily allowance of meal at 14 weeks of age to 1 lb/pig, fed in conjunction with unrestricted amounts of whey, caused a marked reduction in rate of gain. Complete elimination of meal at 17 weeks of age resulted in a virtual cessation of growth. The authors concluded "..... that to attain a reasonable rate of growth under ad. libitum systems of whey feeding, a daily meal allowance of 2 lbs/pig is the absolute minimum."

One can only assume that in this context a "reasonable rate of growth" is one commensurate with the rate of gain achieved under restricted all-meal feeding systems. This need not necessarily be a "reasonable rate of growth" under whey-feeding systems.

A small scale experiment conducted by Dunkin and Carr (1964), involving two groups of four pigs per treatment growing from 45 to 140 lb. liveweight, indicated a decrease in growth performance of the order of only 10%, on reducing the daily meal allowance from 2 to 1 lb/pig plus whey fed to appetite. Although the limitations of this information are appreciated, it is of possible significance that the two levels of meal were fed as such from the beginning of the experimental period, while in the study referred to by Braude et. al. the reduction in meal

allowance was made part way through the growth period. Possible adaptation to diets high in whey *per se*. or lactose could be implicated. It is of further interest to note that the daily liveweight gain and feed efficiency of the pigs recieving only 1 lb. meal daily in the experiment of Dunkin and Carr were 1.11 lb. and 3.75 lb/lb. LWG. respectively. Corresponding values for pigs receiving 3-2 lb. meal daily, reported by Braude *et. al.* (1957), were 1.11 and 4.23. Such differences in performance must influence any contention suggesting a daily meal allowance of 2 lb/pig to be an "absolute minimum".

Mitchell and Sedgwick (1963) fed daily meal allowances per pig, in association with unrestricted whey, of 3 lbs. $2\frac{1}{2}$ lbs. 3 lbs. reducing to 2 lbs. at 13 weeks of age and remaining at that level, or increasing to $2\frac{1}{2}$ lbs. at 20 weeks of age. The growth period studied was from 9 weeks to 200 lbs. liveweight and the experiment was conducted under group-feeding commercial conditions. The treatment involving an increase in meal allowance at 20 weeks of age was included in accordance with observations of Braude *et. al.* (1957), who noted a decline in the growth rate of pigs fed similar diets at this age, or in terms of liveweight, at 150 lbs.

Differences between treatments in growth rate, food economy and carcass quality were small and failed to reach significance.

From a 3 x 3 factorially designed experiment, involving three levels of meal ranging from 0 to $1\frac{1}{2}$ lbs/pig/day, fed in conjunction with whey restricted to three scales based on liveweight (Dunkin 1961 unpub.) found that as the ratio of meal to whey in the diet increased so pig performance improved. Thus pigs receiving diets involving the higher daily allowances of meal grew faster and utilized the total dry matter consumed more efficiently than pigs fed the lower meal diets, at all stages of the entire growth period extending from 50 to 180 lbs. liveweight.

(b) Concentrated Whey Products

Dunkin (1958) reported an experiment where condensed whey, containing approximately 68% dry matter, was fed to pigs from 50 to 110 lb. liveweight. The condensed whey, diluted 1:1 with water, was fed in association with three fixed levels of meal, such that animals of the same weighton each treatment received equal daily allowances of dry matter. Performance of pigs receiving diets containing condensed whey was compared with that of animals fed an all-meal "control" ration.

It was found that reduction of the daily meal allowance below 2 lbs/pig resulted in significant decreases in growth rate and food (d.m.) conversion efficiency, while an allowance of 2 lb. meal gave comparable performance to the all-meal "control" diet. As the refusal of food presented, by animals on meal levels less than 2 lb/day amounted to only 2% for the total growth period, it may be concluded that the physical limit to intake was not grossly exceeded, if at all, and the inferior performance was attributable to other factors specific to the condensed whey. Over the total growth period, whey dry matter contributed 40, 69 and 82% of total dry matter intake for pigs receiving 2, 1 and $\frac{1}{2}$ lb. meal/day respectively.

(c) Dried Whey

In a paper relating to two experiments, Dunkin (1963a) reported that a diet comprising 2 lbs. meal/day and increasing amounts of lactic casein whey powder, gave significantly faster growth and higher efficiency of food utilization when fed to pigs from 50 - (120 - 140) lb. liveweight, than either diets of lower meal and higher whey content, or an all-meal "control" diet. Whey dry matter fed in association with 2 lbs. meal, represented 40% of total dry matter intake over the growth period involved. In one experiment, diets containing more whey powder than this resulted in significantly faster rates

of gain over the growth period 48 - 110 lb. However a relative deterioration in growth rate from 110 to 140 lbs. liveweight resulted in the situation as outlined above for the overall period from 48 to 140 lb.

2. Constant proportions of whey dry matter in the diet -

(a) Fresh Whey

O'Grady (1963) fed fresh whey to pigs of 50 to 200 lb. of weight, such that whey contributed 12.6, 17.7 or 22.3% of daily dry matter intake. Feeding was on a semi ad libitum basis, to a maximum daily allowance. The work was carried out as two separate experiments, the results from these being somewhat discrepant. For this reason the only valid conclusion to be drawn from the results is that whey may be fed up to at least 22% of total dry matter intake without any adverse effect on pig performance.

(b) Dried Whey

Using semi-synthetic diets containing from 0 to 60% dried cheese whey, Becker, Terrill, Jensen and Hanson (1957) were unable to find any significant differences between rate of gain or feed efficiency in pigs of 2 to 6 weeks of age. These results were supported for the most part by Palmer (1961) feeding "practical" diets, incorporating 0 to 45% lactic casein whey powder, to early weaned pigs from the ages of 3 to 8 weeks. Palmer however did find a significant but small linear response in feed efficiency, pigs on diets containing higher levels of whey powder, utilizing their food more efficiently. Becker et. al. (1957) were unable to reproduce their findings using "practical" diets, 20% and 30% whey powder diets causing significant reductions in growth rate. They attempted to explain this phenomenon on the basis of possible differences in the inorganic fractions of the two types of diet, in reference to the observation of Daniel and Harvey (1947) on the influence of whey salts on animal

performance. When similar synthetic diets were fed to pigs of 100 lb. liveweight, the inclusion of 60% whey powder markedly depressed food intake and growth, and induced severe scouring, while 40% had a comparatively small non-significant effect on growth, accompanied by a low level of scouring.

Dunkin (1963b) reported an experiment designed to compare the effects of un-neutralized (WP) and neutralized (NWP) lactic casein whey powders included in the diets of pigs from 50 to 140 lb. liveweight. The rates of incorporation were 0, 25 and 50%. From 50 to 110 lb., diets containing 25% and 50% WP, or 25% NWP, promoted significantly faster growth than those containing no whey powder or 50% NWP. Over the total growth period, there was no difference in the performance of pigs fed the 0% "control" diet or the 25% and 50% WP and 25% NWP diets. Pigs fed the latter three diets grew significantly faster than pigs receiving the 50% NWP diet throughout the entire growth period. Reference has already been made (2C) to the possible cause of the detrimental effect of high NWP, the point of major interest to this section being the observed response to the inclusion of un-neutralized whey powder in the diet.

3. Summary -

From the literature cited the following generalizations may be made as a summary to this section.

(a) Under ad libitum systems of whey-feeding, a minimum daily meal allowance of 2 - 3 lb/pig is necessary to maintain a rate of gain comparable with that achieved on all-meal diets over the growth period 50 - 200 lb. liveweight. Sequential decreases below this allowance result in sequential deterioration in animal performance,

the severity of which may depend partly on the "opportunity" for adaption.

(b) Systems of feeding concentrated and dried whey, designed to simulate fresh whey feeding programmes based on a fixed daily meal allowance, suggest a reduction in animal performance when whey dry matter exceeds approximately 40% of the total dry matter intake during the post weaning growth period up to 100 - 140 lb. liveweight. This situation coincides with a daily meal allowance of 2 lb/pig.

(c) Whey dry matter, when substituted for cereals on a dry matter basis, may have a growth promoting effect. This seems to be particularly applicable to the early post-weaning period (possibly a reflection of the dietary content of protein per se. amino acids or digestible energy).

(d) Whey dry matter, when fed as a fixed percentage of the diet, may represent up to 40 - 50% of intake without any serious detrimental effect on performance, in pigs weighing from 50 to 140 lbs.

(e) Pigs weighing up to approximately 50 lb. are capable of tolerating at least 60% whey dry matter in the diet, but this may be influenced by the type of diet fed.

As the above are only generalizations they will be subject to modification through, for example, physiological, environmental and dietary factors specific to a particular situation.

E. THE PROTEIN CONTENT OF MEAL SUPPLEMENTS FOR WHEY-FED PIGS:

Braude et. al. (1958a) and Braude et. al. (1959) conducted experiments designed primarily to evaluate the comparative nutritive value of skim-milk powder and white fish meal, when incorporated in the meal fraction of the diets of pigs receiving

3 reducing to 2 lbs. (at 13 weeks of age) of meal daily, plus whey fed to appetite. In the first experiment the meals contained 10% white fish meal (WFM) or 10, 15 and 20% skim-milk powder (SMP) giving crude-protein levels of 18.3, 15.4, 16.6 and 17.8% respectively. Pigs receiving the meal supplement containing 20% SMP, grew significantly faster and utilized their food more efficiently than pigs receiving either of the other three meals, between which there were no differences. Differences in carcass quality and whey intake were small and failed to reach significance.

In the second experiment, meal supplements were fed containing 10, 7 or 5% WFM or 10% SMP, giving crude protein levels of 17.4, 15.7, 14.6 and 14.3% respectively. All differences in performance were non-significant, although there was a trend for growth rate and feed efficiency to decline as dietary protein decreased.

Valid comparisons between the results of the two experiments cannot be made due to (a) differences in animal performance involving differences in the pattern and absolute amounts of whey ingested; (b) the absence of a published figure for the protein content of the whey fed in either experiment.

Firm conclusions from either experiment, regarding response to protein level per se. are not possible because of differences in the energy content and biological value of the two types of protein used. It seems probable that the response to SMP in the first experiment could be attributed to either or both of these factors. (c.f. Braude et. al. 1958b; Baker, Braude and Mitchell 1958).

In an attempt to formulate practical recommendations from the two experiments, the authors suggested that meal supplements fed in association with unrestricted supplies of whey, presumably at the rate of 3 - 2 lb/pig/day, should contain a minimum of 10% WFM or 15% SMP. In view of the comparatively small range of protein levels tested and the difficulty of attributing response solely to dietary protein content, the conclusion must be interpreted with caution. Thus neither experiment

conclusively showed that 10% WFM or 15% SMP were in fact minimum requirements. In the first experiment there was no appreciable difference between the performance of pigs fed meal supplements containing either 10 or 15% SMP or in the second experiment between the performance of pigs fed meal supplements containing 10, 7 or 5% WFM. For purposes of this thesis it is concluded that under the conditions of the two experiments, no significant response in growth rate, feed efficiency or carcass quality could be attributed solely to meal-supplement protein levels, ranging in one case from 15.4 to 18.3% and in the other from 14.3 to 17.4%, in pigs weighing from 50 to 200 lb.

A paper by Dunkin (1961) describes an experiment designed to assess the need for supplementary protein of growing pigs (50 - 110 lb. Lwt), fed 1½ reducing to 1 lb. (at 80 lb. Lwt) of meal/day, in association with restricted amounts of cheese whey. The experiment incorporated a comparison between meat meal and buttermilk powder as the source of protein. Meat meal and buttermilk powder each replaced barley meal in the meal supplements, on a weight basis, at the rate of ¼, ½ or 1 lb. and these 6 treatments were compared with a "control", comprising all barley meal. The inclusion of meat meal was without effect on any index of performance, while increases in dietary buttermilk powder promoted a significant linear increase in rate of gain. However correction of the performance of pigs receiving the buttermilk powder diets on the basis of equal TDN intake, suggested that the influence of buttermilk powder on growth rate was largely due to its high energy content.

From the work cited it is apparent that there is no conclusive information on either the need for or the response to supplementary protein in the meal fraction of the diet of pigs receiving 3 - 2 lb. or 1½ - 1 lb. meal daily plus whey.

CHAPTER 3

GENERAL APPROACH TO THE INVESTIGATION

The object of the study was to assess the need for protein concentrates in diets based on whey.

A. SELECTION OF TREATMENTS:

1. Facilities -

The facilities available most suited to the investigation were:-

(a) A Danish-type experimental house, providing accommodation for 28 individually penned and fed pigs, with provision for the control of environmental temperature but not of humidity.

(b) A metabolism unit, suitable for digestibility and balance experiments, comprising 12 individual pig holding-pens, and 8 metabolism cages, designed for use with pigs from weaning to baconweight. There was again provision for the control of environmental temperature but not of humidity.

2. Food Supply -

The availability of whey was restricted to the New Zealand dairy season, extending from approximately August to April - a total of 9 months.

3. Dietary factors -

(a) Meal Level

Pig feeding programmes based on whey, involve supplementation of the diet with a meal concentrate. The actual level of meal fed in practice will depend upon a variety of factors, e.g. the relative costs of whey and meal; the availability of whey; the system adopted in feeding

whey, etc. However, in both the commercial and experimental fields, both in New Zealand and abroad, the daily allowance of meal per pig falls usually in the range of ½ to 3 lbs. Barley meal, as it is more often than not, the cheapest source of concentrate energy, forms the basis of the meal supplements.

On consideration of the relative protein contents of barley meal and whey, one might expect the need for protein supplementation to be greater when the former represents a higher proportion of the diet as a whole. This implies that the requirement for supplementary protein is likely to be greater, the higher the daily allowance of meal, and that this would be particularly so over the earlier stages of growth, when whey intake is comparatively small at a period when the pig has a relatively high requirement for protein.

For these reasons it was concluded that the experiment should include treatments involving at least two levels of meal supplementation.

(b) Levels of protein supplementation

In order to assess possible rectilinear or curvi-linear response to the addition of protein to the diet, it was concluded that at least 3 levels of protein supplementation were necessary within each level of meal supplementation.

(c) Source of supplementary protein

The object of the experiment was to evaluate the requirement and response of the pig to supplementary protein, in quantitative terms alone. This implied that the two other factors of major influence on the fate of dietary protein, viz. protein quality and calorie intake would have to be controlled. With regard to the former, it seemed preferable that the protein selected should be of high quality in order to maximise response.

For this reason, and in relation to the availability of protein sources, dried butter-milk powder (DBMP) was chosen. As DBMP, like whey, is of milk origin it was felt that its addition to the diet would have a relatively small effect on the amino acid pattern of the diet as a whole, in comparison, say, with meat meal.

(d) Control of calorie intake

As the response to dietary protein is influenced by energy intake, it was imperative that the consumption of energy by animals on all treatments should be equal. This implied that whey would have to be fed in controlled (restricted) amounts, such that pigs fed diets involving different levels of meal supplement, would be fed whey to different scales, so adjusted that the total daily intake of energy by animals of the same weight on all treatments would be the same.

It also implied that measures would be necessary to counteract the increases in energy content of meal supplements, resulting from the replacement of barley meal by DBMP.

4. General considerations -

In order to make full use of the available facilities and to obtain as much information as possible, it was decided that two experiments would be conducted.

(a) A performance experiment sited in the Danish experimental house, involving the assessment of diets on the basis of liveweight gain, efficiency of food utilization and carcass quality.

(b) A nitrogen balance/digestibility experiment conducted in the metabolism unit, involving the assessment of diets on the basis of nitrogen retention and digestibility, in relation to the intake of digestible energy.

The desirability of equalising the energy intake of animals on all treatments was emphasized above. However due to the limitation of facilities prior to the start of the experiments, it was not possible to obtain definite information on the energy content of the experimental diets. For this reason, standardization of enery intake was achieved through the use of published figures for the TDN values of the major dietary ingredients (see 4C and D). The digestibility and balance experiment, thus apart from providing information on nitrogen metabolism, furnished positive information on the digestible energy content of the diets, and at the same time served as a check on the accuracy achieved in standardisation of TDN (digestible energy) intake.

5. Summary -

Considerations led to the following conclusions:-

(a) The investigation would involve two experiments: a performance experiment and a digestibility/balance experiment.

(b) Diets involving at least two levels of meal supplementation would be studied.

(c) There would be at least three levels of protein, within each meal level.

(d) DBMP would be used as the source of protein.

(e) Rations would be so adjusted that animals of the same weight on all treatments would have the same daily energy intake.

B. SELECTION OF EXPERIMENTAL DESIGN:

1. Level of Replication -

From an experiment conducted in the Danish experimental house mentioned above, Dunkin (1961) found a coefficient of variation of 4.9% (42 d.f.) for the daily gain of pigs, weighing 50 - 120 lb., fed diets based on whey with low levels

of meal supplementation.

Substituting this value for C in the following equation, it is possible to estimate the number of replicates (n) necessary to show significance between treatment means, when the differences exceed a particular percentage (D) of the general mean. ($t\ 0.05 = 2.021$).

$$n = \left(t \times \frac{2 \times C}{D}\right)^2$$

Thus when D = $2\frac{1}{2}$, 5, $7\frac{1}{2}$ and 10%, n= (approx., to the nearest whole number) 31, 8, 4 and 2 respectively. This agrees well with the table of Bird and Gutteridge (1934). It is apparent that to obtain values of D $<$5%, the number of replicates required increases quite markedly. Thus to double the experimental precision from D = 5 to D = $2\frac{1}{2}$%, involves increasing the level of replication fourfold (2^2).

For the performance experiment, 8 replicates per treatment was considered the minimum acceptable number, giving significane at $p < 0.05$ between treatment means, when the differences exceed approximately 5% of the general mean.

The coefficient of variation used above, in deriving the number of replicates, refers only to growth performance data. During the course of research work conducted at Massey University, the coefficients of variation for carcass characteristics of pigs fed whey diets have been disclosed to be considerably higher than the coefficient pertaining to growth data. For this reason, the number of replicates required to give the same experimental precision for tests between the means of various indices of carcass composition, as for tests between growth data means, would need to be considerably higher, e.g. when D = 5 and C = 10, n = 32 ($p < 0.05$).

Although coefficients of variation in excess of 10% were expected from the carcass composition data, it was not possible, for reasons allied to the facilities available, the duration of the experiment and the number of treatments desired, to achieve a level of replication in excess of 8.

In the case of the digestibility/balance experiment the main factors limiting the level of replication were the availability of facilities and the amount of chemical analysis which could be undertaken by a single operator.

2. Experimental design -

The designs most suited to the investigations were the factorial and the randomized block.

The minimum acceptable number of treatments was 6 viz. treatments involving two levels of meal supplementation and three levels of protein incorporation within meal levels. Thus at first sight a 2 x 3 factorial design seemed appropriate to the experiment. However as different amounts of whey were to be fed to pigs receiving diets involving different levels of meal supplement, level of whey intake would represent a third main effect. Thus the complete factorial design would have involved a minimum of 12 treatments re 2 x 2 x 3. On consideration of the facilities and time available this number of treatments was not possible.

For the reasons outlined above the experimental design most suited to the investigation was the randomized block.

3. Summary -

It was concluded that:-

(a) A minimum of 8 replicates per treatment should apply to the performance experiment.

(b) The number of replicates per treatment involved in the digestibility/balance experiment, would be dependent primarily

upon the amount of chemical analysis etc. which could be satisfactorily handled by a single operator.

(c) The experiments would be based on a randomized block design.

C. TREATMENTS SELECTED IN RELATION TO THE EXPERIMENTAL DESIGN:

1. The performance experiment - Experiment I -

The minimum number of pigs which would be involved in the experiment was 48: viz. a minimum of 6 treatments and 8 replicates per treatment.

The experimental house available for the study, provided accommodation for 28 individually penned pigs at any one time. Thus to meet the desired requirements associated with the number of treatments and replications, it was apparent that at least two sub-experiments would have to be conducted, later ones being repetitions in time of the first.

The maximum duration of such a series of sub-experiments was dictated by the availability of whey; namely 9 months.

Arising from the following considerations:-

(a) Rates of gain of pigs fed diets based on whey.

(b) Adequate length of experimental growth period.

(c) The likely relative requirements for additional protein of pigs, at various stages of growth, fed whey diets.

(d) The problem in interpretation of response to treatments if continued over a large weight range, in view of changing protein needs.

it was concluded that two sub-experiments would be conducted, each involving pigs growing from 50 - 120 lbs. liveweight.

It followed therefore, that in all, the facilities available could accommodate 56 pigs, or more precisely 2 x 28 pigs.

In order to maintain a balanced design both between and within sub-experiments, the two possible alternatives were either randomized blocks involving 6 treatments and 4 replicates or 7 treatments and 4 replicates, in each of two sub-experiments.

To make maximum use of the facilities the latter alternative was selected.

To comply with the conditions already outlined, a 7 treatment experiment would involve two levels of meal supplement fed in association with whey, with three rates of protein supplementation at one meal level and four at the other.

As the need for additional protein is likely to be higher when the meal to whey ratio of the diet as a whole is higher, it was decided that the four rates of protein supplementation should occur at the greater of the two meal levels adopted.

2. <u>The digestibility/balance experiment - Experiment II</u> -

As the object of experiment II was to obtain more detailed information on the fate of the protein consumed by animals fed the same diets as those involved in experiment I, it followed that the experimental diets fed in experiment II would be identical to those fed in experiment I (unless intermediate treatments were omitted, which was considered inadvisable).

Consequently the total number of pigs appearing in experiment II would be some multiple of 7.

In view of the changing pattern with age or weight of the relative protein requirement of the pig, nitrogen balances were to be conducted at various stages throughout the experimental weight range. Three balances per pig was considered a minimum, in order to assess linearity of response.

Thus with one replicate per treatment, a total of 21 balance periods would have been involved.

Due primarily to the resultant volume of chemical analysis involved, two pigs per treatment was considered the maximum level of replication which could be achieved. This implied a total of 42 collection periods with the associated determinations of urinary nitrogen, faecal energy and nitrogen, and food energy and nitrogen.

3. Summary -

The limitations imposed on theoretical preference by practical possibility resulted in the selection of:

(a) An experimental growth period extending from 50 to 120 lbs. liveweight for both Experiments I and II.

(b) Seven treatments for both Experiments I and II, involving two levels of meal supplementation, with three rates of protein incorporation at the lower level of meal and four at the higher.

(c) Four replicates per treatment in each of two similar consecutive sub-experiments, making up Experiment I.

(d) Two replicates per treatment in Experiment II.

CHAPTER 4

EXPERIMENTAL DIETS

A. GENERAL:

The two major ingredients of the meal supplements were barley meal and DBMP.

The whey fed throughout the experiments was lactic casein whey, supplied by a local dairy factory on a daily basis (in an attempt to simulate on farm conditions).

Analyses carried out on samples of whey coming from the factory before the experiments started, showed that it contained approximately 5.7% dry matter, of which 17 - 18% occurred as protein. These values agreed well with the results of a series of analyses performed on whey samples coming from the same factory throughout the previous dairy season.

Before the start of the experiments, a single line of barley, to meet the estimated requirements of the two experiments, was ordered and kept aside at a local mill, to be subsequently drawn upon and ground as required. Pre-experimental Henneberg analysis (A.O.A.C. 1965) of a sub-sample of this barley, obtained by sampling each bag of the specified line gave the proximate composition shown in Table 4/1.

A single consignment of DBMP was obtained before commencement of the experiments, and after thoroughly mixing, was held in sealed polythene bags until required for experimental purposes. A sample taken after mixing was analysed, giving the composition shown in Table 4/1.

In Chapter 3 it was mentioned that the daily meal and whey allowances of animals on all treatments were to be adjusted, so that the energy intakes at any particular liveweight would be the same for all animals. It was also mentioned

Table 4/1: The proximate composition (%) of samples of barley meal and DBMP used throughout Experiments I and II.

	Barley Meal		DBMP	
	Wet Matter Basis	Dry Matter Basis	Wet Matter Basis	Dry Matter Basis
Moisture	13.4	-	4.9	-
Crude Fibre	3.5	4.0	-	-
Ash	2.1	2.4	7.3	7.7
Ether Extract	2.0	2.3	7.7	8.1
Crude Protein	12.3	14.2	32.5	34.2
N. Free Extract	66.7	77.1	47.6	50.0
Gross Energy (k cals/gm)	3.95	4.56	4.72	4.96

that the basis for such adjustment was the TDN values for the major dietary ingredients, obtained from values published in the literature. These are presented in Appendix 4/1, along with other published compositional data, which will be referred to in later sections.

The use of TDN as an estimate of digestible energy (D.E.) has been widely criticised, and as Blaxter (1962) states "the measurement is certainly not a calorimetric one, and is in some respects difficult to express in calorimetric terms."

Maynard (1953) pointed out the inherent errors in the use of TDN as a measure of DE, while Schneider (1954), cited by Swift (1957), regarded TDN as "lacking in scientific concept and nutrition theory compared with other measures of energy".

Despite such criticism, several workers have shown an extremely close correlation between TDN and DE, for both a variety of feedstuufs and species (re Maynard (1963); Swift (1957); Crampton (1957).) because according to Crampton (1957) "..... these are merely two numerical measurements of an identical

biological function".

TDN may be regarded as a laborious, cumbersome and inaccurate effort to determine DE.

Due to the close correlation between TDN and DE (note Robinson (1965) who presented evidence that the relationship may vary somewhat depending upon the nature of the diet), a digestible calorific value has been attributed to TDN. According to the literature referred to above this value approximates to 4.4 k/cals. DE per gramme TDN, or 2,000 k/cals per pound.

For reasons outlined above there is a general trend away from the use of TDN values in favour of DE values, the latter being far easier to obtain and consequently subject to less error. However due to the prevalent use of TDN in the past, there is a greater amount of information available in the literature pertaining to the TDN values of a greater variety of foodstuffs in comparison with DE values. For this reason and because of the close agreement between TDN and DE values, the former were used as a basis for the formulation of rations in the present experiments.

It is worth mentioning at this stage Blaxter's (1962) comments on feeding systems based on DE or TDN. He pointed out that such systems assume the DE of different foods is employed with equal efficiency for maintenance and various productive functions, and although this may be true for rations of fairly standar composition, it is not so for rations of extreme composition. Although the term "standard" and "extrme" are indefinite classifications, it was appreciated that although the estimated TDN intake of animals on all treatments was to be approximately equal, differences in the utilization or allocation of DE might ari between animals on different treatments. This seemed particularly applicable tc animals fed diets containing different proportions of meal and whey, as the differences between such diets could be considered more "extrme" than the differe occurring between diets involving the same level of meal supplementation.

B. LEVELS OF PROTEIN INCORPORATION:

The range of meal protein levels studied was the same for treatments within the two levels of meal supplementation. As it was desirable to include a treatment at each meal level involving the addition of no protein concentrate, i.e. where the meal consisted of 100% barley meal, the lower limit of the range was dictated by the protein content of the barley meal used, viz. 12.3%.

Reference to Chapter 2 shows the protein requirement of the growing pig, expressed as a percentage of the diet, to be approximately 15 - 18%. Thus it is likely that a diet consisting entirely of whey, of the quality outlined above, would be adequate in protein for pigs over the growing period, particularly in view of the high quality of whey protein. Thus in order to maintain the protein content of the diet as a whole, i.e. whey plus meal, at what was considered an adequate level, the upper limit for the range of meal protein levels was adjusted to approximately that of whey viz. 17 - 18% on a d.m. basis.

Using the values obtained from the pre-experimental analyses of the barley meal and DBMP, the provisional meal mixes, shown in Table 4/2, were arrived at, to give the desired range of protein levels.

Table 4/2: Provisional formulations of meal mixes.

Treatment	Barley Meal %	DBMP %	C.P. %
1	100	-	12.3
2	85	15	15.3
3	70	30	18.4
4	100	-	12.3
5	90	10	14.3
6	80	20	16.3
7	70	30	18.4

C. MEAL LEVELS:

The two levels of daily meal supplementation chosen were $1\frac{1}{2}$ and $2\frac{1}{2}$ lbs. per pig. The former relates approximately to current New Zealand commercial practice and the latter to possible future practice, also serving as a means of comparison between these experiments and the limited information available from overseas studies.

Reference to Table 4/3 shows the values of $1\frac{1}{2}$ and $2\frac{1}{2}$ lbs. meal/pig/day entered as approximate values, while the actual allowances of meal are presented in the next column. Such adjustment in daily meal allowances, within meal levels, was necessary to counteract the higher TDN content of those meals containing increasing amounts of DBMP. This method of equalizing the estimated TDN intake from meal, of animals on treatments within meal levels, was preferred to a method involving fillers, or materials of high energy density, due to the introduction of further "unknowns" in such methods.

Using the mean TDN values for barley meal and DBMP obtained from the literature (re App. 4/1), details of the derivation of the adjusted or actual meal allowances are outlined in Table 4/3. It will be noted that the adjusted allowances were rounded to the nearest ounce. For purposes of adjustment, the final meal formulations presented in Table 4/9 were used.

Table 4/3: Approximate and adjusted meal allowances, showing derivation of the latter.

Treatment	Meal TDN %	Approx. Daily Meal (oz)	TDN/Day from Meal (oz)	TDN/Day from Meal (oz)	Exact Meal Allowances (oz)	Rounded Allowances (oz)	TDN Intakes from Meal (oz)
1	69.7	24	16.73	16.73	24.00	24	16.73
2	72.4			16.73	23.11	23	16.65
3	75.0			16.73	22.31	22	16.50
4	69.3	40	27.72	27.72	40.00	40	27.72
5	71.1			27.72	39.00	39	27.73
6	73.0			27.72	37.97	38	27.74
7	74.7			27.72	37.11	37	27.64

D. LEVELS OF WHEY:

In general terms the higher the intake of DE, the higher the requirement for dietary protein for optimum growth performance (Bowland and Berg (1959): Robinson et. al. (1964).)

It seemed necessary therefore that in the present work the plane of feeding (DE intake) should be as high as possible in order that the "demand" for protein would be high. This implied that whey intake should be as high as possible and yet at the same time it was important that there should be little or preferably no refusal of whey at any liveweight, in order to achieve constant intake by animals on collection throughout Experiment II.

In reference to previous whey-feeding experiments conducted at the Massey University Pig Research Centre under similar dietary and environmental conditions, whey scale A (Table 4/4) was adopted as the one to which whey was fed to pigs receiving the lower amount of meal supplement.

Table 4/4: Daily whey allowances (lbs) according to liveweight.

			Estimated TDN from Whey (oz/dy)	
Liveweight(lbs)	Scale A (Tr.1,2,3)	Scale B(Tr.4,5,6,7)	Scale A	Scale B
50	20	5	15.14	3.78
60	25	10	18.92	7.57
70	30	15	22.71	11.35
80	35	20	26.49	15.14
90	39	24	29.52	18.17
100	42	27	31.79	20.44
110	46	31	34.82	23.47
120	50	35	37.85	26.49

Whey scale B (Table 4/4), according to which whey was fed to those pigs on treatments involving the higher level of meal, was derived as follows:

At any liveweight, the difference in TDN intake from meal between animals fed the diets involving low or high levels of meal was approximately 11 ounces (27.7 - 16.7). Consequently the difference in whey allowance at any liveweight had to represent 11 ounces of TDN, to achieve equal daily TDN intake for all animals of the same weight. Taking the TDN value of whey dry matter as 83% (See App. 4/1), in terms of pounds of fresh whey (d.m. 5.7%) this represents:-

$$\frac{11 \times 100}{83} \times \frac{100}{5.7} \times \frac{1}{16} = 14.53 \text{ lbs.}$$

This value was rounded to 15 lbs. Thus it is seen from Table 4/4 that at any liveweight, animals receiving the higher level of meal supplement received 15 lbs. whey less per day than pigs fed diets involving the lower level of meal.

E. OVERALL PLANE OF FEEDING:

From the estimated daily TDN intakes from meal (Table 4/3) and from whey (Table 4/4), the total estimated daily TDN intakes over the experimental growth period from 50 - 120 lbs. for animals in each of the seven treatments are shown in Table 4/5.

Table 4/5: Total daily estimated TDN intake.

Treat / LWT.	1	2	3	4	5	6	7	Mean (oz)	Mean (lbs)	TDN Intakes As% LWT.
50 lb.	31.9	31.8	31.6	31.5	31.5	31.5	31.4	31.6	2.0	4.0
60	35.7	35.6	35.4	35.3	35.3	35.3	35.2	35.4	2.2	3.7
70	39.4	39.4	39.2	39.1	39.1	39.1	39.0	39.2	2.5	3.5
80	43.2	43.1	43.0	42.9	42.9	42.9	42.8	43.0	2.7	3.4
90	46.3	46.2	46.0	45.9	45.9	45.9	45.8	46.0	2.9	3.2
100	48.5	48.4	48.3	48.2	48.2	48.2	48.1	48.3	3.0	3.0
110	51.6	51.5	51.3	51.2	51.2	51.2	51.1	51.3	3.2	2.9
120	54.6	54.5	54.4	54.2	54.2	54.2	54.1	54.3	3.4	2.8

F. MINERAL AND VITAMIN SUPPLEMENTATION:

Reference to Appendix 4/1 shows the derivation of the average mineral contents of the major dietary ingredients. Using these values, and the recommendations presented in the NRC publication on Swine Feeding (1964) for the major and trace element requirements of the growing pig, the addition of mineral supplements to the meal fraction of the 7 experimental diets was carried out as detailed in Table 4/6. The table also shows the associated necessary adjustments in the barley meal content.

Table 4/6: Details of the mineral supplementation of the meal mixes.

Ingredient \ Treatment	1	2	3	4	5	6	7
Barley Meal %	98	83.5	69	97.5	87.75	78.25	68.5
DBMP %	-	15	30	-	10	20	30
Boneflour %	2	1.5	1	2.5	2.25	1.75	1.5
Mineral Mix (mg/lb)*	601	601	601	360	360	360	360

* Containing 180 : 196 : 225 parts by weight of $MnSO_4 4H_2O$, $ZnSO_4 7H_2O$, $FeSO_4 7H_2O$ respectively, and providing 45 mg/lb (100 ppm) of Mn, Zn and Fe when included at the rate of 601 mg/lb, and 27 mg/lb (60 ppm) of each when included at the rate of 360 mg/lb.

The estimated major and trace element contents of the seven experimental meals, formulated to the specifications given in Table 4/6 are shown in Table 4/7.

Table 4/7: The estimated major and trace element contents of the 7 experimental meal mixes.

Treatment		1	2	3	4	5	6	7
Ca	%	0.57	0.58	0.59	0.71	0.74	0.70	0.73
P	%	0.59	0.60	0.61	0.66	0.67	0.66	0.67
Mn	ppm	117.5	115.3	113.9	77.5	76.0	74.7	73.0
Fe	ppm	162.5	155.1	147.6	124.1	119.4	113.9	109.3
Cu	ppm	4.2	3.9	3.6	4.3	4.1	4.2	3.5
Zn	ppm	130.5	130.8	131.1	91.0	91.1	91.2	91.5

Using the values presented in Table 4/7, the estimated values for the mineral content of whey (see App. 4/1), and the details already outlined concerning the levels of whey and meal fed, Table 4/8 has been drawn up to show the estimated mineral content of the 7 experimental diets as a whole, for pigs of 60 and 120 lbs. liveweight. The values are presented on a meal equivalent basis (88% d.m.) and were derived by the use of details already presented for the estimation of the relative contributions of meal and whey dry matter to total dry matter intake at the two liveweights shown.

As milk and its by products are good sources of vitamin of the B complex (NRC) Pub. 1192: 1964: Feed Bag Red Book 1966: Mitchell 1963) there appeared no need to provide additional sources of these vitamins. However whey being practically devoid of fat is consequently deficient in the fat-soluble vitamins A and D (Mitchell 1963). For this reason each pig was given 2 gms. of a liquid Vitamin A and D supplement (Vetemul) once weekly, which provided 10,000 ius. Vitamin A and 2,000 ius. of Vitamin D_3.

Table 4/8: Estimated mineral contents of the total diets (meal plus whey) consumed by pigs of 60 and 120 lbs. liveweight.

Tr.	L.WT.	Ca %	P %	Mn ppm	Fe ppm	Cu ppm	Zn ppm
1	60	0.78	0.69	69.3	114.1	25.0	87.3
	120	0.88	0.73	46.8	91.6	34.7	67.2
2	60	0.79	0.69	68.0	109.9	24.8	87.5
	120	0.88	0.73	46.0	88.9	34.5	67.3
3	60	0.80	0.70	67.2	105.6	24.7	87.6
	120	0.89	0.74	45.4	86.1	34.4	67.4
4	60	0.76	0.68	67.4	113.7	11.1	82.5
	120	0.86	0.72	47.9	93.7	24.1	66.0
5	60	0.79	0.69	66.1	109.7	10.9	82.5
	120	0.88	0.73	47.0	90.9	24.0	66.0
6	60	0.75	0.68	64.9	105.0	11.0	82.6
	120	0.85	0.72	46.3	87.7	24.1	66.1
7	60	0.78	0.69	63.5	101.0	10.4	82.9
	120	0.87	0.73	45.3	95.0	23.7	66.3

G. SUMMARY:

As a summary, full details of the experimental rations and diets fed to pigs in both Experiment I and II, are presented in Table 4/9.

Table 4/9: Meal mixtures and daily allowances of meal and whey fed to pigs in both Experiment I and Experiment II.

MEAL FORMULATIONS:							
Tr. / Ingreds.	1	2	3	4	5	6	7
Barley Meal %	98	83.5	69	97.5	87.75	78.25	68.5
DBMP %	-	15	30	-	10	20	30
Boneflour %	2	1.5	1	2.5	2.25	1.75	1.5
Mineral (mg/lb)	601	601	601	360	360	360	360
Vit A+D Supp (g/wk)	2	2	2	2	2	2	2
Est. TDN %	69.7	72.4	75.0	69.3	71.1	73.0	74.7
Cr. Prot. %	12.3	15.3	18.4	12.3	14.3	16.3	18.4

DAILY MEAL AND WHEY ALLOWANCES/PIG: MEAL IN OUNCES: WHEY IN POUNDS

L.WT. Meal / Whey	M	WH	M	WH	M	WH	M	WH	M	WH	M	WH	M	WH
50 lbs	24	20	23	20	22	20	40	5	39	5	38	5	37	5
60	24	25	23	25	22	25	40	10	39	10	38	10	37	10
70	24	30	23	30	22	30	40	15	39	15	38	15	37	15
80	24	35	23	35	22	35	40	20	39	20	38	20	37	20
90	24	39	23	39	22	39	40	24	39	24	38	24	37	24
100	24	42	23	42	22	42	40	27	39	27	38	27	37	27
110	24	46	23	46	22	46	40	31	39	31	38	31	37	31
120	24	50	23	50	22	50	40	35	39	35	38	35	37	35

CHAPTER 5

EXPERIMENTAL DETAILS AND METHODS

A. EXPERIMENT I:

1. Housing -

The two sub-experiments of Experiment I were conducted in the Danish-type experimental house referred to previously.

In reference to the effects of environmental temperature on pig performance (Sørenson 1961: Seymour, Speer, Hays, Mangold and Hazen 1964: Fuller 1965), the temperature in the house was maintained at approximately 68°F throughout the two sub-experiments. A thermo-hygrograph, suspended from the ceiling (approx. 5 ft. from the floor) provided a constant check on the efficiency of temperature control.

Prior to the start of each sub-experiment the house was evacuated for as long as possible, and thoroughly scrubbed and disinfected.

2. Animals -

The pigs used for the two sub-experiments were selected from the commercial herd of the Massey University Pig Research Centre. They were all Large White x Landrace, and following standard practice within the herd had been weaned at 3 or 4 weeks of age.

3. Selection of Animals -

Selection was carried out when the pigs were 8 weeks of age, or weighed approximately 40 lbs.

For each sub-experiment, seven pigs from each of four litters were selected on the basis of weight, previous growth performance and sex.

4. Allocation of pigs to pens and treatments -

Several references throughout the literature (Bowland and Berg 1959: Jones, Hepburn, Cadenhead and Boyne 1962: Cox 1963: Plank and Berg 1963:

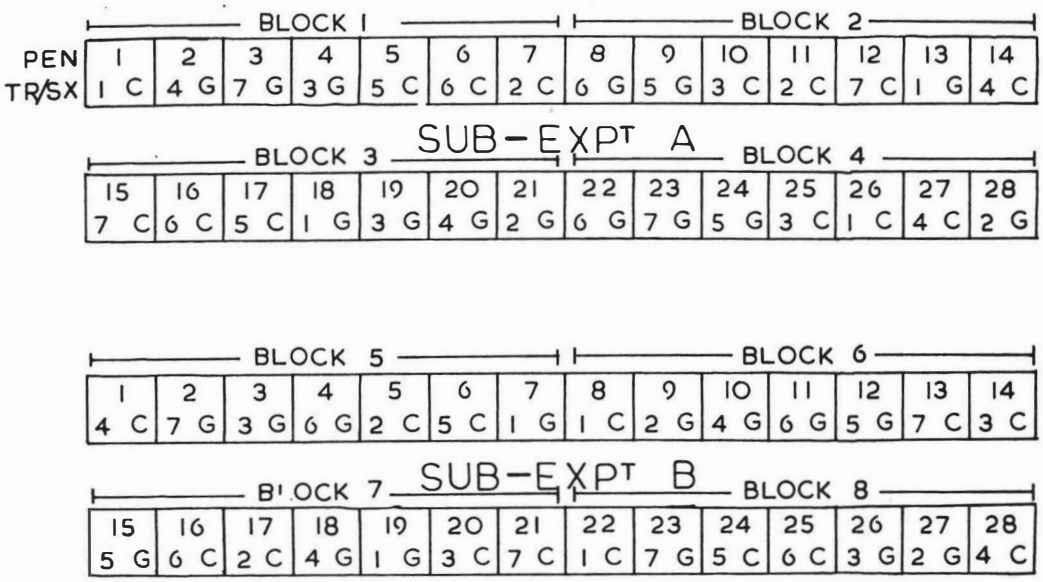


Figure 5/1: Placement of blocks, treatments and sexes in the experimental house for each sub-experiment of Experiment I.

C Castrate : G Gilt

Blair and English 1965: Rahnfield 1965: Robinson 1965: Cuthbertson and Pease 1965) indicate differences in performance between castrates and gilts.

For this reason, pigs were allotted to treatments on a restricted random basis, such that equal numbers of gilts and castrates (2 of each) were on each treatment within each of the two sub-experiments.

Allocation of pigs to pens was again on a restricted random basis, in that the seven pigs of each block (litter) were allotted restrictedly to a set of seven juxtaposed pens, but pigs within blocks were allocated pens at random.

Figure 5/1 shows the placement of blocks, treatments and sexes throughout the experimental house for each sub-experiment.

5. Pre-experimental management -

In accordance with normal practice in the Massey University pig herd, all litters from which the experimental animals were selected had been born and reared on concrete and "pre-starter" rations had been offered from 10 days of age to be replaced at later stages by "starter" and "weaner" rations. After weaning at 3-4 weeks of age, the litters were given access to restricted amounts of lactic casein whey from 6 weeks of age.

On transfer to the experimental house, all animals were sprayed with a proprietary mange and lice dressing, and given a vermifuge, containing piperazine as the active ingredient,

Between entering the house and introduction of the experimental diets, pigs were rationed according to live-weight, as shown in Table 5/1.

The composition of the meal fed over the pre-experimental period was identical with that used in treatment 2 (Table 4/9), and the whey, as in the experimental period, was lactic casein whey supplied daily from the same dairy factory.

Table 5/1: Pre-experimental allowances of meal and whey (lbs/pig/day) according to liveweight.

Liveweight (lbs)	Meal	Whey
35 - 40	$1\frac{1}{2}$	4 - 7
41 - 45	$1\frac{3}{4}$	8 - 10
46 - 50	2	11 - 13

The pigs were fed three times daily at 6 a.m., 11 a.m. and 4 p.m. receiving approximately one third of their daily whey allowance at each feed, while the meal ration, divided by eye, was provided at the first two feeds.

Meal was weighed on a 6 lb. pan balance, reading to $\frac{1}{2}$ ounce, and whey with a 60 x 1/10th lb. spring balance.

Dung races and sleeping areas (where necessary) were cleaned each day.

6. Introduction to experimental diets -

On reaching a minimum of 49.5 lb. liveweight, an abrupt change of the pre-experimental meal to the appropriate treatment meal mixture was made. However changes in the daily allowances of meal and whey were made gradually, so that the experimental levels of feeding were attained on the 7th day after the start of the experiment. These changes are detailed in Table 5/2.

7. Experimental management -

The experimental diets and rations have been presented in Chapter 4. The methods of weighing daily meal and whey allowances, and the feeding regimen adopted, were as for the pre-experimental period.

Table 5/2: Changes in the daily meal and whey allowances during the week immediately following the introduction of the experimental diets.

Treat. \ Day	MEAL ALLOWANCES (oz)							
	0	1 *	2	3	4	5	6	7
1	32	30	30	28	28	26	26	24
2	32	30	30	28	28	26	26	23
3	32	30	30	28	28	26	24	22
4	32	34	34	36	36	38	38	40
5	32	34	34	36	36	38	38	39
6	32	34	34	36	36	38	38	38
7	32	34	34	36	36	37	37	37
WHEY ALLOWANCES (lbs)								
1 + 2 + 3	13	15	17	17	19	21	21	23
4 + 5+ 6 + 7	13	12	12	11	11	10	10	9

* Day 1 applicable to the day on which pigs weighed a minimum of 49.5 lbs.

8. Records -

(a) Growth Data

All animals were weighed routinely throughout the pre-experimental and experimental periods, once weekly.

However when approaching 50 lbs. liveweight, i.e. the weight at which the experiment started, weighing was carried out more frequently in order that animals could be introduced to the experimental diets at a weight as close as possible to 50 lbs.

Animals were slaughtered at approximately 125 lb. liveweight, and all pigs were weighed on the day of dispatch to the factory.

All weighings were conducted at 6 a.m. prior to the first feed of the day, and in an attempt to obtain accurate assessment of empty-body weight, any food remaining in the troughs at 8 p.m. on the evening before weighing was removed. Thus all pig weights were obtained after an approximate 10 hour starvation period.

(b) Food intake

Pigs were rationed in accordance with the scales of feeding already presented, based on their individual weekly weights.

Daily records were kept of the meal and whey presented, as were records of any food refused, which was removed from the troughs and weighed prior to the first feed of the day.

Food consumed was calculated as the difference between the food offered and refused.

The object of presenting the meal at the first two feeds only, was to minimize the risk of food refusals comprising a mixture of meal and whey.

(c) Whey composition

20 ml. samples of the whey fed were taken each day and bulked over weekly periods. The weekly composite samples were preserved with 1% formalin and at the end of the week were analysed for dry matter and protein content.

(d) General

Any abnormalities in health and the occurrence of scouring were recorded.

9. Evaluation of Carcass Quality -

Direct evaluation of carcass quality by dissection or chemical analysis of whole or half carcasses was not possible, due to the destructive nature of such

methods and the associated demands on labour and time.

The comparatively simple measurements made on the carcasses were aimed mainly at assessment of quality on the basis of fat and lean content, and may perhaps be more aptly defined as estimates of carcass composition. Such assessment of quality was considered particularly applicable to the investigation, in view of the likely effect of protein intake on the lean:fat content of the carcasses.

The measurements recorded are detailed below, with reference to their value in appraisal of carcass quality.

(a) Killing-out percentage (KOP)

The yield of carcass from the live animal upon which payment is based is of obvious concern to the producer and Harrington (1958) discussed the economical significane of KOP and some factors affecting its magnitude.

Method: An "empty" liveweight (W_1) was obtained for each animal on the morning of slaughter, prior to dispatch to the factory. Pigs were slaughtered approximately 4-6 hours subsequent to this weighing when an eviscerated hot-carcass weight (less 6% "shrinkage") was obtained from the factory records (W_2). KOP was calculated as $^{100W}2/W_1$.

(b) Specific gravity (SG)

SG and density measurements have comparatively recently come into prominance for use in the estimation of carcass composition. The literature reviewed by Harrington (1958) and the more recent work of Holme, Coey and Robinson (1963): Doorenbahl, Wellington and Stouffer (1962). Bowman, Whatley and Walters (1962a), Adam and Smith (1964): Standal (1965): Urban and Hazel (1965): Joblin (1966b) establishes the existance of a strong correlation between SG and carcass composition. The more recent work

indicates correlations in excess of (-)0.9 between SG and percentage fat and lean, and the authors in general conclude that SG is the most potent single measurement for predicting carcass composition. Adam and Smith (1964) and Joblin (1966b) found that the muscle:fat ratio had a markedly great influence on SG than the muscle:bone ratio, and that for practical purposes the latter could be ignored. SG may be limited when used for the detection of differences between the composition of carcasses from pigs of different genotype or sex (Adam and Smith 1964: Standal 1965: Joblin 1966b), although the exact relationship between these parameters and SG is uncertain.

Method: After removal of the heads, the carcasses were split with a power driven saw and held for approximately 20 hours in a chiller, along with a tank of water. Specific gravities were determined by weighing each side of each carcass in air and water. During weighing, the sides were complete with trotters, flare-fat and fillets. Weights in air were obtained using a 60 x 1/10th lb. spring balance (read to the nearest 1/10th lb.) and weights in water using a 1610 x 1/10 gm. triple-beam balance (read to the nearest gm.) The temperature of the water was recorded at each weighing.

(c) Length and depth

Although a negative correlation exists between carcass length and fat content (Harrington 1958: Bowman et. al. 1962a: Buck, Harrington and Johnson 1962: Doorenbahl et. al. 1962: Henry, Bratzler and Luecke 1963: Fredeen, Berg, Bowland and Doorenbahl 1964: Joblin 1966a) it is of insufficient magnitude to warrant the use of length as an estimate of carcass composition and in fact has never been regarded as such. Carcass

length, measured usually from the 1st rib to the symphysis pubis, in association with depth, taken behind the shoulder, is used as a measure of "balance" or conformation - a feature both subjective in nature and of doubtful significance.

Method: After determination of SG, the carcasses were removed from the chiller. The length of both sides of each carcass was measured from the symphysis pubis to the anterior end of the 1st rib. The depth of each side was measured behind the shoulder and larger of the two values was taken as maximum carcass depth.

(d) Fat depth on the mid-line

The depth of back-fat on the mid-line, measured at various sites, is commonly used during the course of experimental work for evaluation of carcass quality, and often represents the basis for commercial carcass grading. However there is no standard technique regarding the number of measurements taken or the sites at which they are taken. Furthermore the measurements may be used singly in estimating carcass composition, or in certain combinations, e.g. simple arithmetic or "weighted" means. The work of McMeekan (1941) and Kielanowski and Osinska (1954 - cited by Harrington 1958) indicated that the mean of back-fat measurements is more closely correlated with fat content than single measurements. In addition, these workers found that measurements taken in the loin region afforded better estimates of carcass fatness than measurements at any other site, e.g. shoulder or mid-back. In general, depth of fat on the mid-line at the shoulder showed only a weak correlation with fat content and this was particularly applicable to maximum fat depth in this region. Their findings are supported by the more recent work of Joblin (1966a). The

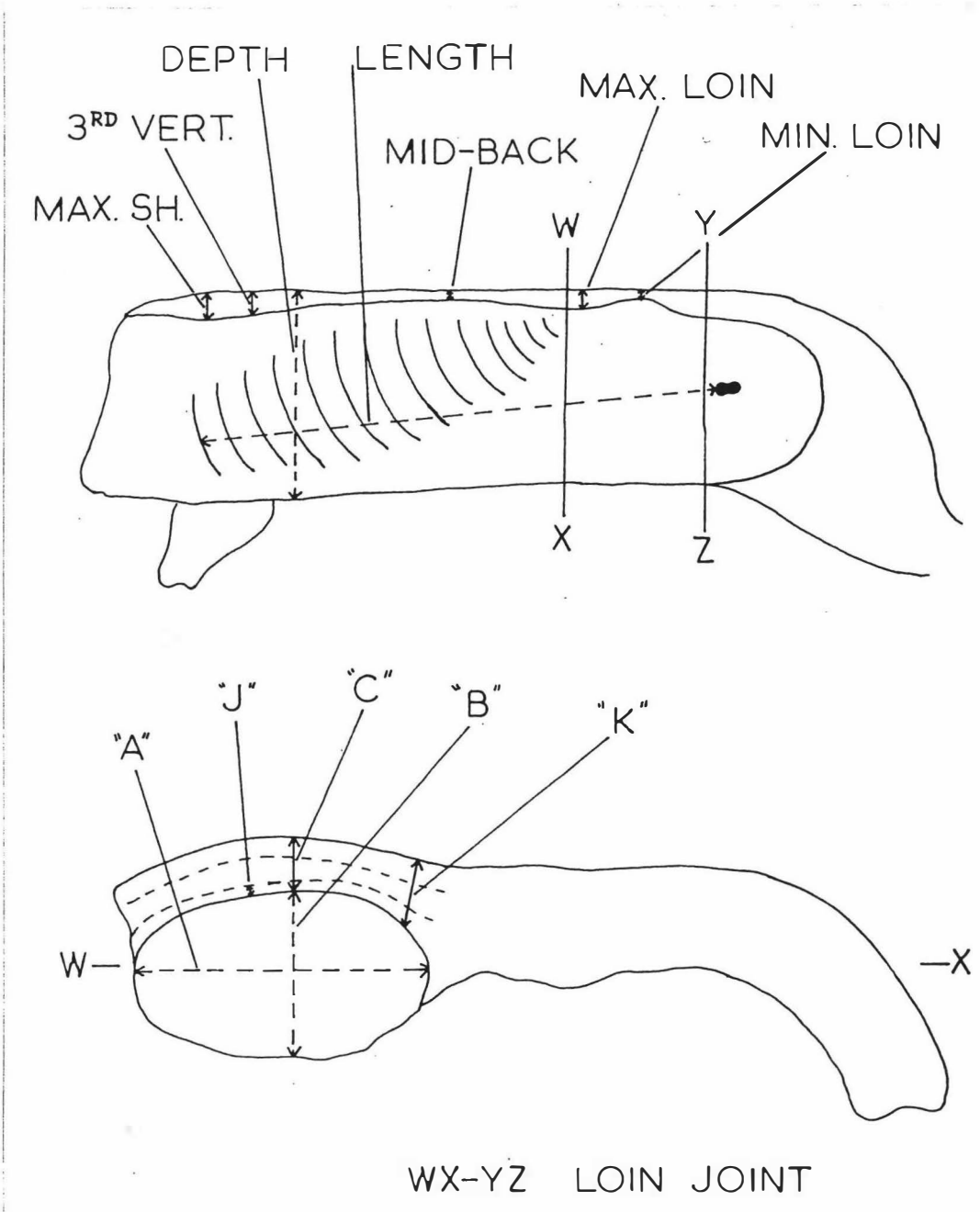


Figure 5/2: Measurements taken of the carcasses.

mean of mid-line back-fat depths may result in biassed estimates of differences between the composition of gilt and castrate carcasses (Buck et. al. 1962: Joblin 1966a).

Method: Fat depth on the mid-line was measured at five sites on each side of each carcass viz. maximum depth at the shoulder: opposite the third thoracic vertebra: minimum depth in the mid-back region: at the anterior end of the gluteus medius (maximum loin): over the gluteus medius (minimum loin).

(e) Fat depth off the mid-line, over the longissimus dorsi ("eye" muscle)

Fat-depth measurements taken over the "eye" muscle on cutting the carcass transversely, provides better estimates of carcass fatness than fat-depth on the mid-line (McMeekan 1941: Joblins 1966a). This is supported by the work of Bowman et. al. (1962a) involving probe measurements taken on the live animals. The work cited, involved transverse cuts at the last rib, but Doorenbahl et. al. (1962) found some variation in the value of such measurements as predictors of fat and lean content, dependent upon the point at which the cut was made.

The three most common fat-depth measurements taken over the "eye" muscle are those denoted by the letters "C", "K" and "J" (re Fig. 5/2). Although the location of "C" differed somewhat in the work of McMeekan (1941) and Joblin (1966a), these authors found "C" to be the most potent single measurement of the three, as an estimate of carcass fat content (r = approx. 0.9) and an improvement on the mean of the fat depths taken on the mid-line. The data of Joblin showed that "K" and "J" gave sequentially lower correlations with percent. dissectable fat (approx. 0.8 and 0.7 respect.)

but in one of two trials "K" added significantly to the estimation of percentage ether extract from "C" alone. "J" in neither trial added to the value of "C" and the author concluded that from the data there was nothing to support the use of "J" as a predictor of carcass fat content.

Method: The left side of each carcass was cut at right-angles to the mid-line through the 7th vertebra anterior to, and including, the last lumbar vertebra. Fat depth measurements "C", "K" and "J" were taken on the anterior face and are shown diagramatically in Fig. 5/2.

(f) Measurements taken of the cross-sectional surface of the "eye" muscle

"Eye" muscle length ("A"), depth ("B") and area (EMA) of the surface revealed on cutting the "eye" muscle transversely (usually at the last rib) are measurements commonly employed as estimates of carcass lean content. Of these three measurements, EMA generally shows the highest correlation with leanness (Harrington 1958: Joblin 1966a). Taken singly, "A" and "B" show comparatively low correlations with lean content, but when used in combination, e.g. A + B or 2A + B, the correlations with leanness approach that of EMA (0.8 - 0.9). Joblin (1966a) found a significant improvement in the correlation with leanness using combinations of EMA and "C", the highest (approx 0.9) resulting from the ratio EMA:"C". However the "C" measurement alone provided as good an estimate of lean content as EMA:"C", suggesting the single measurement "C" represents the most accurate estimate of both lean and fat content, in comparison with any other linear measurement. The author pointed out that the ratio EMA:"C" may be "safer" for use with carcasses which display a wide range of weights

and suggested the use of this ratio for general use in estimating carcass lean and fat contents.

Method: Measurements "A" and "B" were taken of the eye "muscle" on the same cross-sectional surface outlined for "C", "K" and "J" (re Fig. 5/2). A tracing of the "eye" muscle was made, the area of which was later determined using a planimeter.

(g) Sample joint composition

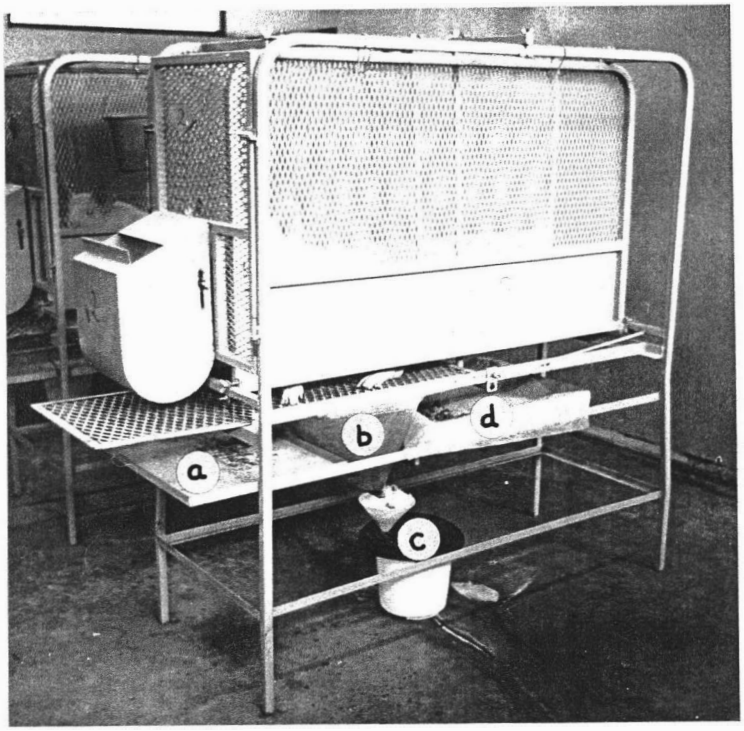
The composition of certain joints of the carcass, assessed by physical dissection or chemical analysis, is highly correlated with the composition of the total carcass. (McMeekan 1941: Aunan and Winters 1949: Bowman et. al. 1962b). Evidence suggests that a sample joint taken from the thoracic region, e.g. "rib-end" provides a more accurate estimate of the total lean, fat and bone content of the carcass (Edwards 1963: Adam and Smith 1966: Joblin 1966c) than joints taken from other regions. However excluding bone content, joints from dorso-posterior regions give comparable estimates of carcass composition, i.e. lean and fat content.

Method: From the posterior half of the left side, a joint was removed by a transverse cut at the anterior end of the last lumbar vertebra. The joint represented a section taken from the loin region, comprising a total of $6\frac{1}{2}$ vertebrae. All joints were stored at $5^{\circ}F$ in sealed polythene bags until dissected (rough, knife) into lean, fat and bone.

B. EXPERIMENT II - GENERAL:

1. Housing and Metabolism Crates -

The metabolism unit in which the work was conducted consisted of two separate, connecting, well insulated, temperature-controlled rooms. One



a. Food-spillage collection tray

b. Urine apron

c. Urine Filter and collection vessel

d. Faecal collection tray

Figure 5/3: Details of metabolism crates (developed at the Rowett) and layout of metabolism room.

contained twelve individual-pig holding-pens and the other, eight metabolism crates.

For reasons already outlined (5A), the temperature in both rooms was maintained throughout at approximately 68°F. Thermo-hygrographs placed in each room (3 ft. from the floor) afforded a check on environmental temperature.

The metabolism crates (Fig. 5/3), suitable for use with pigs of about 50-200 lbs. liveweight, allowed separation of faeces and urine for male pigs only.

2. Animals -

As for Experiment I, pigs were taken from the Pig Research Centre's commercial herd, when they were approximately 8 weeks of age or 40 lb. liveweight. They were all Large White x Landrace and had been weaned at 3-4 weeks of age.

3. Selection of Animals -

Because the metabolism crates were only suitable for use with male pigs, selection was restricted to castrates. The basis of selection was liveweight and previous performance. The total of fourteen pigs were originally selected as two groups of seven, each group comprising four pigs from one litter and three from another (due to the difficulty of obtaining seven castrates from a single litter). Consequently, within each group of seven pigs (one/treatment) it was not possible to allocate treatments on a within-litter basis. The associated loss in experimental control was accepted in preference to the omission of treatments.

In view of the limited facilities it was originally planned that the experiment would be conducted as two consecutive "runs", each involving one pig/treatment. Unfortunately one animal of the first "run" developed an anal prolapse mid-way through the experimental period and had to be discarded (re 6A). To avoid disruption of the routine, this pig was replaced by another which was

included in the second "run". It eventuated therefore that the first group comprised six pigs (three from each of two litters and one pig/each of six treatments) and the second, eight pigs (four from each of two litters and one pig/each of six treatments and two pigs on the remaining treatment). For purposes of statistical analaysis the fourteen animals were treated as a random population, with no reference to litters or groups.

4. Allocation of pigs to pens, metabolism crates and treatments -

Within each group, pigs were allotted to pens and metabolism crates on a restricted random basis and to treatments at random.

5. Pre-experimental management and introduction to treatment diets -

This was identical to the procedure adopted for Experiment I.

6. Experimental Management -

This again was the same as for Experiment I, except that at three stages during the experimental growth period, when the pigs weighed approximately 55, 85 and 115 lbs., animals were transferred from the individual pens to their allotted metabolism crates, for digestibility and N-balance studies. These will be detailed in later sections.

The routine procedure adopted in Experiment I with regard to the once-weekly administration of a liquid (oil-based) Vitamin A + D_3 supplement, was broken in Experiment II, when necessary, to avoid supplementation when the pigs were on collection.

7. Records -

General records of liveweight gain, food intake etc. were kept as for Experiment I, with additional data pertinent to the balance periods. These will be outlined later.

C. EXPERIMENT II - DIGESTIBILITY AND N-BALANCE STUDIES:

1. Number of Animals -

(a) Review

No reference could be found throughout the literature to the number of pigs required per treatment, in relation to the accuracy of digestibility and N-balance experiments.

As no experiments on digestibility or N-balance had been conducted at Massey University prior to the experiment described here, values for coefficients of variation were not available from this source.

Table 5/3 shows some coefficients of variation applicable to nitrogen metabolism, which were calculated from data presented in the literature.

Table 5/3: Approximate coefficients of variation (%) for some N-metabolism data (calculated from data presented in the references cited).

Variable \ Source	Barber et.al (1964)	Jones et.al (1961)†	Fuller (1965)	Means
App. N-Digest. %	3.2	1.7:2.3:3.5:1.7		2.5
N-Retained (Absolute)	6.3	13.3:9.6:4.7:0.5		8.9
N-Retained %	5.6	5.5:3.8:3.1:7.1		5.0
Faecal N/Gross N Int. %			6.1	
Urinary N/Dig. N. Int. %			6.4	
Urinary N/Gross N Int. %			6.9	
Approx. L.Wt. Range of Digs. (lbs)	50 - 120	25 - 60	10-80	

† Values obtained from four similar experiments.

It is apparent from the table that apart from two values obtained from the data of Jones et. al. (1961) and relating to the absolute retention of nitrogen, coefficients of variation for N-metabolism data in general, appear to be of relatively low order and less than 10%. This appears particularly applicable to apparent digestible nitrogen % values, and may in part be due to the fact that such values are expressed as percentages rather than in absolute terms. This is suggested by the coefficients relating to the absolute and percentage retention of nitrogen.

From these values the number of replicates required to give any particular level of experimental precision, appears about the same as for liveweight gain (3B).

However, whether or not differences between means reach statistical significance at particular levels, is not only influenced by level of replication but also by experimental design and the actual method of statistical analysis employed. Thus where more than one observation/animal of a single variable is taken, the effective level of replication is increased on a within-animal basis.

This situation is more often than not found in digestibility and N-balance experiments with growing pigs, where throughout the course of the experiment each animal may undergo at least two collection periods. Thus, providing the data from each period is used in the statistical analysis, the effective level of replication, and consequently the experimental precision, is higher than would be the case if only single observations were available for the same number of animals.

Irrespective of experimental precision, the major factors determining the number of animals and collection periods involved in digestibility and N-balance experiments, seems to be the limitations imposed by facilities,

and perhaps of greater significance, the amount of chemical analaysis etc. which can be satisfactorily handled under any given set of circumstances.

The net result of these factors, is that in many experiments involving aspects of N/metabolism, the sensitivity of the experiment is such that only tentative conclusions can be drawn from the results.

In an attempt to increase the precision of the N-balance experiment, Jones et. al. (1961) adopted a method involving a comparison between diets on a within-pig basis. The major drawbacks to such a method would be the possibility of carry-over effects; the difficulty in "persuading" animals to change to different diets over relatively short time intervals; the loss of information on growth performance and food conversion efficiency.

(b) Method

The number of animals/treatment was restricted to two, and the number of collection periods/animal to three. This gave in all a total of forty-two collection periods, and the associated "volume" of chemical analysis was considered the maximum amount which could be satisfactorily carried out by a single operator.

2. Duration of collection and pre-collection periods -

(a) Review

In comparison with ruminants little published information exists on the length of digestibility and N-balance experiments with pigs, in relation to the accuracy of results.

In view of the fast growth-rate and changing protein requirement of the growing pig (Lucas 1958: Braude 1958) it may be concluded that to obtain accurate information on nitrogen metabolism at a particular liveweight, the duration of the balance experiment should be as short as possible. This is supported by the results obtained by Lassiter, Terrill, Becker and Norton

(1956), who found that sub-division of a 7-day collection period into 3 and 2-day sub-periods, indicated a decrease in nitrogen retained by pigs weighing 150 lbs. fed high protein diets, as the experiment progressed.

However, shorter periods are subject to greater error associated with the excretion pattern of the animal. Consequently the theoretical desirability of short collection periods is offset by increased error and the implications of this with regard to the number of animals required to gain accurate information on nitrogen metabolism.

The single report by Lassiter et. al. (1956) showed that with a 10-day preliminary period, a 7-day collection period offered little advantage in accuracy over 3 or 5-day periods. These workers estimated the number of pigs required to yield the same error for 3, 5 and 7-day periods to be 25, 20 and 19 respectively.

Methods adopted in the course of digestibility and balance experiments with pigs, vary considerably. Thus Miller et. al. (1964) followed a procedure involving 3-day collection periods; Barber, Braude, Chamberlain, Hosking and Mitchell (1964) periods of 4 days; Jones et. al. (1961) and Robinson (1965) 5-day periods, and Diggs, Becker, Jensen and Norton (1965) 6-day periods. The methods of Cunningham, Friend and Nicholson (1963a) Lowrey (1963) and Fuller (1965) involved continuous successive collection periods of from 5 to 7 days in length, and extending in total over periods ranging from 10 days to 8 weeks. Reference to these texts, shows in addition many differences in the pre-collection management of the experimental animals. These will be referred to later.

A common factor to any study of nutrient absorption is the necessity to be able to relate intake to faecal output. In an attempt to do this with some accuracy, markers such as ferric oxide may be used. These are fed before and after the experimental diet, the voidings between the two

appearances of the marker in the faeces being taken as the food residues pertaining to the diet. The assumptions inherent in the method, regarding the relative rates of passage of food and marker, will be appreciated.

When the food under test is of reasonably uniform quality, it is not necessary however to relate faecal output exactly to food intake. Thus if a constant amount of the test diet is fed daily for a long enough period, faeces voided over the later stages may be related with some confidence to food eaten over the same period. In order to establish the minimum length of time necessary between the presentation of a fixed daily food allowance and the start of faecal collection, some knowledge on the rate of passage of food through the intestine is required.

Castle and Castle (1956: 1957) working with pigs fed all-meal diets, found that 95% of the food residues appeared in the faeces at a mean of 53 hours after feeding, but that there was a significant negative correlation between the mean retention time and the total weight of ingesta, i.e. meal plus water.

From this information it may be concluded that faeces collected during the course of digestibility experiments is related to food fed approximately 48 hours before. The experiments of Castle and Castle indicated that apart from between-pig variation, the nature of the diet itself will influence the validity of this conclusion. Furthermore, as the experiments were conducted with pigs housed in pens, it does not necessarily follow that the results can be extended as such to include pigs restricted in metabolism crates.

Cunningham et. al. (1962), in describing a re-entrant fistula for use in digestibility experiments, noted that materials such as skimmilk passed through the small intestine in less than 12 hours.

Many reports on digestibility and balance experiments, not involving the use of markers, fail to detail the exact procedure with regard to pre-collection food intake.

The method of Miller et. al. (1964) involved 3 to 5 day "adjustment" periods. Diggs et. al. (1965) commenced collection "after the pigs had been on feed for at least 2 days". Jones et. al. (1961), in a comparison between diets on a within-pig basis, commenced collection after 5-day preliminary periods on the diets. Robinson (1965) reported that a 2-day acclimatization period in the crates was preceded by "a much longer period" for acclimatization to rations in individual feeding pens. Barber et. al. (1964) stated "Animals were placed in cages on Monday mornings, collection periods beginning at noon on that day ....." with no reference at all to food intake or preliminary feeding periods. Baker (1966) following a 5 or 7-day collection period procedure, preceded by 7 or 9-day preliminary periods, failed to detail the nature of the preliminary periods. Finally, in those methods involving continuous and successive collections, faeces voided over all but the first period, must in part be related to food consumed during the previous period.

The references cited serve to illustrate the variability in methods adopted for digestibility and N-balance studies, in relation to the duration of pre-collection and collection periods.

Bearing in mind the obvious lack of information and standardized procedure for digestibility and balance experiments with pigs, the following method was adhered to throughout the experiment.

(b) Method

Between collection periods animals were rationed in accordance with liveweight, to the scales of feeding presented elsewhere.

When approaching the predetermined liveweights at which nitrogen balance was determined viz. 55, 85 and 115 lbs. the pigs were presented with fixed allowances of meal and whey, determined by treatment and collection period (weight), two days before transferance from the individual feeding-pens to the metabolism crates.

Before being placed in the crates, pigs were weighed.

Pigs remained in the crates for 7 days at each period, receiving throughout, the same fixed daily allowances of meal and whey. The first 2 days served as an acclimatization period, collection commencing at 7.30 a.m. on the third day and terminating at 7.30 a.m. on the eighth.

On removal from the crates pigs were again weighed.

The fixed daily allowances of meal and whey corresponding to the three collection periods and to the seven treatments are presented in Table 5/4.

Table 5/4: Daily meal and whey allowances per pig while on collection.

Collection Period	Meal (oz)			Whey (lbs)		
	A	B	C	A	B	C
Approx. L.Wt. (lbs)	55	85	115	55	85	115
Treatment 1	24	24	24	27	39	48
2	23	23	23	27	39	48
3	22	22	22	27	39	48
4	40	40	40	12	24	33
5	39	39	39	12	24	33
6	38	38	38	12	24	33
7	37	37	37	12	24	33

Before the start of the experiment, sufficient individual daily lots of meal for each treatment were weighed up to meet the total requirements of all pigs for all pre-collection and collection periods. Until required, they were sealed in plastic bags and stored at 5°F. All lots of meal of the same treatment were taken from a single bulk mix.

The feeding regimen while on collection was the same as for the between-collection periods. Thus pigs were fed three times daily, receiving meal and whey at the first two feeds and whey alone at the third. Meal and whey offered were weighed accurately to the nearest gramme and 1/10th lb. respectively.

Food intake during collection was calculated as the difference between food presented and food refused and/or spilled.

3. Sampling and Analysis of Food -

(a) Meal

Sampling: Representative samples of the meal fed, while the pigs were in the crates, were ground with a laboratory mill through a 1 .m. sieve and when necessary stored in sealed glass jars at 5°F until analysed.

Determination of N content: N content was determined in triplicate by the macro-Kjeldahl method (A.O.A.C. 1965), using 2 gm. samples. Sodium sulphate was used to accelerate digestion and mercuric sulphate as the catalyst. Digestion was continued for approximately $3\frac{1}{2}$ hours.

Determination of Energy content: The energy content of 1 gm. pelleted samples was determined in duplicate, using an adiabatic oxygen bomb calorimeter, calibrated with thermochemical-grade benzoic acid. Temperature rises were

measured with 11 x 0.01°C thermometers.

Determination of dry-matter content: 2 gm. duplicate samples were dried in a forced draught oven for 16 hours at 100°C.

(b) Whey

Sampling: During each pre-collection and collection period (7 days), 20 ml. aliquots of the daily samples of whey fed were accumulated and preserved with 1% formalin. Additional 20 ml. aliquots, taken from the cumulative samples, were bulked throughout the entire experiment and stored in the frozen state at 5°F.

Determination of N content: N content was determined in duplicate on 5 ml. samples taken from the samples of whey pertaining to each pre-collection/collection period, by the macro-Kjeldahl method (A.O.A.C. 1965). Potassium sulphate was used to accelerate digestion and copper sulphate as the catalyst. Digestion was continued for approximately $2\frac{1}{2}$ hours.

Determination of energy content: The bulk, frozen sample accumulated throughout the experiment was freeze-dried. Energy content of the freeze-dried product was determined in duplicate on 1 gm. pelleted samples, using the bomb calorimeter already described.

Determination of dry-matter content: Dry-matter content of the samples analysed for N content were determined in duplicate using 2 ml. sub-samples. Drying was continued for 7 hours at 100°C. The dry matter content of the freeze-dried product was determined using duplicate 2 g.m. samples

dried for 16 hours in a forced draught oven at 100°C.

4. Collection, Sampling and Analysis of Excreta -

(a) Review

From the discussion following a paper presented by Vercoe (1964) it is apparent that discrepance often exists between the results of N-balance experiments and carcass data obtained on slaughter of the same animals. Although this may be partly due to the technique used in assessing carcass composition, it is more likely related to errors inherent in N-balance studies, and associated with gaseous or skin losses not accounted for, or with losses of volatile materials occurring between voiding and analysis of excreta. All such losses result in an inflated value for nitrogen retained.

Evidence that losses of nitrogen occur from both faeces and urine between voiding and analysis is provided by Butterworth (1963): Chalupa and Fisher (1963): Henry (1965) and Martin (1966). Graham, Wainman, Blaxter and Armstrong (1959): Graham (1964) and Fuller (1965) found that faecal nitrogen may be influenced by environmental temperature, associated with increased decomposition of the voided faeces in a warm environment, resulting in an over-estimation of digestibility at higher climatic temperatures. Of the above references only that pertaining to the work of Fuller relates specifically to pigs, the remainder being in reference to ruminants.

No reference could be found relating to losses of faecal or urinary energy subsequent to voiding but before preparation and analysis of excreta.

The losses described above may be termed "natural", in that they arise from normal processes of decomposition occurring in excreta on standing in air. Losses of even greater magnitude may be incurred during the preparation of excreta for analysis. Of particular significance is the loss of nitrogen, and to a lesser extent energy, resulting from oven-drying of faeces.

Although Forbes et. al. (1946) found no loss of nitrogen on oven-drying sheep faeces, an increasing amount of evidence suggests that such loss may be considerable (Gallup and Hobbs 1944: Raymond and Harris 1954: Colovos, Keener and Davis 1957: Ludvigsen and Thorbek 1958: van Es 1958: Juko, Bredon and Marshall 1961.) Losses reported range to as high as 40% of total faecal nitrogen.

The work of Raymond and Harris (1954) indicated that the diverse methods used by different workers in oven drying, and related to length of drying period and temperature (re Juko et. al. 1961: Table 1), may account for the divergency of the results obtained regarding the magnitude of the loss. Raymond and Harris (1954) concluded that the optimum temperature for drying faeces (sheep) was 100 to 105°C.

Comparatively little information exists on the loss of energy occurring from faeces during oven drying. Colovos et. al. (1957), apart from finding losses of nitrogen ranging from -4.3 to 37.1%, found concomitant losses of energy of 8.0 to 19.4% on oven-drying ruminant faeces. During the discussion following a paper presented by Ludvigensen and Thorbek (1958), Flatt reported on having found losses of approximately 3% in faecal energy (cow), while losses of less than 1% of total carbon were reported by van Es.

From studies with ruminant faeces, it seems to be generally concluded that loss of energy does occur on oven-drying but the magnitude is uncertain and yet appears less than similar loss of nitrogen. In accordance with the results of Raymond and Harris (1954) it may be that loss of energy depends on drying technique, while the comments of Graham (1958) suggest "..... a great deal depends on the type of faeces".

No reference was found relating specifically to losses of nitrogen and energy from pig faeces during oven-drying. However subsequent to the

experiments described here, Carr and Holmes (1966 unpub.) found losses of nitrogen and energy in the order of 10% and 2% respectively on drying pig faeces at 100°C for 48 hours in a forced draught oven.

From the work cited, it is generally recognized that to minimize losses of energy, and of nitrogen in particular, estimates of faecal energy and nitrogen should preferably be obtained by analysis of the wet, fresh material. However, adoption of such a procedure creates problems in itself, associated with accuracy of sampling and ignition of comparatively wet substances.

Raymond, Harris and Harker (1953) pointed out that the use of fresh faeces for nitrogen determinations, demanded a sampling method more accurate than they found possible by taking small samples direct from the bulk sumple. The method they recommended involved blending the faeces with water and subsequent sampling from the macerate produced. Ludvigsen and Thorbek (1958) found the coefficient of variation of the errors in determining nitrogen content, to be approximately four times greater for wet faeces than for dried faeces (2% compared with 0.5%). However they found that when the wet faeces were mixed by "a more effective process" - although not detailed, probably one involving maceration - the coefficient of variation was reduced fourfold, approximating to that of the errors in determination of nitrogen concentration using dried faeces.

For reasons outlined above, the determination of faecal nitrogen in N-balance/digestibility experiments, with both ruminants and pigs is usually carried out using wet, macerated samples. Presumably a similar method should be adopted to increase the accuracy of faecal energy determinations. However added difficulties arise in this case, related to incomplete combustion of wet faeces. Colovos et. al. (1957) reported

that wet, unblended faecal samples can be successfully ignited by the addition of alcohol. Although this method overcomes the loss of energy from oven drying, it is still subject to the sampling errors associated with unblended faeces. Maceration with water would aggravate the difficulty of achieving complete combustion and render the use of "starters" such as alcohol somewhat ineffective. On reference to the literature it is not surprising to find therefore that, in the majority of cases, faecal energy determinations are carried out on ground, oven-dried samples. From the references cited and from information received from Hutton (pers. comm), it is probable that the inaccuracy resulting from the use of oven-dried faeces for the determination of energy content, is less than that for nitrogen determined in the same way.

Despite the realization that losses of nitrogen and energy are likely to arise from both faeces and urine during the course of balance/digestibility experiments, no standard method has been developed to minimize these losses, in relation to techniques of collection, preservation, storage, sampling, preparation and analysis of excreta, for any species. It is probable that each research establishment has developed its own "standard" method, which may or may not have been critically assessed.

Bearing in mind this lack of standard procedure, the method to be described was adopted after reference to techniques reported, and in view of available information on factors influencing losses of nitrogen and energy from excreta.

N O T E: A bomb calorimeter was not available for use while the experiment was in progress.

(b) Method

Collection: Excreta was collected from 7.30 a.m. on the third day after the pigs were transferred to the crates, to 7.30 a.m. on the eighth day.

Faeces was collected on polythene sheets covering the faecal-collection trays, being removed twice daily (7.30 a.m. : 4 p.m.) into covered plastic buckets. The total voidings of individual pigs were bulked and stored at 5°F. for each 5-day collection period. Care was taken at each collection to remove any faeces adhering to the polythene sheets and crates, and to retrieve faeces which appeared on the urine filters.

Urine was collected under toluene, via polythene aprons and glass-wool filters, in covered plastic dustbins. Voidings were removed twice daily (as for faeces), when they were weighed, and 5% aliquots taken by volume. During collection, the aliquots of urine from individual pigs were bulked and stored under toluene in covered plastic buckets at 40°F. At each collection of urine the polythene aprons were washed down into the dustbins with distilled water.

Preparation, Sampling and analysis: At the end of each collection period the bulked total faecal voidings and urinary aliquots were removed from cold storage and left standing overnight in the metabolism room (68°F).

After weighing, faeces were mixed thoroughly in a proprietory food-mixer.

Faecal N: From the mixed bulk sample, an approximate, unweighed 150 gm. sample was taken and blended with approximately 250 mls. distilled water and 5 mls. toluene (thought by Raymond et. al. (1953: 1954) "to interfere with enzymic processes" and "to reduce bacterial action during subsequent handling".) From the resultant macerate (of smooth-cream consistency), triplicate 10 gm. samples were weighed on to watch-glasses, and washed via a long-stemmed funnel into 500 ml. Kjeldahal flasks. N content was determined as for meal samples.

Faecal dry-matter: From the mixed bulk sample, duplicate 500 gm. samples were weighed accurately to the nearest gramme into weighed metal trays, and dried for 48 hours at 100°C in a forced-draught oven. 20 gm. duplicate samples of the faecal macerate were weighed into dried silica basins and dried for 24 hours at 100°C in a forced-draught oven.

Faecal energy: After drying, the two 500 gm. samples taken for the determination of dry-matter content, were pooled and ground in a laboratory mill, through a 1 mm. sieve, sealed in plastic bags and stored at 5°F. The energy content of the dried, ground material was determined in duplicate, using 1 gm. pelleted samples and the adiabatic bomb calorimeter referred to previously. Prior to combustion the pellets were dried overnight in an oven at 100°C to avoid the necessity of additional dry-matter determinations. This technique is suitable for use with materials which have been

previously subjected to oven-drying (Hutton pers. comm).

Urinary N: Triplicate 5 ml. samples of urine, from the accumulated 5% aliquots, were pipetted into Kjeldahl flask, and N content was determined as for meal and faecal samples, but digestion was continued for only $2\frac{1}{4}$ hours. At the beginning of the experiment a 5 ml. pipette was selected on its accuracy in delivering 5 gms. water at room temperature. This same pipette was used throughout the whole experiment.

Urinary specific gravity: Triplicate 5 ml. samples were weighed direct on to watch-glasses.

5. Expression of Results -

All analytical results were expressed on a dry-matter basis except the nitrogen content of urine, which was calculated per gramme of wet material (using the estimates of SG).

Meal and whey intakes, and faecal output, were recorded on a wet-matter basis and transformed to corresponding dry-matter values.

Apparent digestible nitrogen and energy intakes were calculated in absolute and percentage terms, as that amount or proportion of nitrogen and energy ingested from meal plus whey, which did not appear in the faeces.

Nitrogen retained was calculated in absolute and percentage terms, as that amount or proportion of nitrogen ingested, which did not appear in the faeces or urine.

Nitrogen retained was also expressed on the basis of unit body weight, using the mean of the liveweights recorded at the beginning and end of the balance period, in conjunction with the absolute amount of nitrogen retained.

D. BIOMETRICAL METHODS:

1. General -

The biometrical methods used for analysis of the data of both experiments were based on the approach outlined by Henderson (1960), involving the identification of factors in heirarchical classification, as fixed effects or random variables.

2. Experiment I -

(a) Analysis of Variance : Method X

Ignoring sex effects, the experimental design may be considered a complete randomized block, involving seven treatments and four replications (Blocks, litters) in each of two sub-experiments.

On this basis the classifications are as follows:

Main:

Treatments (T) - $n_t = 7$

Experiments (E) - $n_e = 2$

Nested:

Blocks within experiments (B:E) - $n_b = 4$.

If T and E are taken as fixed effects and B:E as a random variable, then the analysis of variance table is as shown in Table 5/5.

Table 5/5: EXPERIMENT I : Analysis of Variance Table (X)

Mean Square	df	Expectation of Mean Square
T	6	$\sigma^2_w + \sigma^2_{tb:e} + 8\sigma^2_t$
E	1	$\sigma^2_w + 7\sigma^2_{b:e} + 28\sigma^2_e$
B:E	6	$\sigma^2_w + 7\sigma^2_{b:e} +$
TE	6	$\sigma^2_w + \sigma^2_{tb:e} + 4\sigma^2_{te}$
TB:E	36	$\sigma^2_w + \sigma^2_{tb:e}$

Consequently the tests of significance are as follows:

For T = $^{T}/_{TB:E}$

" E = $^{E}/_{B:E}$

" TE = $^{TE}/_{TB:E}$

" B:E = None

(b) Analysis of Variance : Method Y

As sexes were distributed more or less at random between blocks, any test including blocks could not include sex, and vice-versa. The analysis outlined in Table 5/5 allowed the removal of block effects from the residual sum of squares, but ignored the effect of sex. The analysis to be outlined in this section represents the other approach, permitting the isolation of sex effects by ignoring the effect of blocks. With equal numbers of castrates and gilts on each treatment and in each sub-experiment, the classifications are as follows:

Main:

Treatments (T) - $n_t = 7$

Experiments (E) - $n_e = 2$

Sex (S) - $n_s = 2$

Nested:

Animals within T, E and S (A:TSE) - $n_a = 2$

Taking T, S and E as fixed effects and A:TSE as a random variable, the analysis of variance table is presented in Table 5/6.

Table 5/6: EXPERIMENT I : Analysis of Variance Table (Y)

Mean Square	df	Expectation of Mean Square
T	6	$\sigma^2_w + \sigma^2_{a:tse} + 8\sigma^2_t$
S	1	$\sigma^2_w + \sigma^2_{a:tse} + 28\sigma^2_s$
E	1	$\sigma^2_w + \sigma^2_{a:tse} + 28\sigma^2_e$
TS	6	$\sigma^2_w + \sigma^2_{a:tse} + 4\sigma^2_{ts}$
TE	6	$\sigma^2_w + \sigma^2_{a:tse} + 4\sigma^2_{te}$
SE	1	$\sigma^2_w + \sigma^2_{a:tse} + 14\sigma^2_{se}$
TSE	6	$\sigma^2_w + \sigma^2_{a:tse} + 2\sigma^2_{tse}$
A:TSE	28	$\sigma^2_w + \sigma^2_{a:tse}$

Thus in this case all main effects and first and second order interactions are tested against A:TSE.

(c) Tests of Significance

The effects of T, E and TE were tested according to method X, and those of S, TS, SE and TSE according to method Y.

(d) Subdivision of Treatment sum of squares

In order to evaluate the influence of the meal:whey ratio on animal performance, and the response to added DBMP within meal:whey ratios, the treatment sum of squares with six d.f., was sub-divided into components

based on single degrees of freedom.

Details of the subdivision are set out in Table 5/7:

Table 5/7: EXPERIMENT I : Subdivision of Treatment sum of Squares.

S o u r c e	df	Component
TREATMENT	6	
Trs (1+2+3) v (4+5+6+7)	1	A
Linear response Trs. 1-3	1	B
Quad. " " "	1	C
Linear response Trs. 4-7	1	D
Quad. " " "	1	E
Cubic " " "	1	F

From Table 5/7, component A represents the comparison between the effects of a lower (Tr 1+2+3) and higher (Tr 4+5+6+7) contribution of TDN from meal, upon animals having the same estimated total daily TDN intake. Components B and C serve to evaluate the direction and pattern of response to increased dietary DBMP, of animals receiving the lower contribution of TDN intake from meal. Components D, E and F correspond to B and C, but relate to the higher contribution of TDN from meal.

the coefficients applicable to the derivation of the orthogonal comparisons among treatment components, as detailed above, are presented in Table 5/8. Further information on the subdivision of treatment sums of squares is provided by Cochran and Cox (1957).

Table 5/8: Coefficients for Orthogonal Comparisons between treatment Components (re Table 5/7).

Component / Treatment	A	B	C	D	E	F
1	-4	-1	1			
2	-4	0	-2			
3	-4	+1	1			
4	+3			-3	+1	-1
5	+3			-1	-1	+3
6	+3			+1	-1	-3
7	+3			+3	+1	+1
D	84r	2r	6r	20r	4r	20r

The sum of squares for a treatment component based on 1 d.f. is as follows:

$$s.s. = \frac{Z^2}{D}$$

where Z = the sum of products of the coefficients and the treatment totals

r = the number of items/treatment total.

Where linear regression proved significant, the corresponding regression coefficient was calculated as follows:

$$b = \frac{Z}{DI}$$

where I = Interval between coefficients in terms of % buttermilk powder (15 for treatments 1, 2 and 3, and 10 for treatments 4, 5, 6 and 7).

Thus all regression coefficients were calculated on the basis of 1% buttermilk powder.

(e) Standard errors

Standard errors were calculated for the differences between means (SED's)

For differences between individual treatment means SED $= \sqrt{\frac{2S^2}{n}}$

where S^2 = error mean square

n = number of observations/mean.

For differences between grouped treatment means, e.g. (1+2+3) v (4+5+6+7)

$$SED = \sqrt{\frac{S^2 (n_1 + n_2)}{n_1 \times n_2}} \quad \text{(Snedecor 1956)}$$

where S^2 = error mean square

n_1 = number of observations for $\bar{x}_1$

n_2 = " " " " $\bar{x}_2$

Standard errors for regression coefficients of treatment components were calculated as follows:

$$S_b = \frac{A S^2}{D I^2}$$

where S^2 = error mean square

A = square of the coefficient interval.

D, I = as above.

3. Experiment II -

For reasons already outlined, the fourteen pigs involved in this experiment were taken from a total of four litters, and consequently animals from the same litter were not allocated to all treatments. Consequently it was not possible to remove litter (block) effects from the residual sum of squares.

The classifications are outlined below:

(a) Main

Treatment (T) - $n_t = 7$

Collection Period (C) - $n_c = 3$

(b) Nested:

Animals with T and C (A:TC) - $n_a = 2$

Taking T and C as fixed effects and A:TC as a random variable, the analysis of variance table is detailed in Table 5/9.

Table 5/9: EXPERIMENT II : Analysis of Variance Table

Mean Square	df	Expectation of Mean Square
T	6	$\sigma^2_w + \sigma^2_{a:tc} + 21\,\sigma^2_t$
C	2	$\sigma^2_w + \sigma^2_{a:tc} + 14\,\sigma^2_c$
TC	12	$\sigma^2_w + \sigma^2_{a:tc} + 2\,\sigma^2_{tc}$
A:TC	21	$\sigma^2_w + \sigma^2_{a:tc}$

It follows therefore that the denominator for tests of significance of the main effects T and C, and the interation TC, is in each case A:TC.

Where appropriate the method outlined for Experiment I was used for sub-division of treatment and collection period sums of squares.

The derivation of standard errors for differences between means and for regression coefficients was as for Experiment I.

4. Standard analytical procedures -

In certain instances additional analyses were carried out, e.g. regression and covariance. The procedures adopted were standard, as outlined by Snedecor (1956).

Levels of significance used throughout both experiments are indicated as follows:

†	$p < 0.10$
*	$p < 0.05$
**	$p < 0.01$
***	$p < 0.005$

CHAPTER 6

RESULTS

A. EXPERIMENT I:

1. Whey Composition -

The mean dry matter and protein (Nx6.38) contents (± s.d.) of the weekly composite samples of whey taken throughout sub-experiments A and B are presented in Table 6/1.

Table 6/1: Mean dry matter and protein contents (± s.d.) of the weekly composite whey samples taken during sub-experiments A and B.

Sub-Expt.	Dry Matter %	Protein %	Protein:D.M.%
A	5.65 ± 0.157	1.00 ± 0.036	17.7
B	5.50 ± 0.169	1.00 ± 0.067	18.2

The t-test (Snedecor 1956) showed the differences between the mean dry-matter contents of the two whey samples to be statistically significant ($p < 0.05$). As sub-experiment A was conducted over the period extending from 24.8'65 to 30.11.'65 and sub-experiment B from 11.1.'66 to 12.4.'66, it is probable that the difference in whey composition was associated with seasonal changes in milk composition or manufacturing technique.

2. Health -

During the experiment, a total of four pigs developed some degree of lameness, typified by dropped pasterns and subsequently, abrasion to pasterns and "dew claws". In sub-experiment A, the pigs in pens 5, 10 and 13 (treatments 5, 3 and 1 respectively) showed the condition, and in sub-experiment B, pig 8 on

treatment 1. In view of the severity of lameness, pigs 10 and 13 were provided with shavings in their sleeping areas and each received a 3-day course of penicillin administration.

Apart from the four pigs referred to, the general health of animals was good and the incidence of scouring was negligible.

3. Refusal of Food -

The feeding regimen adopted was successful in preventing the refusal of meal. There was however some refusal of whey and the details are presented in Table 6/2:

Table 6/2: Treatment of means whey refused throughout Experiment I in relation to whey consumed.

Treatment	Whey Consumed (lbs)	Whey Refused (lbs)	Whey Refused %
1	16695	205	
2	16249	7	0.95
3	15895	254	
4	9177	-	
5	8895	29	0.17
6	9006	1	
7	8647	32	

It is apparent that over all treatments very little whey was refused. The comparatively high refusal by pigs on treatments 1 and 3 was largely a reflection of the reduced appetite of the pigs in pens 13 and 10, which became lame.

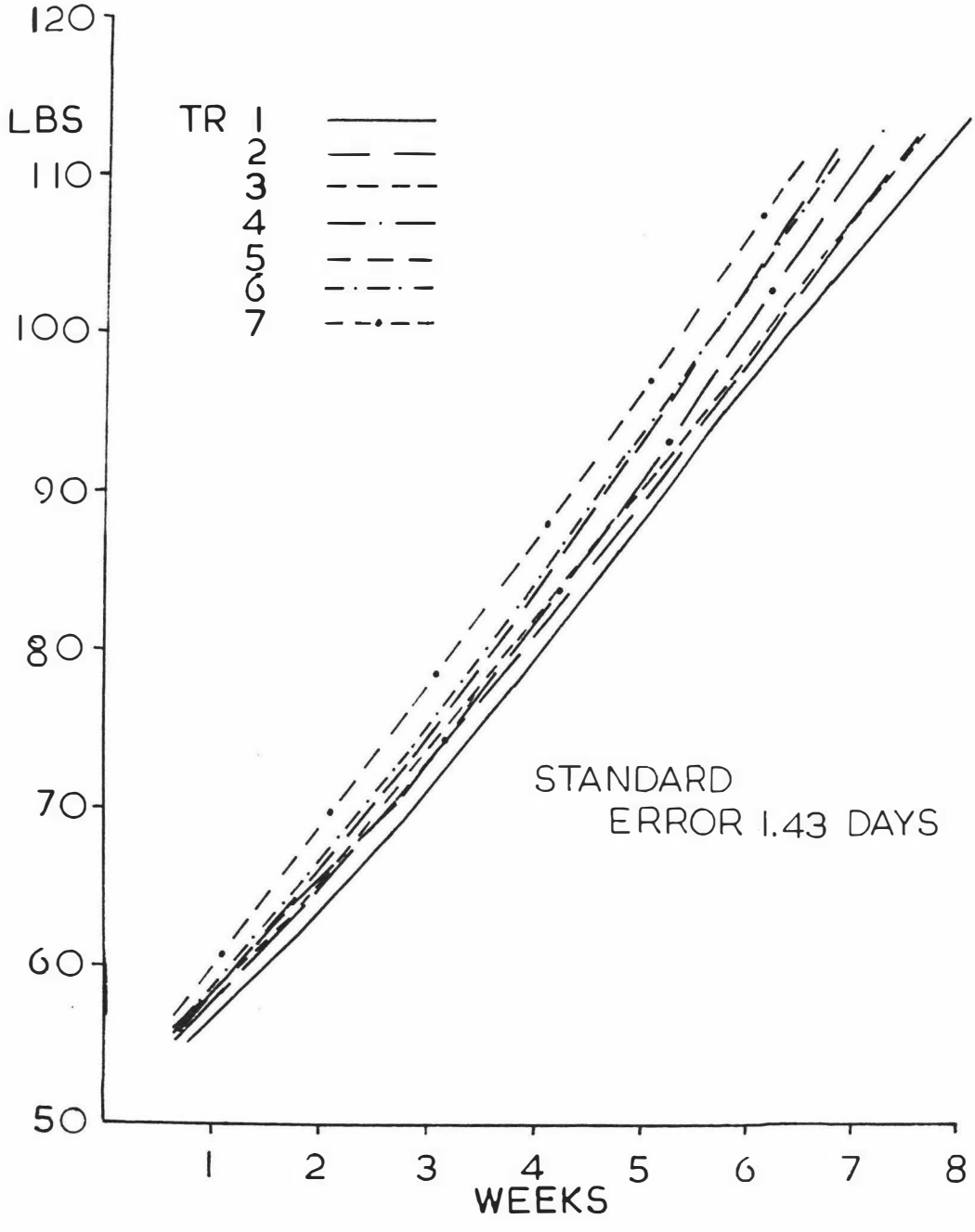


Figure 6/1: Experiment I : Treatment mean growth curves for the pooled data of sub-experiments A and B.

Table 6/3: Experiment I : Regression Analysis (Liveweight on Time) - Tests of significance for differences between regressions due to treatment, sex and treatment x sex effects.

Source	df	MS	F Tests
TREATMENT:			
Diffs. Between Regs.	6	6.79	10.33 ***
Dev. From Ind. Regs.	35	0.657	
SEX:			
Diffs. Between Regs.	1	3.71	7.03 *
Dev. From Ind. Regs.	10	0.528	
TREATMENT x SEX:			
Diffs. Between Regs.	13	11.50	16.06 ***
Dev. from Ind. Regs.	70	0.716	

* $p < 0.05$: *** $p < 0.005$

4. Growth data -

(a) General

The treatment mean growth curves for the pooled data of sub-experiments A and B are shown in Figure 6/1. The mean growth curves of castrates and gilts over all treatments and both sub-experiments are presented in Figure 6/2.

Analysis of the growth data was undertaken employing both regression analysis and analysis of variance techniques.

For regression purposes, time (weeks) was taken as the independent variable (X) and liveweight as the dependent variable (Y). The analysis was conducted for the pooled results of both sub-experiments on the basis of treatment, sex and treatment x sex effects. Values of Y were the means of the appropriate number of individual pig weights obtained on the routine

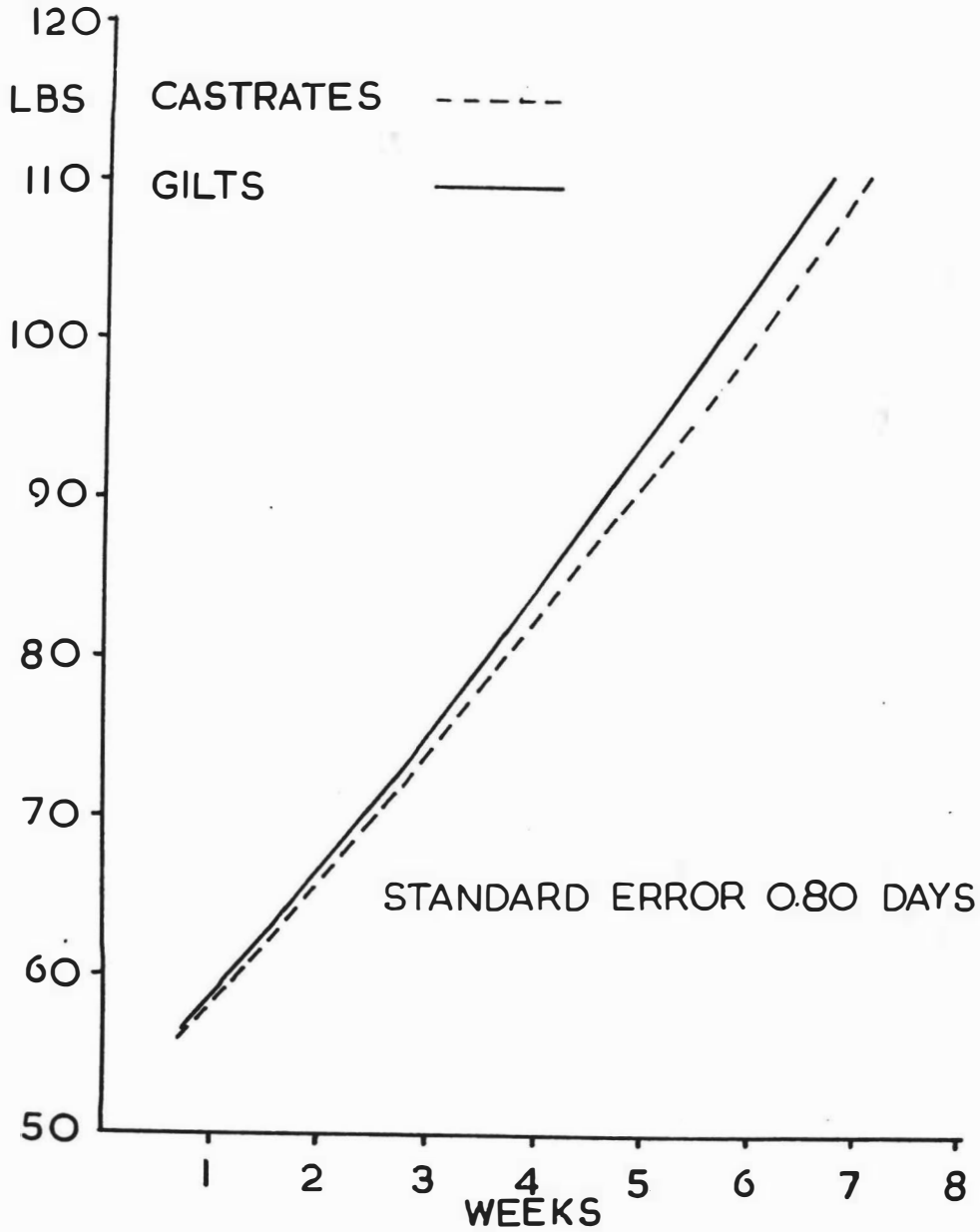


Figure 6/2: Experiment I : Sex mean growth curves for the pooled data of sub-experiments A and B.

weekly weighing days. Thus for treatment, sex and treatment x sex, each value of Y represented the mean weight of 8, 28 and 4 pigs respectively. The maximum number of complete weeks to which the analysis could be applied was 7. i.e. X = 1, 2, ... 7, as subsequent to this, individual pigs on treatments promoting the fastest growth were reaching slaughter weight. The values of Y corresponding to X = 1 were the mean weights of pigs recorded on the first routine weekly weighing day after introduction to the experimental diets.

For analysis of variance, the total growth period was divided arbitrarily into two equal sub-periods each of 35 lb. liveweight duration viz. 50 - 85 lbs. and 85 - 120 lb. The number of days taken by individual pigs to cover the total growth period and the two sub-periods were obtained by interpolation from individual growth curves. Analyses of variance were then conducted for the three periods on the basis of "number of days taken", according to the plan outlined in Chapter 5.

(b) Regression Analysis

The raw data and details of the analysis are presented in Appendix 6/1 and the results in Table 6/3. Treatment and sex effects proved significant, as did the treatment x sex interaction. In view of the significant interaction, comparisons between regression coefficients were made on a within-sex and within-treatment basis, using t-tests for evaluation of significance (Snedecor 1956).

The regression coefficients and corresponding S.E.'s are presented in Table 6/4 on a treatment x sex basis.

The standard error of the difference between two regression coefficients was computed as follows:

$$SED_b = \sqrt{S_{b1}^2 + S_{b2}^2} \quad \text{(Goulden 1939)}$$

Table 6/4: Experiment I - Regression coefficients and their standard errors, derived from the regression analysis of liveweight on time.

Tr.	Castrates	Gilts	Casts. + Gilts
1	7.482 ± 0.1775	8.898 ± 0.1600	8.190 ± 0.1628
2	8.335 ± 0.1393	8.339 ± 0.1312	8.336 ± 0.1292
3	8.416 ± 0.0529	8.166 ± 0.1086	8.290 ± 0.0671
4	8.425 ± 0.2518	8.897 ± 0.2568	8.661 ± 0.249
5	8.625 ± 0.1735	9.879 ± 0.2035	9.253 ± 0.1863
6	8.601 ± 0.1308	9.566 ± 0.1136	9.084 ± 0.1149
7	9.505 ± 0.0700	9.242 ± 0.1188	9.373 ± 0.0863
TOTAL	8.484 ± 0.1269	8.998 ± 0.1470	

Table 6/5: Experiment I - Significance of differences between regression coefficients for castrates and gilts within treatments.

Tr.	t	Sig. of Diff. (n = 10)
1	5.922	CASTRATES ◁ GILTS * * *
2	0.023	N.S.
3	2.069	CASTRATES ▷ GILTS †
4	1.311	N.S.
5	4.696	CASTRATES ◁ GILTS * * *
6	5.578	CASTRATES ◁ GILTS * * *
7	2.629	CASTRATES ▷ GILTS *

† $p \lhd 0.10$: * $p \lhd 0.05$: *** $p \lhd 0.005$:
N.S. $p \rhd 0.10$.

Table 6/6: Experiment I - Significance of differences between regression coefficients for treatments within sexes and meal levels.

C A S T R A T E S		
COMPARISON	t	Sig. of Difference (n = 10)
T1 V T2	3.772	T1 ◁ T2 * * *
T1 V T3	5.049	T1 ◁ T3 * * *
T2 V T3	◁ 1	NS
T4 V T5	◁ 1	NS
T4 V T6	◁ 1	NS
T4 V T7	4.121	T4 ◁ T7 * * *
T5 V T6	◁ 1	NS
T5 V T7	4.704	T5 ◁ T7 * * *
T6 V T7	6.062	T6 ◁ T7 * * *
G I L T S		
T1 V T2	2.699	T2 ◁ T1 *
T1 V T3	3.792	T3 ◁ T1 * * *
T2 V T3	1.019	NS
T4 V T5	2.994	T4 ◁ T5 *
T4 V T6	2.383	T4 ◁ T6 *
T4 V T7	1.219	NS
T5 V T6	1.341	NS
T5 V T7	2.700	T7 ◁ T5 *
T6 V T7	1.979	T7 ◁ T6 †

† $p \lhd 0.10$: * $p \lhd 0.05$: *** $p \lhd 0.005$: NS $p \rhd 0.10$

Table 6/5 details the significance of differences between sex regression coefficients within treatments, and Table 6/6 the significance of differences between treatment regression coefficients within sexes and meal levels.

At the lower level of meal supplementation, castrates fed the diet containing 30% DBMP grew significantly faster than castrates receiving no DBMP in their diet. The reverse situation was true for gilts. These opposite trends in growth performance resulted in gilts growing significantly faster ($p < 0.005$) than castrates when fed the diet devoid of DBMP, but slower ($p < 0.10$) on the diet containing 30% DBMP in the meal.

At the higher level of meal supplementation, the growth performance of castrates improved as the DBMP content of the diet increased, while the response of gilts was negatively curvilinear. Thus although the incorporation of 10% DBMP in the diet promoted a a significant increase ($p < 0.05$) in the growth rate of gilts, any further increase in dietary DBMP content was accompanied by reduced rate of gain. This difference in the pattern of response of castrates and gilts to the level of DBMP in the meal supplement, resulted in the significant differences between sexes, on a within-treatment basis, shown in Table 6/5.

(b) Analysis of Variance

The raw data and details of analysis are presented in Appendix 6/2. Individual treatment means, and treatment means grouped according to level of meal supplement, are shown in Tables 6/7 and 6/8, for castrates, gilts and castrates and gilts considered together. The results of statistical analysis are detailed in Table 6/9.

Table 6/7: Experiment I - Days taken to grow over liveweight ranges specified - treatment and sex means.

Growth Period (lb. L.Wt.)	Sex	Treatment Means								Sex Means		
		1	2	3	4	5	6	7	SED	C	G	SED
50 - 85	C	34.8	31.8	31.0	31.0	30.3	29.5	25.8	2.33	30.6	28.9	0.73
	G	30.0	31.5	30.0	30.0	26.8	26.5	27.3	1.45			
	C+G	32.4	31.6	30.5	30.5	28.5	28.0	26.5	1.33			
85 - 120	C	29.8	28.0	27.5	26.8	27.3	27.3	26.0	1.71	27.5	26.1	0.58
	G	27.0	27.5	29.0	24.5	24.0	25.0	25.5	1.40			
	C+G	28.4	27.8	28.3	25.6	25.6	26.1	25.8	1.10			
50 - 120	C	64.5	59.5	58.5	57.8	57.5	56.8	51.8	2.73	58.1	54.9	1.12
	G	57.0	59.0	59.0	54.5	50.8	51.5	52.8	2.02			
	C+G	60.8	59.4	58.8	56.1	54.1	54.1	52.3	2.02			

Table 6/8: Experiment I - Days taken to grow over liveweight ranges specified - treatment means grouped according to meal level.

	CASTRATES + GILTS			CASTRATES			GILTS		
Treatment Groups	1+2+3	4+5+6+7	SED	1+2+3	4+5+6+7	SED	1+2+3	4+5+6+7	SED
50 - 85 lb Lwt	31.5	28.4	0.72	32.5	29.2	1.25	30.5	27.7	0.78
85 - 120	28.1	25.8	0.60	28.4	26.8	0.92	27.8	24.8	0.75
50 - 120	59.6	54.2	1.09	60.9	55.9	1.47	58.3	52.4	1.09

Table 6/9: Experiment I - Significance of Differences between Individual and grouped treatment means and between sex means (days/growth period).

Growth Period (lb. Lwt)	Sex	Means			Comparison	Tr 1-3		Tr 4-7	
		Tr.	Sex	Tr x S	(1 to 3)v(4 to 7)	LIN	QUAD	LIN	QUAD
50 - 85	C	†			*	NS	NS	*	NS
	G	*			* * *	NS	NS	†	†
	C+G	***	*	NS	* * *	NS	NS	**	NS
85 - 120	C	NS			NS	NS	NS	NS	NS
	G	*			* * *	NS	NS	NS	NS
	C+G	*	*	NS	* * *	NS	NS	NS	NS
50 - 120	C	*			* * *	*	NS	*	NS
	G	***			* * *	NS	NS	NS	NS
	C+G	***	**	NS	* * *	NS	NS	†	NS

† $p < 0.10$: * $p < 0.05$: ** $p < 0.01$: *** $p < 0.001$: NS $p > 0.10$

C Castrates : G Gilts

In contrast to the results of the regression analysis, analysis of variance failed to detect a significant treatment x sex interaction, in the data pertaining to any of the three growth periods. On the assumption that the results of the regression analysis were more precise, analyses of variance were carried out on the data of castrates and gilts separately, despite the absence of a significant treatment x sex interaction from the initial analyses of variance. Consequently, for each growth period, analysis was conducted on the data of castrates (C), gilts (G) and on the pooled data of castrates and gilts (C + G).

Growth period 50 - 85 lb. liveweight.

C + G fed diets including the higher level of meal, grew significantly faster than those receiving the lower level of meal supplement ($p < 0.005$). The individual-sex analyses showed this to be a reflection of both C and G performance.

At the lower level of meal, increases in the dietary content of DBMP were without significant effect on the growth rate of C, G or C + G, although the non-significant trends agree quite well with the results of the regression analysis.

The number of days taken to grow to 85 lb. liveweight by C + G, decreased linearly ($p < 0.01$: $b = -0.125 \pm 0.042$) as the DBMP content of the higher level of meal supplement increased. Analysis of C and G data separately also demonstrated negative linear trends. However, the linear response of castrates ($p < 0.05$: $b = -0.165 \pm 0.074$) was of greater significance than that of gilts ($p < 0.10$) which was associated with a curvilinear trend.

G grew significantly faster than C ($p < 0.05$).

Growth period 85 - 120 lb. liveweight.

C + G and G on the higher meal diets grew significantly faster than their counterparts fed the lower meal diets. ($p < 0.005$), but the difference between C means failed to reach significance.

Within meal levels, DBMP content was without significant effect on the growth rate of C, G or C + G.

G grew significantly faster than C ($p < 0.05$).

Growth period 50 - 120 lb. liveweight.

C, G and C + G receiving the higher daily allowance of meal, grew significantly faster than those fed the lower level of meal ($p < 0.005$).

At the lower level of meal supplementation the incorporation of DBMP to as high as 30% was without significant effect on the rate of gain of C + G. However the linear trend in C performance did prove significant ($p < 0.05$: $b = -0.200 \pm 0.091$), while the opposite response of G failed to reach significance.

Increasing the DBMP content of the diets involving the higher meal level, reduced the number of days taken by C + G to grow to 120 lb. liveweight ($p < 0.10$: $b = -0.116 \pm 0.067$). The result of the analysis of C and G data separately suggested the above response to be largely due to the performance of C, for which the linear trend proved significant at $p < 0.05$ ($b = -0.188 \pm 0.064$), whereas the response of G failed to reach significance. Examination of the means and mean squares indicated that the response of G was curvilinear in nature rather than linear, with maximum rate of gain when DBMP contributed 10% of the meal supplement. Although not significant, this pattern of response agrees closely with the results of the regression analysis.

G grew significantly faster than C. ($p < 0.01$).

(d) Summary

Statistical analysis of the data was conducted using both regression analysis and analysis of variance techniques. A highly significant treatment x sex interaction was isolated by regression analysis ($p < 0.005$) but the interaction failed to reach significance using the analysis of variance method. This was considered a reflection of the relative efficiency of the two methods of analysis (the m.s. used for testing the significance of the interaction by regression analysis and analysis of variance were based on 70 d.f. and 28 d.f. respectively). For this reason, and to gain further information on the differential response

of G and C, analyses of variance were conducted on the data of each sex separately, as well as on the combined-sex data.

The effect of sex

Over all growth periods G grew significantly faster than C (5-6% for each period).

The effect of meal level

Pigs fed diets involving the higher daily allowance of meal, in general grew faster than those receiving the lower quantity of meal. The magnitude of these differences in rate of gain are shown in Table 6/10.

Table 6/10: Percentage increase in rate of gain of pigs fed the higher compared with the lower daily allowance of meal.

Growth Period	Castrates	Gilts	Castrates + Gilts
50 - 85 lbs.	11.3	10.1	10.9
85 - 120	6.0	11.2	8.9
50 - 120	8.9	11.1	10.0

The effect of the level of DBMP

Regression analysis indicated that as the proportion of DBMP in the diets involving either level of meal supplement increased, so the growth performance of C improved. G on the other hand showed a negative linear response at the lower meal level as DBMP content increased, and a negative curvilinear response at the higher level of meal, with maximum rate of gain occurring on a diet containing 10% DBMP.

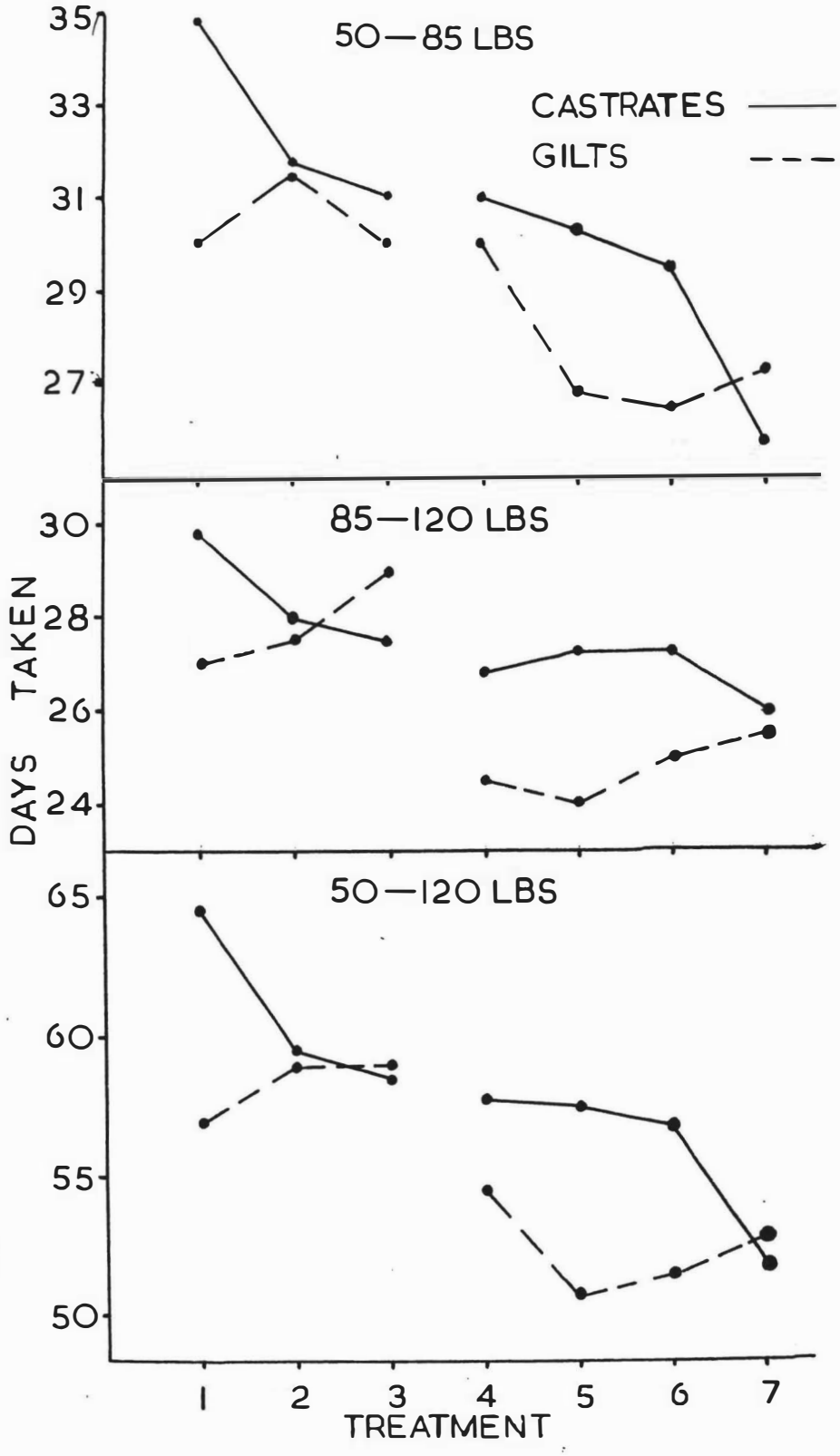


Figure 6/3: Experiment I : Mean number of days taken to grow over the specified liveweight ranges, in relation to treatment and sex.

These observations were supported by the results of the analyses of variance where significance was found, and by trends apparent from the data where differences failed to reach significance. Furthermore, analysis of variance suggested that response to increases in dietary DBMP was largely restricted to the growth pericd from 50-85 lb. liveweight.

The mean number of days taken to grow from 50-85, 85-120 and 50-120 lb. liveweight in relation to treatment, for C and G are presented graphically in Figure 6/3.

5. Food Intake and Efficiency of food utilization -

(a) General

Total whey, dry matter (DM) and crude protein (CP) intakes were calculated for individual animals over the three growth periods, using the number of days taken to cover each period, as derived for analysis of the growth data. The raw data are presented in Appendix 6/3. Total DM and CP values represent the sum of the contributions from meal and whey, obtained from the daily food consumption records, in combination with the relevant data on the composition of the meal and whey fed.

Analysis of the data was carried out according to the plan outlined in Chapter 5, on the basis of C + G only. Means are presented in the Tables for C, G and C + G.

(b) Growth period 50 - 85 lb. liveweight

The results are summarized in Tables 6/11 and 6/12. Details of statistical analysis are included in Appendix 6/3 and the results of analysis shown in Table 6/13.

As the DBMP content of the meal supplement, fed at the lower rate, increased, the total consumption and consumption/lb. LWG of both whey and

DM decreased linearly ($p < 0.05$). For each 1% increase in the proportion of DBMP, pigs consumed in total 2.25 lb. and 0.289 lbs. less of whey and DM respectively. Total CP consumption increased as the DBMP content of the lower level of meal supplement increased ($p < 0.05$) and consequently the efficiency of CP utilization declined ($p < 0.05$: $b = 0.001 \pm 0.0006$).

It should be pointed out that there was some indication ($p < 0.10$) of an interaction between treatment and sex for whey intake. Examination of the means suggested that the linear responses to level of DBMP outlined above, were largely associated with C performance, G showing comparatively little and curvilinear response.

At the higher level of meal, increases in the dietary content of DBMP resulted in a significant linear decrease in the total quantity of whey consumed and a positive linear response in the efficiency of whey utilization ($p < 0.05$). Similar highly significant trends in DM intake and utilization were found ($p < 0.005$).

With each 1% increase in DBMP the total consumption of whey and DM fell by 2.06 lb.s and 0.452 lbs. respectively. As for the lower level of meal, there were significant positive linear trends in total CP intake and CP/lb. LWG. ($p < 0.01$: $b = 0.002 \pm 0.0005$), as the DBMP content of the diet increased.

Pigs fed the higher level of meal, consumed significantly less DM and CP in total and per lb. LWG, than those receiving the lower allowance of meal ($p < 0.005$ in each case), but significantly more DM/day ($p < 0.005$). There was no significant difference between the mean daily CP intakes of the two groups.

Table 6/11: Experiment I - Treatment and sex means of food intake - growth period 50 - 85 lb. liveweight.

Pounds	Sex	Treatment Means								Sex Means		
		1	2	3	4	5	6	7	SED	C	G	SED
Total Whey Intake	C	956.3	842.0	814.0	437.0	432.5	422.0	349.3		607.6	570.0	15.9
	G	803.5	831.8	810.5	426.3	369.8	367.5	381.0				
	C+G	879.9	836.9	812.3	431.6	401.1	394.8	365.1	27.5			
Total DM Intake	C	100.0	89.5	86.0	90.5	87.9	84.5	72.5		87.3	82.1	1.94
	G	85.8	88.7	82.5	87.8	76.8	75.9	77.1				
	C+G	92.9	89.1	84.3	89.1	82.3	80.2	74.8	3.47			
Mean Daily DM Intake	C	2.89	2.83	2.79	2.92	2.91	2.87	2.81		2.86	2.85	0.017
	G	2.86	2.82	2.75	2.92	2.87	2.87	2.83				
	C+G	2.87	2.82	2.77	2.92	2.89	2.87	2.82	0.028			
Total CP Intake	C	15.9	15.7	16.2	13.4	14.4	15.2	14.2		15.0	14.2	0.34
	G	13.6	15.5	15.9	13.0	12.6	13.7	15.1				
	C+G	14.8	15.6	16.1	13.2	13.5	14.4	14.7	0.59			
Mean Daily CP Intake	C	0.459	0.494	0.526	0.433	0.474	0.516	0.552		0.494	0.493	0.0027
	G	0.453	0.492	0.530	0.432	0.476	0.515	0.554				
	C+G	0.456	0.493	0.528	0.432	0.475	0.516	0.553	0.0040			

C Castrates

G Gilts

Table 6/12: Experiment I - Treatment means of food intake, grouped according to meal level, for castrates, gilts and castrates and gilts considered together - growth period 50 - 85 lb. liveweight.

Pounds	Castrates + Gilts			Castrates			Gilts		
	Trs 1+2+3	Trs 4+5+6+7	SED	Trs 1+2+3	Trs 4+5+6+7	SED	Trs 1+2+3	Trs 4+5+6+7	SED
Total Whey Intake	843.0	398.2	14.9	870.8	410.2		815.3	386.1	
Total dm. Intake	88.8	81.6	1.87	91.9	83.8		85.7	79.4	
Mean Daily dm. Intake	2.82	2.87	0.015	2.83	2.88		2.81	2.87	
Total CP Intake	15.5	13.9	0.32	15.9	14.3		15.0	13.6	
Mean Daily CP Intake	0.492	0.494	0.0022	0.493	0.494		0.491	0.494	

Table 6/13: Experiment I - Significance of differences between treatment means and between sex means of food intake - growth period 50 - 85 lb. liveweight.

Variable	Means			Comparison	Tr. 1 to 3		Tr. 4 to 7	
	Tr.	Sex	TrxS	(1-3)v(4-7)	LIN.	QUAD.	LIN.	QUAD.
Total Whey Intake	* * *	*	†	* * *	*	NS	*	NS
Total DM Intake	* * *	*	NS	* * *	*	NS	***	NS
Mean Daily DM Intake	* * *	NS	NS	* * *	-	-	-	-
Total CP Intake	* * *	*	NS	* * *	*	NS	**	NS
Mean Daily CP Intake	* * *	NS	NS	NS	-	-	-	-

Table 6/14: Experiment I - Treatment and sex means of food intake - growth period 85 - 120 lb. liveweight.

Pounds	Sex	Treatment Means								Sex Means		
		1	2	3	4	5	6	7	SED	C	G	SED
Total Whey Intake	C	1288.8	1197.8	1131.3	754.0	757.5	770.8	721.3		945.9	896.7	21.5
	G	1125.5	1190.8	1218.0	677.0	664.0	691.3	710.3				
	C+G	1207.1	1194.3	1174.6	715.5	710.8	731.0	715.8	39.8			
Total DM Intake	C	110.3	102.3	96.4	100.5	100.2	99.7	94.0		100.5	95.2	2.03
	G	97.7	100.9	105.1	90.7	88.4	91.0	92.4				
	C+G	104.0	101.6	100.8	95.6	94.3	95.3	93.2	3.92			
Mean Daily DM Intake	C	3.71	3.65	3.51	3.76	3.68	3.66	3.62		3.65	3.65	0.024
	G	3.62	3.67	3.64	3.70	3.68	3.64	3.62				
	C+G	3.66	3.66	3.58	3.73	3.68	3.65	3.62	0.043			
Total CP Intake	C	18.3	17.8	18.0	15.7	16.9	18.1	18.0		17.5	16.6	0.39
	G	15.9	17.8	19.5	14.0	14.7	16.4	17.8				
	C+G	17.1	17.8	18.7	14.8	15.8	17.2	17.9	0.88			
Mean Daily CP Intake	C	0.615	0.636	0.655	0.586	0.619	0.663	0.692		0.638	0.635	0.0052
	G	0.587	0.648	0.673	0.572	0.613	0.654	0.698				
	C+G	0.601	0.642	0.664	0.579	0.616	0.659	0.695	0.0071			

C Castrates

G Gilts

Table 6/15: Experiment I - Treatment means of food intake, grouped according to meal level, for castrates, gilts and castrates and gilts considered together - growth period 85 - 120 lb. liveweight.

Pounds	Castrates + Gilts			Castrates			Gilts		
	Trs 1+2+3	Trs 4+5+6+7	SED	Trs 1+2+3	Trs 4+5+6+7	SED	Trs 1+2+3	Trs 4+5+6+7	SED
Total Whey Intake	1192.0	718.3	21.5	1205.9	750.9		1178.1	685.6	
Total dm Intake	102.1	94.6	1.12	103.0	98.6		101.3	90.6	
Mean Daily dm. Intake	3.63	3.67	0.023	3.62	3.68		3.64	3.66	
Total CP Intake	17.9	16.4	0.48	18.0	17.2		17.7	15.7	
Mean Daily CP Intake	0.636	0.637	0.0038	0.635	0.640		0.636	0.634	

Table 6/16: Experiment I - Significance of differences between treatment means and between sex means of food intake - growth period 85 - 120 lb. liveweight.

Variable	Means			Comparison	Tr.1 to 3		Tr. 4 to 7	
	Tr.	Sex	Tr.x S	(1-3)v(4-7)	LIN.	QUAD.	LIN.	QUAD.
Total Whey Intake	* * *	*	NS	* * *	NS	NS	NS	NS
Total DM Intake	NS	*	NS	* * *	NS	NS	NS	NS
Mean Daily DM Intake	+	NS	NS	NS	-	-	-	-
Total CP Intake	* * *	*	NS	* * *	+	NS	***	NS
Mean Daily CP Intake	* * *	NS	NS	NS	-	-	-	-

+ $p < 0.10$: * $p < 0.05$: ** $p < 0.01$: *** $p < 0.005$: NS $p > 0.10$

G consumed significantly less whey, DM and CP, in total and per lb. LWG, than C ($p < 0.05$), but differences between the mean daily intakes of the two sexes failed to reach significance.

(c) Growth period 85 - 120 lb. liveweight

The data are shown in Tables 6/14 and 6/15. Details of statistical analysis are presented in Appendix 6/3 and the results in Table 6/16.

The proportion of DBMP in the meal supplement, fed at either level, was without significant effect upon the total amounts of whey and DM consumed. At the lower level of meal, CP intake and the efficiency of CP utilization showed slight linear increases ($p < 0.10$) as the proportion of DBMP in the diet increased. At the higher meal level, the positive linear trends in CP intake were highly significant ($p < 0.005$).

Pigs receiving the higher daily allowance of meal consumed significantly less DM and CP than those fed the lower amount of meal, and consequently they utilized these two dietary fractions with significantly greater efficiency ($p < 0.005$). There was no significant difference between the mean daily intakes of DM and CP of pigs on the higher or lower level of meal supplement.

The efficiencies of whey, DM and CP utilization were significantly greater for G than for C ($p < 0.05$ in each case), but the mean daily intakes of DM and CP of the two sexes were not significantly different.

(d) Growth period 50 - 120 lb. liveweight

Treatment and sex means, and the results of statistical analysis are shown in Tables 6/17, 6/18 and 6/19. Details of the analyses of variance are presented in Appendix 6/3.

Table 6/17: Experiment I - Treatment and sex means of food intake - growth period 50 - 120 lb. liveweight.

Pounds	Sex	Treatment Means								Sex Means		
		1	2	3	4	5	6	7	SED	C	G	SED
Total Whey Intake	C	2245.0	2039.8	1945.3	1191.0	1190.0	1192.8	1070.5		1553.5	1466.7	31.7
	G	1928.8	2022.5	2028.5	1103.3	1033.8	1058.8	1091.3				
	C+G	2086.9	2031.1	1986.9	1147.1	1111.9	1125.8	1080.9	58.8			
Total DM Intake	C	210.4	192.1	182.4	191.1	188.1	184.1	166.2		187.8	177.2	3.50
	G	183.3	189.3	187.6	178.5	165.2	166.9	169.5				
	C+G	196.8	190.7	185.0	184.8	176.7	175.5	167.9	6.65			
Mean Daily DM Intake	C	3.26	3.21	3.13	3.31	3.27	3.25	3.21		3.23	3.23	0.016
	G	3.22	3.22	3.18	3.28	3.26	3.24	3.21				
	C+G	3.24	3.21	3.16	3.29	3.26	3.24	3.21	0.028			
Total CP Intake	C	34.2	33.5	34.2	29.1	31.2	33.3	32.2		32.5	30.7	0.64
	G	29.4	33.3	35.3	27.0	27.3	30.0	32.9				
	C+G	31.8	33.4	34.8	28.0	29.3	31.7	32.6	1.17			
Mean Daily CP Intake	C	0.531	0.560	0.587	0.504	0.543	0.587	0.623		0.562	0.560	0.002
	G	0.516	0.564	0.599	0.494	0.538	0.583	0.624				
	C+G	0.524	0.562	0.593	0.499	0.540	0.585	0.623	0.0050			

C Castrates

G Gilts

Table 6/18: Experiment I - Treatments means of food intake, grouped according to sex, for castrates, gilts and castrates and gilts considered together - growth period 50 - 120 lb. liveweight.

Pounds	Castrates + Gilts			Castrates			Gilts		
	Trs 1+2+3	Trs 4+5+6+7	SED	Trs 1+2+3	Trs 4+5+6+7	SED	Trs 1+2+3	Trs 4+5+6+7	SED
Total Whey Intake	2035.0	1116.4	31.7	2076.7	1161.1		1993.3	1071.8	
Total dm. Intake	190.8	176.2	3.59	195.0	182.4		186.7	170.0	
Mean Daily dm. Intake	3.20	3.25	0.015	3.20	3.26		3.20	3.25	
Total CP Intake	33.3	30.4	0.63	34.0	31.5		32.7	29.3	
Mean Daily CP Intake	0.560	0.562	0.0027	0.559	0.564		0.560	0.560	

Table 6/19: Experiment I - Significance of differences between treatment means and between sex means of food intake - growth period 50 - 120 lb. liveweight.

Variable	Means			Comparison	Tr. 1 to 3		Tr. 4 to 7	
	Tr.	Sex	Tr. x S	(1-3)v(4-7)	LIN.	QUAD.	LIN.	QUAD
Total whey Intake	* * *	*	*	* * *	†	NS	NS	NS
Total DM Intake	* * *	**	NS	* * *	†	NS	*	NS
Mean Daily DM Intake	* * *	NS	NS	* * *	-	-	-	-
Total CP Intake	* * *	**	NS	* * *	*	NS	***	NS
Mean Daily CP Intake	* * *	NS	NS	NS	-	-	-	-

As the DBMP content of the meal supplement fed at the lower level increased, total whey and DM consumption decreased linearly, and thus efficiency of whey and DM utilization increased linearly. However these responses only reached significance at a low level ($p < 0.10$). Positive linear trends in CP intake and efficiency of CP utilization, reached significance at $p < 0.05$ ($b = 0.001 \pm 0.0006$: lbs/lb. LWG).

At the higher meal level, increases in the proportion of DBMP were without significant effect upon whey intake and utilization, but the negative linear trends in DM intake and DM intake/lb. LWG proved significant at $p < 0.05$. Thus pigs consumed 0.518 lbs. DM less for each 1% increase in DBMP. The positive linear trends in CP intake as dietary DBMP content increased, proved highly significant ($p < 0.005$), pigs consuming 0.002 ± 0.005 lbs/lb. LWG more, for each 1% increase in DBMP.

It should be noted that the treatment x sex interaction proved significant ($p < 0.05$) for whey intake. Examination of the means suggested that at the lower level of meal, increases in the dietary content of DBMP were accompanied by increases in the efficiency of whey utilization by C, but decreases in efficiency for G. The means pertaining to animals fed the higher level of meal, indicated that the response of G was positively curvilinear, while increases in the proportion of DBMP (from 0 to 20% at least), had little effect on the intake of whey by C.

Pigs fed the higher amount of meal supplement, consumed significantly less DM and CP ($p < 0.005$) than pigs on treatments involving the lower level of meal. The mean daily intake of DM was significantly greater for animals receiving the higher meal allowance ($p < 0.005$), but the difference in mean daily CP intakes failed to reach significance. The total intakes and intakes/lb. LWG, of whey, DM and CP, were significantly less for G than

for C ($p < 0.05$: $p < 0.01$: $p < 0.01$ respectively).

(e) Summary

The effect of sex.

Over each of the three growth periods, G consumed significantly less whey, DM and CP than C (approx. 6%), and consequently were more efficient in the utilization of these three dietary fractions (approx. 6%). Differences between the mean daily intakes of DM and CP, by C and G, failed to reach significance.

The effect of meal level.

For each growth period, pigs fed the higher daily allowance of meal, consumed highly significantly less DM and CP, than animals receiving the lower meal allowance, and thus were more efficient in DM and CP utilization. From 50 - 85 and 50 - 120 lb. liveweight, the mean daily intake of DM was greater for animals fed the higher, compared with those fed the lower amount of meal, but no significant difference was detected between the mean daily CP intakes of the two groups. The magnitude of the differences referred to are presented in Table 6/20.

Table 6/20: Differences (%) between the total ane mean daily intakes of dry matter (DM) and crude protein (CP), by pigs fed the higher, compared with those fed the lower daily meal allowance.

Growth Period	50 - 85 lbs.	85 - 120 lbs.	50 - 120 lbs.
Total DM Intake	- 8.8	- 7.9	- 8.3
Mean DM Intake/day	+ 1.8	+ 1.1	+ 1.6
Total CP Intake	-11.5	- 9.1	- 9.5
Mean CP Intake/day	+ 0.4	+ 0.2	+ 0.4

The effect of the level of DBMP.

From 50 - 85 lb. liveweight, whey and DM intakes of pigs receiving either level of meal, decreased linearly as the proportion of DBMP increased, while CP intake increased linearly.

From 85 - 120 lb. liveweight, increases in the level of dietary DBMP at either level of meal supplementation, were without significant effect on whey and DM intake, but resulted in a highly significant positive linear trend in CP intake at the higher level of meal.

Over the entire growth period, increases in the DBMP content of meal supplements fed at either of the two rates, promoted significant positive linear trends in CP intake. In view of the lack of response in whey and DM intakes, to increasing levels of DBMP from 85 - 120 lb. liveweight, only the negative linear trend in DM intake of pigs receiving the higher meal allowance, reached significance ($p < 0.05$) for the entire period. A significant treatment x sex interaction for whey intake, suggested differential response of C and G to increases in the level of DBMP, particularly at the lower level of meal supplementation (-ve for C, +ve for G).

6. Indices of carcass composition -

(a) General

Where measurements were taken on both sides of each carcass, the mean values were used for purposes of analysis. The raw data for those measurements considered to provide the best estimates of carcass composition (re Chapter 5) are presented in Appendix 6/4.

In certain cases no analysis was carried out and in the majority of cases, statistical analysis was only performed on a combined-sex basis. From the tables, the presence or absence of SED's indicates where analysis was or was not conducted. Separate analyses of the data of each sex were conducted for those characteristics considered to give the best estimates of carcass composition.

(b) Carcass weight, killing-out %, length and depth

Treatment and sex means are shown in Tables 6/21 and 6/22. Details of the analyses of variance are presented in Appendix 6/4 and the results are summarized in Table 6/23.

Treatment was without significant effect on carcass weight, but carcasses of G were significantly heavier (1.5 lb.) than those of C ($p < 0.05$).

Differences between treatment means and between sex means for killing-out% and length were small and non-significant.

Data for maximum depth were not analysed, but there appeared no marked effect of either treatment or sex.

(c) Backfat depth taken on the mid-line

The mean data are shown in Tables 6/24 and 6/25, the details of analyses in Appendix 6/4 and the results of analyses in Table 6/26.

Treatment was without significant effect ($p > 0.10$) on any of the fat-depth measurements recorded and analysed.

G had significantly less fat over the third vertebra than C ($p < 0.05$), and differences of the same nature for fat depth over the gluteus medius muscle were significant at $p < 0.10$.

Table 6/21: Experiment I - Treatment and sex means; carcass weight killing-out percentages, length and depth.

	Sex	Treatment Means								Sex Means		
		1	2	3	4	5	6	7	SED	C	G	SED
Carcass Weight (lbs)	C	88.0	87.5	87.3	90.5	88.3	88.3	89.3		88.4	89.9	0.54
	G	90.8	90.5	89.0	90.5	88.5	90.3	89.5				
	C+G	89.4	89.0	88.1	90.5	88.4	89.3	89.4	1.09			
Killing-out percentage	C	72.1	72.4	71.7	71.9	72.0	71.8	72.1		72.0	72.4	0.30
	G	72.8	72.4	72.1	72.0	72.1	73.2	72.5				
	C+G	72.4	72.4	71.9	71.9	72.1	72.5	72.3	0.50			
Length (m.m.)	C	683	684	693	685	696	705	698		692	695	5.14
	G	694	694	698	698	698	692	692				
	C+G	688	689	696	691	697	698	695	6.03			
Depth (mm)	C	290.0	281.8	282.3	287.3	288.0	276.0	278.0		283.3	282.5	
	G	278.8	288.0	282.8	281.8	283.5	282.5	280.5				
	C+G	284.4	284.9	282.5	284.5	285.8	279.3	279.5				

Table 6/22: Experiment I - Treatment means grouped according to meal level; carcass weight, killing-out percentage, length and depth.

	Castrates + Gilts			Castrates			Gilts		
	Tr. 1+2+3	Tr. 4+5+6+7	SED	Tr. 1+2+3	Tr. 4+5+6+7	SED	Tr. 1+2+3	Tr. 4+5+6+7	SED
Carcass Weight (lbs)	88.8	89.4	0.59	87.6	89.1		90.1	89.7	
Killing-out percentage	72.2	72.2	0.27	72.1	72.0		72.4	72.4	
Length (mm)	691	695	3.26	687	696		695	695	
Depth (mm)	283.9	282.2		284.7	282.3		283.2	282.1	

Table 6/23: Experiment I - Levels of Significance of differences between means; carcass weight, killing-out percentage and length.

Variable	Means			Comparison	Tr.1 to 3		Tr.4 to 7	
	Tr.	Sex	Tr.x S	(1-3)v(4-7)	LIN.	QUAD.	LIN.	QUAD.
Carcass weights	NS	*	NS	NS	NS	NS	NS	NS
Killing-out percentage	NS	NS	NS	NS	-	-	-	-
Length	NS	NS	NS	NS	-	-	-	-
Depth	-	-	-	-	-	-	-	-

* $p < 0.05$: NS $p > 0.10$: C Castrates : G Gilts

Table 6/24: Experiment I - Treatment and sex means; backfat depth taken on the mid-line.

m.m.	Sex	Treatment Means								Sex Means		
		1	2	3	4	5	6	7	SED	C	G	SED
Maximum Shoulder	C	32.5	30.8	30.8	31.8	30.8	33.3	32.3		31.7	30.3	
	G	27.5	31.0	33.3	32.5	28.8	30.0	28.8				
	C+G	30.0	30.9	32.0	32.1	29.8	31.6	30.5				
Third Vertebra	C	24.5	26.0	25.0	24.8	26.5	25.8	26.8		25.6	23.8	0.88
	G	21.8	23.3	26.5	25.0	22.3	23.8	24.0				
	C+G	23.1	24.6	25.8	24.9	24.4	24.8	25.4	1.43			
Mid-back	C	15.0	12.0	12.0	14.5	13.8	13.0	14.5		13.5	12.5	0.67
	G	11.0	12.8	14.8	11.8	12.8	11.0	13.5				
	C+G	13.0	12.4	13.4	13.1	13.3	12.0	14.0	1.13			
Maximum Loin	C	23.5	22.3	21.3	23.3	22.8	22.8	23.3		22.7	22.4	0.85
	G	21.5	23.8	24.5	23.5	21.8	21.0	21.0				
	C+G	22.5	23.0	22.9	23.4	22.3	21.9	22.1	1.27			
Minimum Loin	C	19.0	17.8	17.5	17.5	18.5	18.0	18.8		18.8	15.5	0.87
	G	15.3	19.3	17.5	17.5	15.3	15.8	15.5				
	C+G	17.1	18.5	17.5	17.5	16.9	16.9	17.1	1.44			

Table 6/25: Experiment I - Treatment means grouped according to meal level; backfat depth taken on the mid-line.

m.m.	Castrates + Gilts			Castrates			Gilts		
	Tr. 1+2+3	Tr. 4+5+6+7	SED	Tr. 1+2+3	Tr. 4+5+6+7	SED	Tr. 1+2+3	Tr. 4+5+6+7	SED
Max. shoulder	31.0	31.0		31.3	32.0		30.6	30.0	
Third vertebra	24.5	24.8	0.77	25.2	25.9		23.8	23.8	
Mid-back	12.9	13.1	0.61	13.0	13.9		12.8	12.3	
Max. Loin	22.8	22.4	0.69	22.3	23.0		23.3	21.8	
Min. Loin	17.7	17.1	0.78	18.1	18.2		17.3	16.0	

Table 6/26: Experiment I - Levels of significance of differences between means; backfat depth taken on the mid-line.

Variable	Means			Comparison	Tr. 1 to 3		Tr. 4 to 7	
	Tr.	Sex	Tr.xS	(1-3)v(4-7)	LIN.	QUAD.	LIN.	QUAD.
Max. shoulder	-	-	-	-	-	-	-	-
Third Vertebra	NS	*	NS	NS	-	-	-	-
Mid-back	NS	NS	NS	NS	-	-	-	-
Maximum Loin	NS	NS	NS	NS	-	-	-	-
Minimum Loin	NS	†	NS	NS	-	-	-	-

† $p < 0.10$: * $p < 0.05$: NS $p > 0.10$: C Castrates : G Gilts

(d) Fat depth over the "eye" muscle and measurements taken of the "eye" muscle

The relevant data are summariesed in Tables 6/27 and 6/28. Analytical details are included in Appendix 6/4 and the results of analysis are shown in Table 6/29.

For the data of C and G considered together, differences between the means of pigs receiving either the higher or lower daily allowance of meal failed to reach significance ($p \triangleright 0.10$) for any characteristic. Similarly, increases in the proportion of DBMP at either level of meal supplement were without significant effect ($p \triangleright 0.10$) on any characteristic,

Length of "eye" muscle ("A") and "eye"muscle area (EMA) were both significantly greater for G than for C ($p < 0.05$ and 0.005 respectively). "C" was significantly greater for C than G ($p \triangleleft 0.005$) while $^{EMA}/_{"C"}$ proved significantly higher for G ($p \triangleleft 0.005$).

As "C" is reputedly the best of the linear measurements, taken singly, for predicting either carcass lean or fat content (re Chapter 5), statistical analysis of this characteristic was performed in greater detail.

Despite the fact that the treatment x sex interaction for "C" failed to reach significance, examination of the individual sex means suggested differential response of C and G to changes in the level of meal supplementation, and to changes in the proportion of DBMP. Analysis of the data for each sex separately showed meal level to be without significant effect ($p \triangleleft 0.10$) for either sex. While increases in the proportion of DBMP were without significant effect on treatment means for "C" of G carcasses, the negative linear response at the lower level of meal for C did reach significance ($p \triangleleft 0.01$: $b = -0.1667 \pm 0.0560$).

In view of the effect of sex on carcass weight, an analysis of covariance was conducted, adjusting "C" means on a basis of equal carcass weight (see Appendix 6/4). It was appreciated that the results of such an analysis would necessitate some caution in interpretation. The difference between the adjusted means for "C" of C and G proved significant ($p \triangleleft 0.05$:

Table 6/27: Experiment I - Treatment and sex means of fat depth over the "eye" muscle and measurements of the "eye" muscle.

	Sex	Treatment Means								Sex Means		
		1	2	3	4	5	6	7	SED	C	G	SED
"A" (mm)	C	71.5	72.0	73.0	70.5	71.5	70.8	68.5		71.1	73.4	1.10
	G	76.3	72.3	70.0	72.8	74.5	74.0	74.0				
	C+G	73.9	72.1	71.5	71.6	73.0	72.4	71.3	2.22			
"B" (mm)	C	37.5	39.8	41.8	39.8	43.0	40.0	40.0		40.3	41.9	
	G	40.8	41.3	42.0	41.5	40.5	42.0	45.5				
	C+G	39.1	40.5	41.9	40.6	41.8	41.0	42.8				
"Eye" muscle area (cm^2)	C	17.7	19.1	19.0	17.7	19.6	18.3	18.8		18.6	20.7	0.61
	G	21.6	19.8	20.2	19.4	21.0	21.6	21.6				
	C+G	19.7	19.4	19.6	18.5	20.3	19.9	20.2	1.03			
"C" (mm)	C	19.8	14.3	14.8	17.0	15.8	16.8	15.8	1.68	16.3	14.3	0.63
	G	13.8	14.5	15.8	15.0	14.0	13.8	13.5	1.64			
	C+G	16.8	14.4	15.3	16.0	14.9	15.3	14.6	1.35			
"K" (mm)	C	24.3	18.3	20.5	22.3	20.0	20.8	19.5		20.7	18.5	
	G	17.8	18.3	21.0	19.0	17.8	18.5	17.5				
	C+G	21.0	18.3	20.8	20.6	18.9	19.4	18.5				
"J" (mm)	C	6.0	3.8	5.0	6.0	4.0	5.3	5.8		5.1	4.2	
	G	4.0	3.8	4.5	4.8	4.3	4.5	3.8				
	C+G	5.0	3.8	4.8	5.4	4.1	4.9	4.8				
EMA / C	C	0.932	1.387	1.325	1.073	1.262	1.103	1.217		1.185	1.498	0.083
	G	1.586	1.377	1.324	1.308	1.554	1.699	1.642				
	C+G	1.259	1.382	1.324	1.190	1.408	1.401	1.430	0.165			

C Castrates

G GILTS

Table 6/28: Experiment I - Treatment means grouped according to meal level; fat depth over the "eye" muscle and measurements of the "eye" muscle.

	Castrates + Gilts			Castrates			Gilts		
	Tr. 1+2+3	Tr. 4+5+6+7	SED	Tr. 1+2+3	Tr. 4+5+6+7	SED	Tr. 1+2+3	Tr. 4+5+6+7	SED
"A" (mm)	72.5	72.1	1.20	72.2	70.3		72.8	73.8	
"B" (mm)	40.5	41.5		39.7	40.7		41.3	42.4	
"Eye" Muscle area (cm^2)	19.6	19.7	0.56	18.6	18.6		20.5	20.9	
"C" (mm)	15.5	15.2	0.73	16.3	16.3	0.90	14.7	14.1	0.88
"K" (mm)	20.0	19.3		21.0	20.5		19.0	18.2	
"J" (mm)	4.5	4.8		4.9	5.3		4.1	4.3	
EMA/C	1.322	1.357	0.089	1.215	1.164		1.429	1.551	

Table 6/29: Experiment I - Levels of significance of differences between means : fat depth over the "eye" muscle and measurements of the "eye" muscle

Variable		Means			Comparison	Tr. 1 to 3		Tr.4 to 7	
		Tr.	Sex	Tr.xS	(1-3)v(4-7)	LIN.	QUAD.	LIN.	QUAD.
"A"		NS	*	NS	NS	NS	NS	NS	NS
"Eye" muscle area		NS	***	NS	NS	NS	NS	NS	NS
"C"	C	†			NS	**	†	NS	NS
	G	NS			NS	NS	NS	NS	NS
	C+G	NS	***	NS	NS	NS	NS	NS	NS
EMA/C		NS	***	NS	NS	NS	NS	NS	NS

† $p < 0.10$: * $p < 0.05$: ** $p < 0.01$: *** $p < 0.005$: NS $p > 0.10$

G < C), but the effect of treatment and the treatment x sex interaction failed to reach significance.

Comparison of the appropriate error mean squares from the analyses of variance and covariance, indicated the latter to have a relative efficiency of 97% and 78% for tests significance of differences between treatment and sex means respectively. It is probable that the reduction in efficiency was allied to opposite effects of carcass weight on "C", on a between as opposed to a within-group basis. Thus the sums of squares and sums of products for sex, indicated a comparatively large negative regression coefficient, which would be expected from the effects of sex on carcass weight and "C" already demonstrated. However it is unlikely that within sexes an increase in carcass weight was accompanied by a decrease in "C". For such reasons, the use of covariance analysis, involving the adjustment of means to equal carcass weight, was considered inappropriate for the analysis of carcass data.

As the incomplete balance of design, regarding the distribution of C and G within and between blocks and treatments, probably reduced experimental precision, analysis of variance of "C" was carried out by a method of constant fitting (see Appendix 6/4). ** The effect of sex proved significant ($p < 0.01$), but the treatment effect and the treatment x sex interaction failed to reach significance (at $p < 0.05$), despite an approximate 8% increase in efficiency over the standard method of analysis of variance.

** I am indebted to the late Mr. A. C. Glenday who conducted this analysis.

Table 6/30: Experiment I : Treatment and sex means, carcass specific gravity and loin-joint data.

	Sex	Treatment Means								Sex Means		
		1	2	3	4	5	6	7	SED	C	G	SED
Specific Gravity	C	1.048	1.059	1.055	1.051	1.059	1.057	1.060	0.0028	1.056	1.059	0.0013
	G	1.059	1.058	1.055	1.059	1.060	1.062	1.062	0.0038			
	C+G	1.054	1.058	1.055	1.055	1.059	1.060	1.061	0.0026			
Loin Joint Weight (gms)	C	3101	2710	2866	3009	2886	2999	2782		2907	2898	47.5
	G	2834	3035	2980	2911	2794	2892	2840				
	C+G	2968	2872	2922	2960	2840	2945	2811	93.9			
Loin Joint % Lean	C	36.0	43.4	40.0	37.2	39.9	37.4	40.6		39.2	42.3	1.04
	G	42.8	39.9	39.8	40.8	43.6	45.1	44.0				
	C+G	39.4	41.6	39.9	39.0	41.8	41.3	42.3	1.67			
Loin Joint Lean:Fat Ratio	C	0.702	1.020	0.885	0.743	0.877	0.787	0.903	0.101	0.845	0.965	0.042
	G	0.993	0.888	0.847	0.878	1.043	1.077	1.031	0.121			
	C+G	0.848	0.954	0.866	0.810	0.960	0.932	0.967	0.071			
Loin Joint % Fat	C	52.0	43.4	45.4	50.3	46.2	47.8	45.2		47.2	44.3	1.01
	G	43.4	45.4	47.4	46.6	42.2	42.6	43.5				
	C+G	47.7	44.4	46.4	48.4	44.2	45.2	44.3	1.82			

C Castrates

G Gilts

Table 6/31: Experiment I - Treatment means grouped according to meal level; carcass specific gravity and loin-joint data.

	Castrates + Gilts			Castrates			Gilts		
	Tr. 1+2+3	Tr. 4+5+6+7	SED	Tr. 1+2+3	Tr. 4+5+6+7	SED	Tr. 1+2+3	Tr. 4+5+6+7	SED
Specific gravity	1.056	1.059	0.0014	1.054	1.057	0.0015	1.057	1.061	0.0020
Joint weight (gms)	2921	2889	50.7	2892	2919		2950	2859	
Lean %	40.3	41.1	0.91	39.8	38.8		40.8	43.4	
Fat %	46.2	45.5	0.99	46.9	47.4		45.4	43.7	
Lean:Fat Ratio	0.889	0.917	0.038	0.869	0.827	0.054	0.909	1.007	0.065

Table 6/32: Experiment I - Levels of significance of differences between means; carcass specific gravity and loin-joint data.

		Means			Comparison	Tr. 1 to 3		Tr. 4 to 7	
		Tr.	Sex	Tr. x S	(1-3)v(4-7)	LIN.	QUAD.	LIN.	QUAD.
Specific Gravity	C	**			NS	*	**	*	NS
	G	NS			NS	NS	NS	NS	NS
	C+G	†	*	NS	*	NS	†	*	NS
Join Weights		NS	NS	†	-	-	-	-	-
Lean %		NS	**	NS	NS	NS	NS	†	NS
Fat %		NS	*	NS	NS	NS	NS	†	NS
Lean:Fat Ratio	C	†			NS	†	*	NS	NS
	G	NS			NS	NS	NS	NS	NS
	C+G	NS	**	†	NS	NS	NS	†	NS

† $p < 0.10$: * $p < 0.05$: ** $p < 0.01$: NS $p > 0.10$.

C Castrates : G Gilts

(e) Specific Gravity (SG) and loin-joint dissection

Treatment and sex means are presented in Tables 6/30 and 6/31; details of statistical analyses in Appendix 6/4; and the results of analysis in Table 6/32.

SG data were analysed both on a combined and individual-sex basis. The combined-sex analysis showed G carcasses to have a significantly greater mean SG than carcasses from C ($p < 0.05$). Pigs receiving the higher daily allowance of meal produced carcasses of greater SG than those on the lower level ($p < 0.05$). There was some suggestion of a negative curvilinear trend in carcass SG as the DBMP content of the meal supplement fed at the lower level increased ($p < 0.10$). At the higher meal level a significant positive linear trend in SG accompanied increases in dietary DBMP content ($p < 0.05$: $b = +0.0002 \pm 0.00008$).

On analysis of the data of C and G separately, it was found that whereas increases in DBMP at either meal level were without significant effect on the SG of G carcasses, both the linear and quadratic responses at the lower meal level ($p < 0.05$ and p 0.01 respectively), and the linear response at the higher level ($p < 0.05$), proved significant for C. This apparent differential response of G and C may be partly explicable in terms of the lower variance of C, but in view of the nature and magnitude of C, in contrast to G response, and on consideration of the highly significant treatment x sex interaction for rate of gain detected by regression analysis it seems likely that changes in the DBMP content of the diet had different effects on the SG of G and C carcasses.

No significant difference was detected between the mean carcass SG of pigs receiving the higher or lower levels of meal, for either C or G.

Statistical analysis of the sample-joint dissection data, gave some indication ($p < 0.10 : p > 0.05$) of an interaction between treatment and sex for joint weight and lean:fat ratio.

Loin joints from G carcasses contained significantly less dissectable fat ($p < 0.01$), more dissectable lean ($p < 0.05$) and consequently a greater ratio of lean:fat ($p < 0.01$) than those from C.

No significant effect of the level of meal supplement upon sample-joint composition, was detected.

Increases in the DBMP content of the meal supplement fed at the higher level, induced a positive linear response in the lean content and lean:fat ratio of sample joints from C + G, and a negative linear trend in fat content. Although these trends were significant at only a low level ($p < 0.10$), they agree with the significant trends found in carcass SG ($p < 0.05$).

Analysis of the loin-joint lean:fat ratios for C and G separately, showed the negative-curvilinear response of C to increasing proportions of dietary DBMP at the lower meal level to reach significance at $p < 0.05$, while no significant response was detected in the data of G. These observations are again in agreement with the results of analysis of SG.

(f) Summary

The effect of sex.

Carcasses of G were slightly, but significantly heavier (1.5 lb.) than those from C, but sex was without significant effect on killing-out %.

The majority of measurements indicated that G carcasses contained significantly more lean and less fat than carcasses from C, although the difference was not readily detectable from measurements of backfat depth taken on the mid-line.

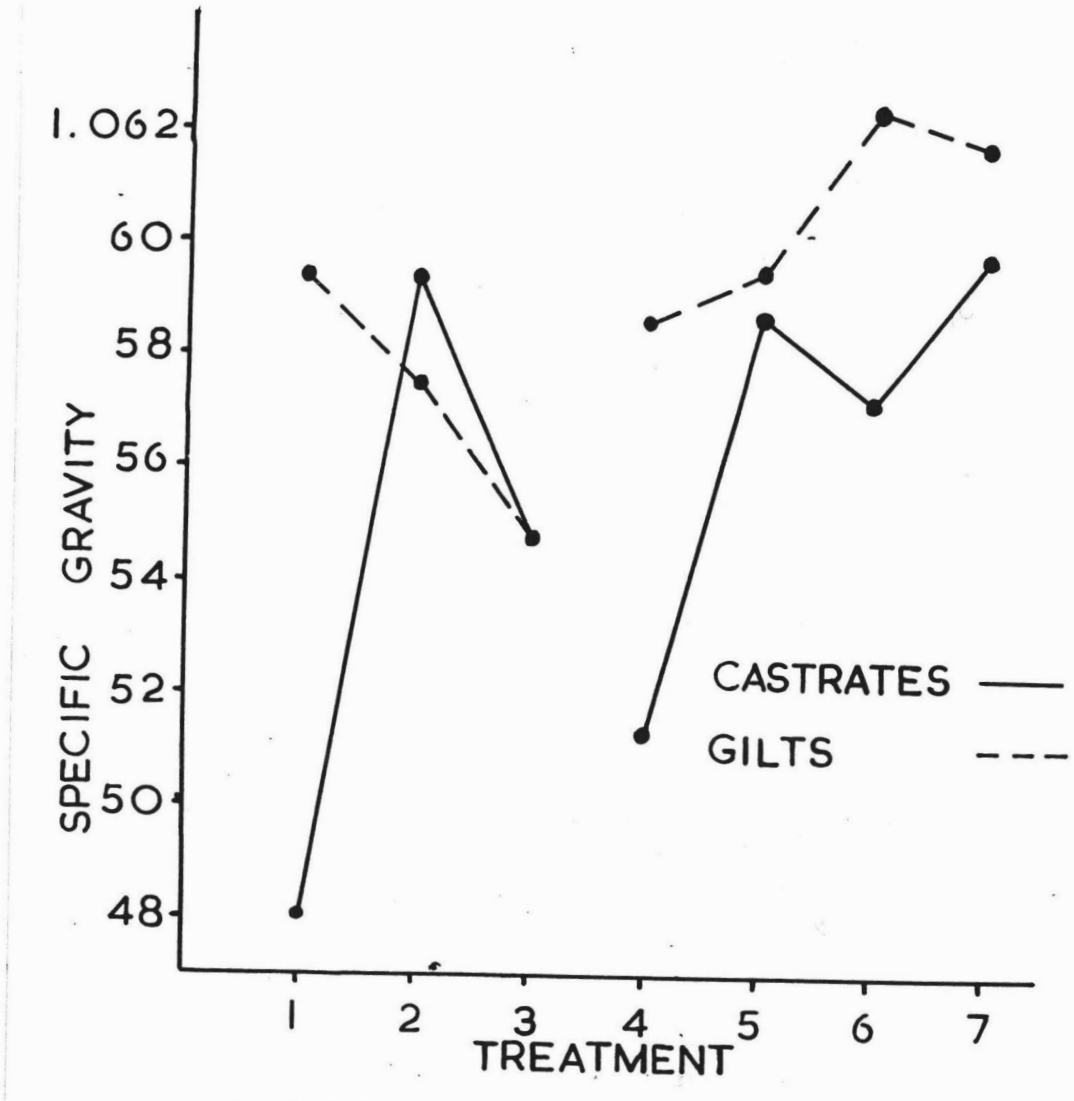


Figure 6/4: Experiment I : Treatment means of carcass specific gravities for castrates and gilts.

The effect of meal level.

With the exception of SG, the level of meal supplement was without effect on any index of carcass composition. In the case of SG, carcasses from pigs fed the higher level of meal had a greater mean SG than those from pigs on the lower meal diets, although in relative terms the difference was less than 1%.

Although not reaching statistical significance, those characteristics providing the best estimates of carcass composition suggested that G receiving the higher daily allowance of meal were leaner than those fed the lower level of meal, while the reverse situation appeared true for C.

The effect of the level of DBMP

At the lower daily meal allowance, the proportion of DBMP was without any real effect on the indices of carcass composition for C + G, although the negative curvilinear response in SG data reached significance at $p < 0.10$. As the DBMP content of the meal supplement fed at the higher level increased, SG and loin-joint estimates of leanness increased linearly ($p < 0.05$: $p < 0.10$ respectively).

A treatment x sex interaction was suggested from the analysis of loin-joint lean:fat ratios ($p < 0.10$), and differential response of C and G increasing proportions of DBMP was indicated from analysis of SG, lean:fat ratio and "C" on a within-sex basis. In general, as the DBMP content of the meal supplement fed at the lower level increased, there was a significant positive linear/negative curvilinear trend in

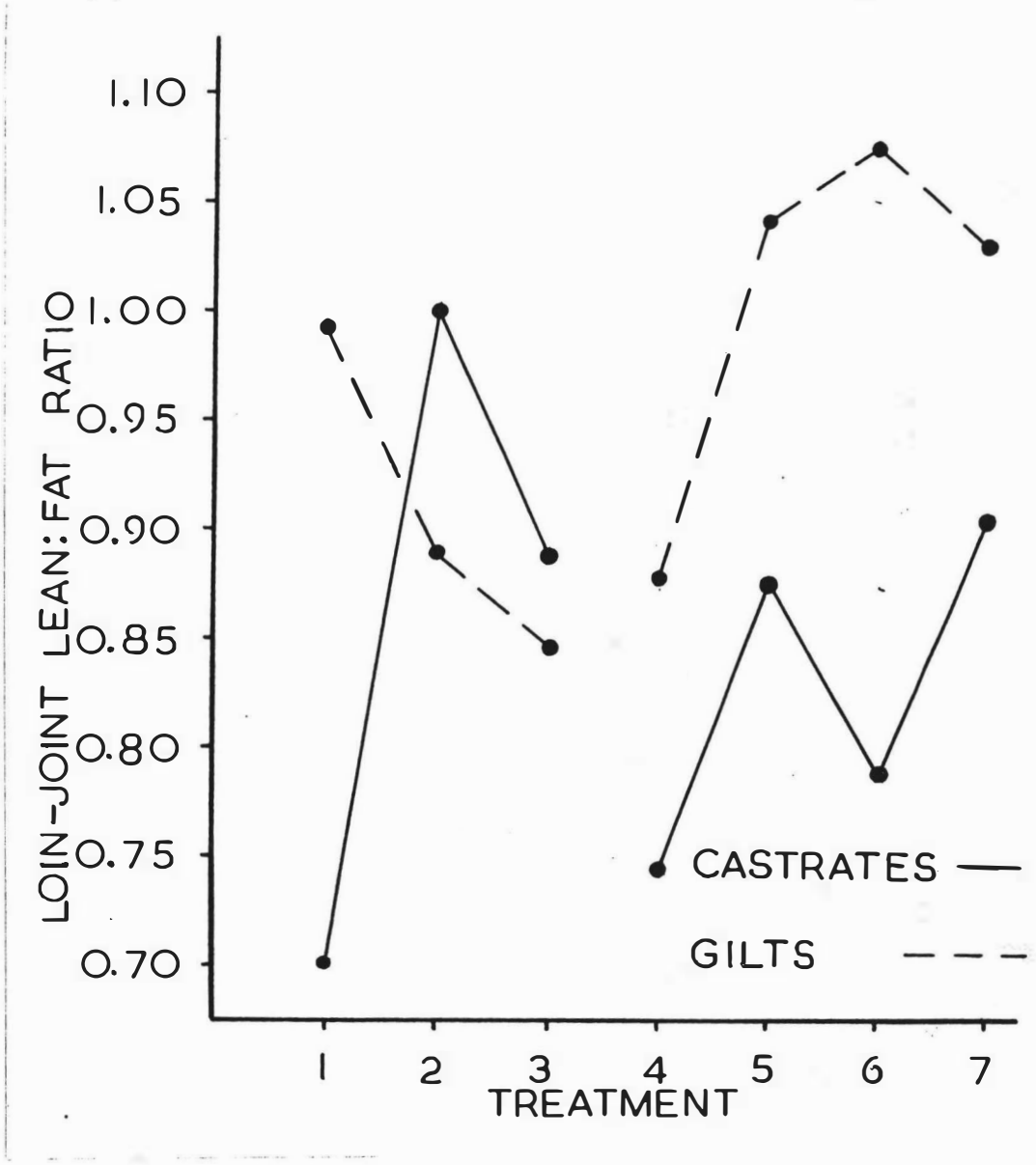


Figure 6/5: Experiment I : Treatment means of loin-joint lean:fat ratios for castrates and gilts.

indices of the lean content of C carcasses, while the negative linear trend in the case of G failed to reach significance. At the higher meal level, increasing proportions of DBMP promoted a significant positive linear response in carcass SG for C, but was without effect on G carcasses. The differences in response of C and G to changes in the level of DBMP are shown diagramatically in Figures 6/4 and 6/5, for SG and loin-joint lean:fat ratio.

7. General Summary -

(a) The effect of sex

Over all growth periods gilts grew significantly faster than castrates (5-6%) and yet had the same mean daily intake of dry matter and crude protein. Consequently the total consumption of dry matter and crude protein by gilts, for each of the growth periods, was significantly less than that by castrates, and the efficiency of dry matter and crude protein utilization significantly greater (approx. 6%).

Carcasses from gilts were slightly (1.5 lb.) but significantly heavier than those from castrates, and as sex was without significant effect on killing out percentage, it may be concluded that gilts were heavier than castrates at slaughter. (In view of the faster rate of gain of gilts and the procedure followed in determining when pigs were dispatched for slaughter, discrepance in weight at slaughter, between gilts and castrates, might have been expected).

Measurements of carcasses, reputed to provide the best estimates of carcass composition, indicated that gilt carcasses were significantly leaner than those from castrates.

(b) The effect of meal level

Pigs fed diets involving the higher level of meal, grew significantly faster than those receiving the lower allowance of meal, overall stages of growth (approx. 10%). There was some indication that the growth response of gilts to the higher meal level was greater than that of castrates, particularly during the 85 - 120 lb. period.

The efficiency of dry matter and crude protein utilization was significantly greater for pigs receiving the higher daily allowance of meal, for each growth period. Mean daily crude protein intakes were similar for the two groups of pigs, but animals on the higher meal diets consumed significantly more dry matter/day than those fed the lower level of meal, over the 50 - 85 and 50 - 120 lb. liveweight growth period.

Differences between indices of the composition of carcasses from pigs fed either the higher or lower level of meal failed to reach significance, with the exception of SG - the SG of carcasses from pigs fed the higher meal level being significantly greater than the value for carcasses of pigs on the lower meal diets. There was some indication (non-significant) that gilts fed the higher daily allowance of meal were leaner than those receiving the lower allowance, while the reverse situation appeared true for castrates.

(c) The effect of the level of DBMP

Diets involving the lower level of meal supplementation

Regression analysis and analysis of variance showed no significant effect of increases in DBMP on the rate of gain of castrates and gilts considered together.

The growth rate of castrates increased linearly as the DBMP content of the diet increased, while that of gilts declined linearly.

From 50 - 85 lb. liveweight the efficiency of dry matter utilization increased linearly with increases in the proportion of DBMP, but the efficiency of crude protein utilization decreased linearly. Changes in the dietary content of DBMP during the 85 - 120 lb. period were without significant effect on food utilization.

Trends apparent throughout the data suggested a negative curvilinear response in the carcass lean content of pigs, irrespective of sex, as the DBMP content of the diet increased, but all failed to reach significance except that for carcass SG. Analysis of the data of each sex separately, suggested the trends were largely a reflection of castrate response, comparatively small negative linear trends in indices of the lean content of gilt carcasses failing to reach significance.

Diets involving the higher level of meal supplement

As the DBMP content of the diet increased, the growth rate of castrates and gilts considered together, increased linearly, but the response was restricted to the period from 50 - 85 lb. liveweight. The growth response of castrates to increasing proportions of DBMP was positively linear, while that of gilts was negatively curvilinear, being maximum when DBMP was included at the rate of 10%. The individual responses of castrates and gilts were again largely restricted to the 50 - 85 lb. growth period.

The efficiency of dry matter utilization of pigs without reference to sex, increased linearly with increases in DBMP over the 50 - 85 lb. period, but not during the 85 - 120 lb. period. As the DBMP content of the diet increased, the efficiency of crude protein utilization deteriorated significantly over all stages of growth.

Positive linear trends in estimates of carcass leanness, as the proportion of DBMP increased, proved significant for sample-joint composition and SG alone. Separate analysis of the castrate and gilt data, indicated a positive linear relationship between carcass lean content and the level of dietary DBMP for castrates, while the negative curvilinear trends in the data of gilts failed to reach significance.

B. EXPERIMENT II:

1. Whey and meal composition -

The whey fed throughout the experiment had a mean dry-matter content of 5.69 ± 0.17% and a mean crude protein content (Nx6.38) of 1.00 ± 0.04%.

As the meal samples fed to the two pigs on each treatment during the six pre-collection/collection periods, had been taken from the same bulk mix, the policy of analysing meal samples pertaining specifically to each period within treatments, was considered unnecessary. Table 6/33 shows the N content of meal samples fed during three different collection periods, in relation to treatment,

Table 6/33: Experiment II - N content (%) of samples of the meal fed during three collection periods in relation to treatment

Treatment	Sample 1	Sample 2	Sample 3	Mean
1	1.80	1.76	1.78	1.78
2	2.37	2.39	2.39	2.39
3	2.85	2.83	2.90	2.86
4	1.79	1.82	1.76	1.79
5	2.30	2.26	2.26	2.27
6	2.49	2.56	2.53	2.53
7	2.84	2.78	2.79	2.80

Samples 1 and 2 were taken during the course of the first two collection periods, on a within-treatment basis, i.e. irrespective of pigs, while sample 3 was taken at the last collection. The approximate length of time between obtaining samples 1 and 3 was 12 weeks, during which the pre-weighed lots of meal had been stored in sealed plastic bags at 5°F. (re Chapter 5). No deterioration of the samples, typified by changes in N content was evident. The mean values shown in Table 6/33 were used for calculation of N intakes.

The calorific values of the whey and meal samples accumulated throughout the experiment (re Chapter 5) are detailed in Table 6/34.

Table 6/34: Experiment II - Calorific values of the treatment meal mixes and the representative whey sample (k/cals/gm.DM)

Treatment Meal Mixes							WHEY
1	2	3	4	5	6	7	
4.30	4.41	4.46	4.34	4.35	4.39	4.44	3.89

2. Health -

After undergoing the first collection period, one pig developed an anal prolapse. This animals was removed from the experiment and replaced by another (re Chapter 5). The results pertaining to the single collection were discarded.

Apart from a slight degree of lameness in all animals (developing during the first balance periods, and probably associated with the relative size of the pigs' feet and the weld-mesh floors of the crates), the general health of pigs was good, and scouring was absent.

3. Food Refusal -

There was no refusal of food by any pig either between or during collection periods.

4. Collection Preservation and Storage of Excreta -

Throughout collection, there was little contamination of faeces with urine, or vice-versa.

Before the start of the experiment, samples of faeces and urine were collected from each of four pigs receiving the experimental diets of treatments 1, 3, 4 and 7. N determinations were carried out on the fresh materials soon after voiding, and at the end of a 5-day storage period. Methods of sampling, analysis and storage were as detailed elsewhere. The results of the analyses are presented in Table 6/35. The changes in N content did not appear to be great for either urine or faeces, and from this small scale appraisal, the proposed methods of preservation and storage appeared suitable for use throughout the experiment.

Due to the volatility of toluene, it was found necessary to add more of this chemical to the urine samples during storage, to ensure complete coverage.

Throughout the experiment this procedure was adopted routinely by the addition of approximately 50 ml. toluene to the stored urine samples, once daily, at the first sampling period.

Table 6/35: Experiment II - Changes in the N content of urine and faeces from pigs fed treatment diets 1, 3, 4 and 7, after storage for 5 days.

	Urinary N (gms/100 gms)			Faecal N (gms./100 gms)		
Treatment Diet fed	At Voiding	After 5 days	% Change	At Voiding	After 5 days	% Change
1	0.1463	0.1442	- 1.5	0.3637	0.3650	+ 0.4
3	0.1745	0.1723	- 1.3	0.5244	0.5201	- 0.8
4	0.3006	0.2967	- 1.3	0.3621	0.3601	- 0.6
7	0.4039	0.4007	- 0.8	0.4500	0.4521	+ 0.5

5. Analysis of food and excreta -

The means, standard deviations and coefficients of variation for N determinations carried out on faeces (in triplicate) and urine (in duplicate) and for faecal energy determinations (in duplicate) are shown in Table 6/34.

Table 6/36: Experiment II - Means, standard deviations and coefficients of variation for determinations of faecal and urinary N and faecal energy contents.

	df	Mean ± SD	Coeff. of Variation %
FAECAL N (% wet matter)	70	0.4522 ± 0.0276	6.10
URINARY N (mls. $^{N}/10$ H_2SO_4/5 ml)	67	8.76 ± 0.272	3.11
FAECAL E (k/cals/gm DM)	52	3.88 ± 0.026	0.68

The level of repeatability attained in the determination of both faecal and urinary N was inferior to that reported by Ludvigsen and Thorbek (1958), the coefficients of variation obtained in the present work, being approximately tenfold those reported by Ludvigsen and Thorbek, for both faeces and urine. In view of the non-specific nature of the analytical inaccuracy, it is probable that it resulted from causes associated with either the operator or the chemical apparatus, rather than from sampling methods. As there was no apparent indication that improvement in repeatability occurred as the experiment progressed (as might be expected if operator inexperience had been the major cause of variation), it was tentatively concluded that fault lay in the apparatus.

The method used in determination of N, unavoidably involved the transfer of the residues of digestion from Kjeldahl flasks to distillation flasks. It is possible that losses may have occurred during this process. Throughout digestion, flasks were heated by means of bunsen burners. Due to changes in gas pressure along the line of burners throughout the course of a single set of digestions, it was particularly difficult to ensure that all replicate samples digested at approximately the same rate. This fact may have contributed to the loss in repeatability, in view of the possible effect of digestion rate on the results of N determinations by the Kjeldahl method (Bradstreet 1965). It is worth noting that in reference to the levels of repeatability reported by Ludvigsen and Thorbek (1958) in determination of the N content of a variety of materials, Flatt (1958) pointed out that he had not been able to attain such accuracy in his laboratory, but gave no indication of the repeatability which he was in fact able to achieve.

6. Growth data -

The number of days taken for each pig to cover the growth periods 50 - 85 lb., 85 - 120 lb. and 50 - 120 lb. were obtained by interpolation from

the individual growth curves. The mean values of two pigs per treatment are shown in Table 6/37 and the grouped-treatment means in Table 6/38. The only difference to reach significance was that between the number of days taken by pigs fed the lower meal diets to grow from 50 - 85 lbs. and the corresponding value for animals receiving the higher level of meal ($p < 0.05$).

Table 6/37: Experiment II - Treatment means of the growth data and some carcass characteristics.

Treatment	1	2	3	4	5	6	7
Days 50 - 85 lb. L.wt.	31.0	31.5	30.0	30.0	28.0	27.5	29.0
" 85 -120 lb. L.wt.	29.0	27.0	27.0	25.5	26.5	28.5	27.5
" 50 - 120 lb. L.wt.	60.0	58.5	57.0	55.5	54.5	56.0	56.5
Carcass Specific Gravity	1.044	1.049	1.052	1.048	1.050	1.048	1.046
Loin Joint % Lean	32.9	38.2	38.5	35.2	33.8	37.2	32.8
" % Fat	54.5	48.7	48.6	50.6	51.7	49.8	53.7
" Lean:Fat ratio	0.605	0.796	0.794	0.702	0.666	0.747	0.624

Table 6/38: Experiment II - Treatment means grouped according to meal level, of the growth data of some carcass characteristics.

Treatment Groups	1+2+3	4+5+6+7
Days 50 - 85 lb. L.wt.	30.8	28.6
" 85 - 120 lb. L.wt.	27.7	27.0
" 50 - 120 lb. L.wt.	58.5	55.6
Carcass Specific Gravity	1.048	1.048
Loin-Joint % Lean	36.5	34.8
" % Fat	50.6	51.5
" Lean:Fat ratio	0.732	0.685

The failure of other differences to reach significance was probably related to the small number of pigs involved in the experiment.

Table 6/39: Experiment II - Gross and apparent-digestible intakes of nitrogen and energy : Treatment and collection-period means.

	CP	Treatment Means							$\overline{CP}$	SED		
		1	2	3	4	5	6	7		Tr.	CP	Tr. x CP
Gross N Intake (gms/5 days)	A	156.8	174.8	186.5	144.9	168.8	176.7	186.5	170.7	2.13	1.39	3.69
	B	194.8	210.9	226.6	185.3	206.5	216.3	232.8	210.4			
	C	230.4	254.2	262.2	221.8	242.8	253.7	265.1	247.1			
	$\overline{Tr.}$	194.0	213.3	225.1	184.0	206.0	215.5	228.1				
App. Dig. N Intake (gms/5 days)	A	126.8	144.9	158.8	115.1	131.6	150.0	161.6	141.2	2.88	1.89	4.99
	B	161.5	174.7	192.3	149.0	166.7	171.0	198.8	173.4			
	C	196.2	210.2	221.4	182.6	198.4	209.5	222.9	205.9			
	$\overline{Tr.}$	161.5	176.5	190.8	148.9	165.6	176.8	194.4				
Gross Energy Intake (k/cals/5 days)	A	26700	26165	26044	27350	27034	26899	26483	26668	252	165	436
	B	32177	31396	31773	33010	32480	32663	32858	32337			
	C	36487	36798	36319	37788	37164	37382	37223	37023			
	$\overline{Tr.}$	31788	31453	31378	32717	32226	32314	32188				
App. Dig. Energy Intake (k/cals/5 days)	A	23295	23077	23519	23092	22776	23727	23689	23311	267	175	463
	B	28708	28089	28756	28343	28022	28282	29304	28500			
	C	32875	33035	33001	32839	32507	33173	33237	32952			
	$\overline{Tr.}$	28293	28067	28425	28091	27768	28394	28743				

Table 6/40: Experiment II - Gross and apparent-digestible intakes of nitrogen and energy : Treatment means grouped according to meal level.

	Treatment Groups		S E D
	1+2+3	4+5+6+7	
Gross N Intake (gms/5 days)	210.8	208.4	1.15
App. Dig. N Intake (gms/5 days)	176.3	171.4	1.56
Gross Energy Intake (k/cals/5 days)	31540	32361	136
App. Dig. Energy Intake (k/cals/5 days)	28261	28249	144

Table 6/41: Experiment II - Significance of differences between means of nitrogen intakes and energy intakes.

	Means			(1-3) v (4-7)	Tr.1 to 3		Tr.4 to 7		CP A to C	
Variable	Tr.	CP	Tr. x CP		LIN.	QUAD.	LIN.	QUAD.	LIN.	QUAD.
Gross N Intake	***	***	NS	*	***	†	***	**	***	NS
App. Dig. N Intake	***	***	NS	**	***	NS	***	NS	***	NS
Gross Energy Intake	***	***	NS	***	NS	NS	†	NS	***	**
App. Dig. Energy Intake	*	***	NS	NS	NS	NS	**	†	***	*

† $p < 0.10$: * $p < 0.05$: ** $p < 0.01$: *** $p < 0.005$: NS $p > 0.10$.

7. Energy Intake and Digestibility -

The raw data, on an individual-pig basis, are presented in Appendix 6/5 and the treatment and collection-period means in the tables. Detailes of the statistical analyses are included in Appendix 6/5 and the results summarised in Table 6/41 and 6/44.

The gross energy intake of pigs receiving the higher level of meal supplement, was significantly greater than that of animals fed the lower level of meal ($p < 0.005$). However, because of the highly significant difference in the apparent digestibility of energy from the two types of diet, the difference between the apparent digestible energy (ADE) intakes of the two groups of pigs was small and failed to reach significance.

At the lower level of meal, increases in the proportion of DBMP were without significant effect on ADE intake, but at the higher level resulted in a significant linear increase in the intake of ADE ($p < 0.01$), the positive curvilinear trend reaching significance at $p < 0.10$.

As the percentage of DBMP in diets involving either level of meal supplement increased, there was a significant linear increase in ADE% ($p < 0.005$).

ADE% increased linearly ($p < 0.005$) as the experiment progressed.

8. N Balance Data -

Full details of N intake and excretion for each pig are presented in Appendix 6/5. Treatment and collection-period means, and the results of statistical analyses are shown in the tables and the details of analysis in Appendix 6/5.

Pigs fed the higher daily allowance of meal, consumed significantly less N and apparent digestible N (ADN) than those receiving the lower allowance ($p < 0.05$: $p < 0.01$ respectively). ADN% was significantly less ($p < 0.05$) for diets

involving the higher, as opposed to the lower level of meal.

N retained (gms/5 days) by pigs fed the higher meal allowance was greater than that retained by animals receiving the lower amount of meal ($p < 0.05$). Similarly pigs fed the higher level of meal retained a significantly greater percentage of the N consumed ($p < 0.01$) and more N/kg. body weight ($p < 0.10$), than pigs on the lower meal diets.

Table 6/42: Experiment II - Coefficients of apparent digestibility of nitrogen and energy, and nitrogen retention data : Treatment and collection-period means.

	CP	Treatment Means							$\overline{CP}$	SED		
		1	2	3	4	5	6	7		Tr.	CP	Tr. x CP
App. Dig. N %	A	80.8	83.0	85.2	79.5	78.0	84.9	86.7	82.6	1.10	0.72	1.90
	B	82.8	82.8	84.9	80.4	80.7	79.1	85.4	82.3			
	C	85.2	82.7	84.2	82.4	81.8	82.6	84.1	83.3			
	$\overline{Tr.}$	82.9	82.8	84.8	80.7	80.2	82.2	85.4				
App. Dig. Energy %	A	87.3	88.2	90.3	84.5	84.3	88.3	89.5	87.5	0.69	0.46	1.20
	B	89.3	89.5	90.5	85.9	86.3	86.6	89.2	88.2			
	C	90.1	89.8	90.9	86.9	87.5	88.8	89.3	89.0			
	$\overline{Tr.}$	88.9	89.2	90.6	85.7	86.0	87.9	89.3				
N Retained (gms/5 days)	A	55.0	65.8	69.1	52.5	68.6	71.7	73.4	65.1	6.35	4.16	11.00
	B	44.3	49.8	57.8	66.5	71.6	68.7	65.6	60.6			
	C	52.3	65.5	63.8	71.2	62.6	70.9	56.0	63.2			
	$\overline{Tr.}$	50.5	60.3	63.5	63.4	67.6	70.4	65.0				
N Retained %	A	35.1	37.6	37.2	36.0	40.6	40.6	39.4	38.0	2.90	1.90	5.03
	B	22.7	23.7	25.5	34.8	34.7	31.8	28.2	28.7			
	C	22.7	25.8	24.4	32.2	25.8	27.9	21.1	25.7			
	$\overline{Tr.}$	26.8	29.0	29.0	34.3	33.7	33.4	29.5				
N Retained (gms/5 days k/kg.)	A	2.10	2.21	2.50	1.82	2.45	2.51	2.67	2.32	0.163	0.107	0.282
	B	1.10	1.22	1.41	1.55	1.76	1.64	1.60	1.47			
	C	1.01	1.26	1.20	1.33	1.18	1.37	1.09	1.20			
	$\overline{Tr.}$	1.40	1.56	1.70	1.57	1.79	1.84	1.79				

Table 6/43: Experiment II - Coefficients of apparent digestibility of nitrogen and energy, and nitrogen retention data : Treatment means grouped according to meal level.

	Treatment Groups		S E D
	1+2+3	4+5+6+7	
App. Dig. N %	83.5	82.1	0.59
App. Dig. Energy %	89.5	87.2	0.36
N Retained (gms/5 days)	58.1	66.6	3.43
N Retained %	28.3	32.7	1.57
N Retained (gms/5 days/kg.)	1.55	1.75	0.088

Table 6/44: Experiment II - Significance of differences between means of coefficients of apparent digestibility of nitrogen and energy, and between means of nitrogen retention data.

	Means			(1-3) v (4-7)	Tr.1 to 3		Tr.4 to 7		CP A to C	
Variable	Tr.	CP	Tr.x CP		LIN.	QUAD.	LIN.	QUAD.	LIN.	QUAD.
App. Dig. N %	***	NS	NS	*	NS	NS	***	†	NS	NS
App. Dig Energy %	***	**	NS	***	*	NS	***	NS	***	NS
N Retained (gms/5 days)	NS	NS	NS	*	†	NS	NS	NS	NS	NS
N Retained %	NS	***	NS	**	NS	NS	NS	NS	***	†
N Retained (gms/5 days/kg)	NS	***	NS	†	†	NS	NS	NS	***	**

† $p < 0.10$: * $p < 0.05$: ** $p < 0.01$: *** $p < 0.005$: NS $p \geq 0.10$

As the proportion of DBMP in the meal supplement fed at the lower rate increased, so N retained (gms/5 days) and N retained/kg. bodyweight increased linearly. However both trends only reached significance at a low level ($p < 0.10$). Changes in the content of DBMP at the higher meal level, were without significant effect upon N retention.

On ageing, pigs retained significantly less N/kg. bodyweight, but the highly significant linear response ($p < 0.005$) was associated with a positive curvilinear trend, significant at $p < 0.01$. Over all treatments, the percentage of N retained declined linearly with age ($p < 0.005$).

9. Indices of Carcass Composition -

In view of the low level of replication, measurements taken on the carcasses were not subjected to statistical analysis. Treatment means of SG and sample-joint composition are presented in Tables 6/37 and 6/38. The magnitude of the measurements, compared with those of castrate carcasses from Experiment I, suggested that the animals of Experiment II were fatter. Apart from genotypic differences between the two groups of pigs, the apparent differences in carcass composition may have been allied to higher energy intake, or more probably, lower energy expenditure of the pigs restricted in crates.

10. Summary -

The data of Experiment II related only to castrates.

The methods adopted for collection, preservation and storage of excreta, appeared satisfactory.

In comparison with published values, the coefficients of variation for the determination of faecal and urinary N were high. This was considered largely a reflection of the method adopted, in relation to the chemical apparatus used.

(a) The effect of meal level

ADE% was greater for diets involving the lower level of meal.

The ADE intakes of pigs fed either the higher or lower level of meal were

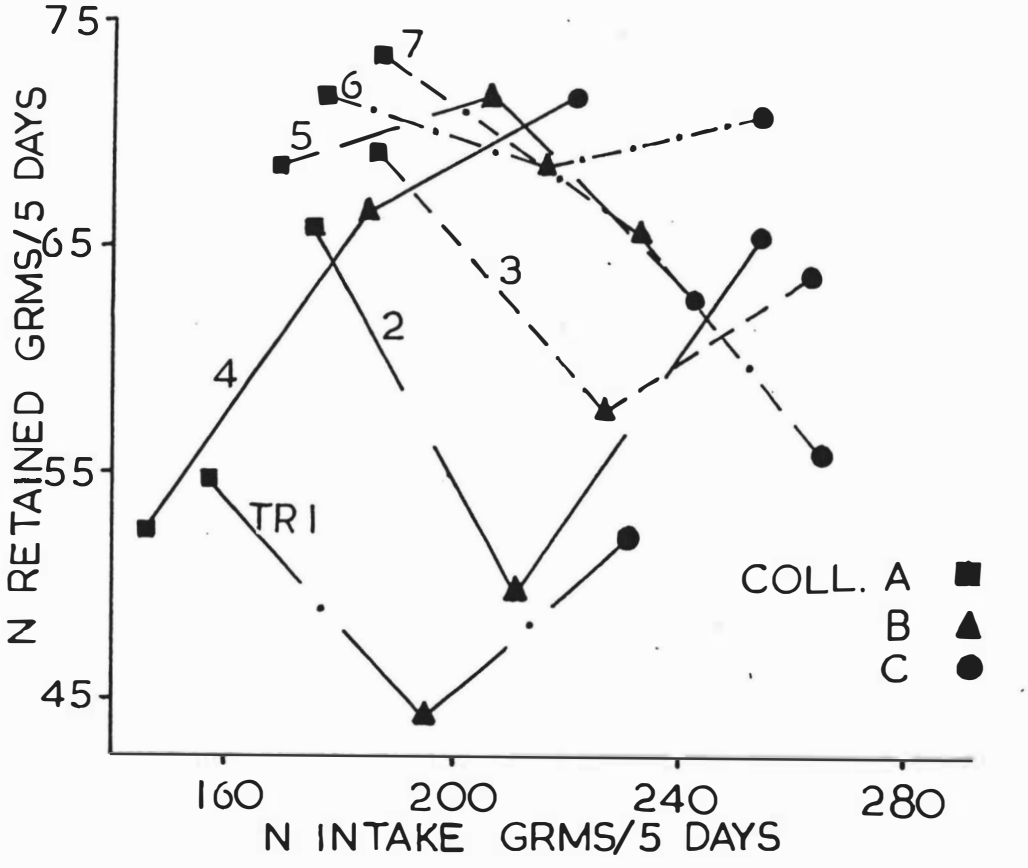


Figure 6/6: Experiment II : N retained in relation to N intake, treatment and collection period (each value the mean of two pigs).

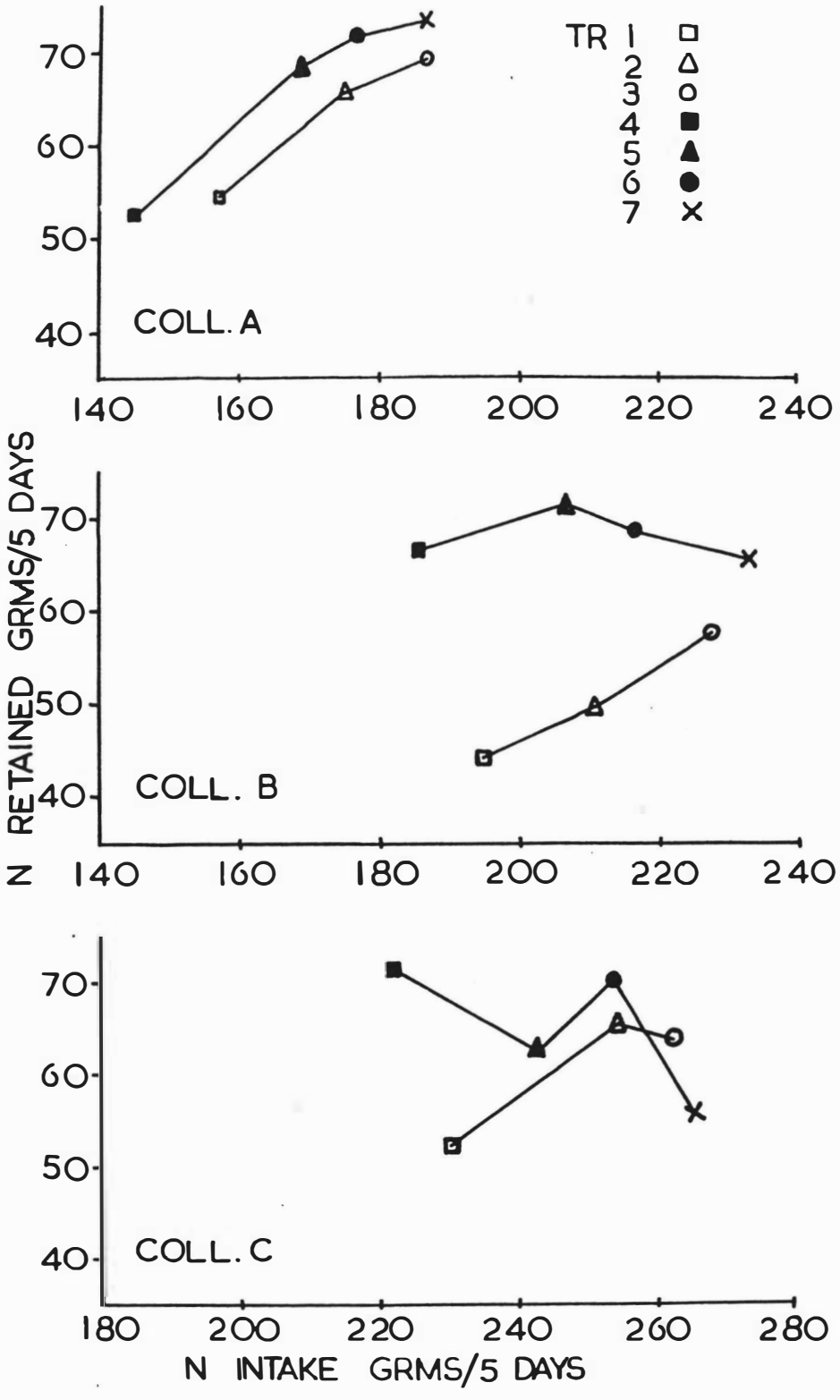


Figure 6/7: Experiment II : N retained in relation to N intake and treatment for each collection period (each value the mean of two pigs).

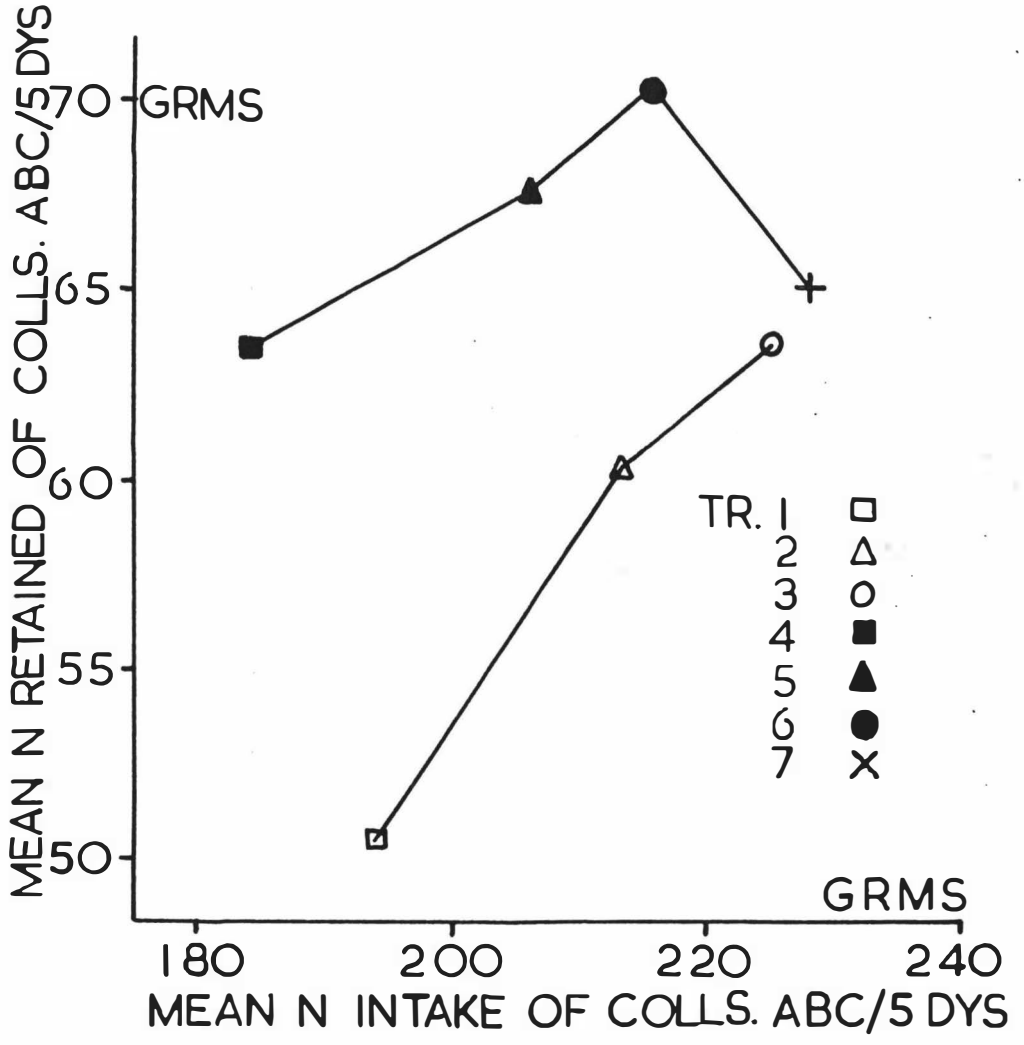


Figure 6/8: Experiment II : N retained in relation to N intake and treatment (each value the mean of three collection periods for each of two pigs).

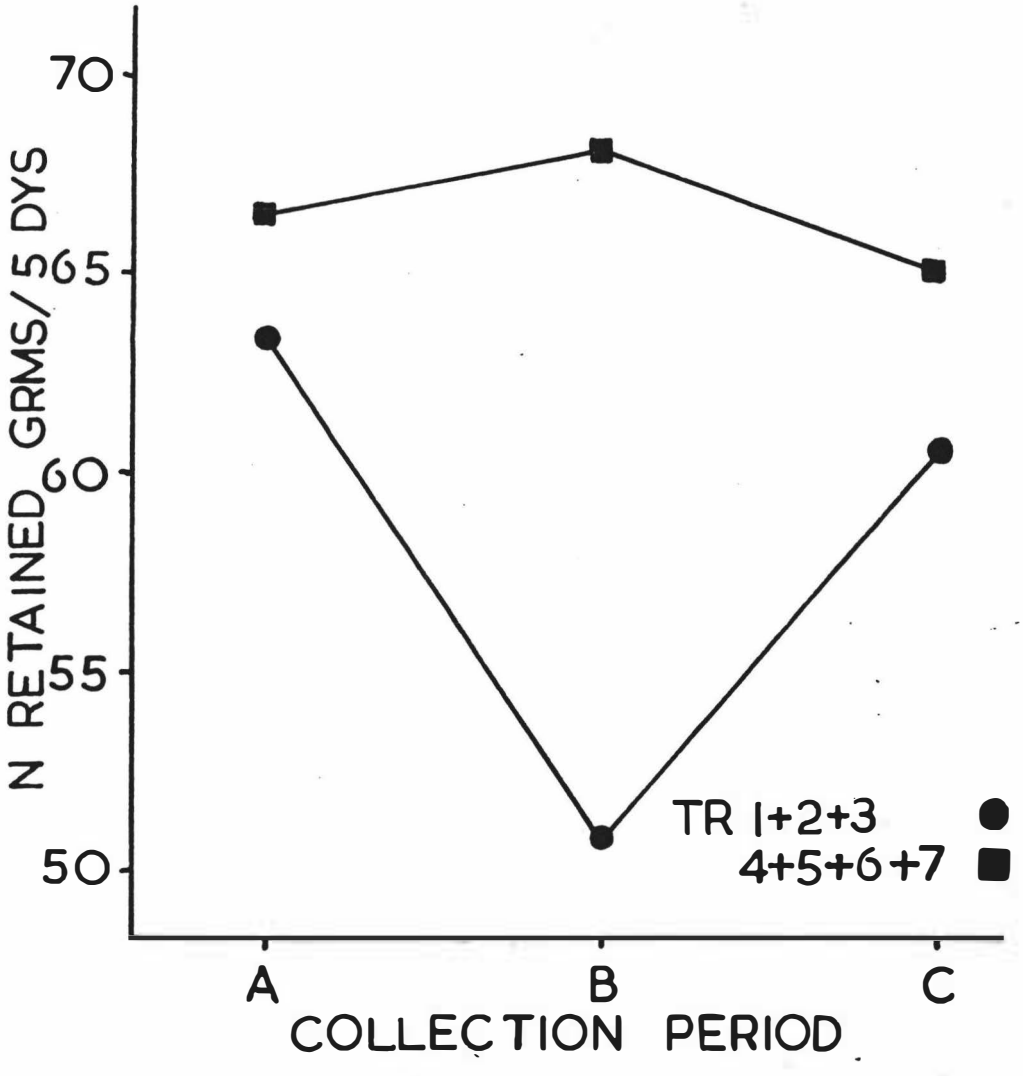


Figure 6/9: Experiment II : N retained in relation to collection period and level of meal supplement.

CHAPTER 7

DISCUSSION, CONCLUSION and SUMMARY

A. DISCUSSION OF RESULTS:

1. General -

The results of the two experiments will be discussed in relation to each other. The cautions necessary in such an approach are outlined below.

A highly significant treatment x sex interaction was demonstrated in Experiment I for rate of gain, on analysis by regression technique. As growth rate is simply the cumulative resultant of the relative rates of deposition of various body tissues, one would expect that where interactions between diet and sex occur in data pertaining to growth, they would also be likely to occur in data of energy and N metabolism. For this reason it was concluded that interpretation of the results of experiments conducted with members of a single sex, in terms of a population comprising individuals of two sexes, may be subject to severe limitations. Throughout the discussion, the results of Experiment II (which involved castrates only), are related solely to the performance of castrates in Experiment I, with the exception of the digestibility data. Blaxter (1962) regards digestibility as being more a function of the ration than of the animal, while Ludvigsen and Thorbek (1955) were unable to detect any differences between the digestive ability of castrates and gilts.

The growth data and indices of carcass composition for the castrates of Experiments I and II indicated the latter to have grown faster and to have layed down proportionally more fat. Apart from genotypic differences between the two groups of pigs, these observations suggested a lower expenditure and/or a higher intake of energy by the castrates of Experiment II. In view of the inter-relationships between dietary energy and protein, any discrepance in the energy

"status" of the two lots of pigs, may well lead to errors in comparison of results. This point should be borne in mind.

2. Digestibility data -

Little will be said regarding changes in the coefficients of apparent digestibility of energy and N with age or intake. Factors affecting digestibility are discussed by Crampton (1956), and Maynard and Loosli (1956). The observed changes in ADE %, accompanying alterations in the diet (either in the level of meal or the proportion of DBMP) were to be expected from the estimated TDN values of the various dietary ingredients. Trends in ADN % with age or intake were in agreement with those presented in the literature (Jones et. al. 1961: Barber et. al. 1964: Fuller 1965).

The relatively high values of the digestibility coefficients, compared with those for pigs fed all-meal diets, may be considered a reflection of the high digestibility of whey.

The coefficients of apparent digestible energy and the TDN value of fresh whey was estimated from the data presented, as follows. Taking the TDN value of barley meal as 71%, its gross energy content as 1790 k.cals/lb. (estimated in the current work) and the calorific value of TDN as 2,000 k.cals/lb., ADE % for barley meal approximates to 80%. Using this value, and the data on energy intake for pigs on treatments 1 and 4, i.e. where barley meal formed all the meal supplement, the mean coefficient of apparent digestible energy for whey dry matter was calculated to be approximately 96%, giving a TDN value of 84.8% (gross energy content of whey DM 3.89 k.cals/gm.)

The results of Experiment II showed that there was no significant difference between the mean daily intakes of digestible energy by pigs fed either the lower or higher level of meal supplement. Thus in this respect, the utilization of published values for the TDN contents of the various dietary ingredients, for

purposes of ration formulation, was successful. However, quite marked differences were found between the performance of pigs fed either the higher or lower level of meal, in both Experiments I and II. As animals on the higher meal diets grew faster, utilized their food more efficiently, and in the case of castrates at least, retained significantly more N, it can be concluded that their intake of metabolizable or "productive" energy was higher. These observations effectively demonstrate the limitations of feeding systems based on TDN or digestible energy (re Chapter 4), which inherently assume that digestible energy provided in different forms is equally utilizable.

For reasons already outlined, it will be assumed throughout the remainder of the discussion, that the results obtained from Experiment II (with castrates only) on digestibility and intake of digestible "nutrients", are applicable to both castrates and gilts.

3. The effect of Sex -

On average, gilts were superior to castrates in rate of gain, feed efficiency and carcass lean content. Reference has already been made to sex dimorphism (Chapter 5) and it is well established that gilts produce leaner carcasses than castrates, although the influence of sex on growth rate appears less certain. Under ad libitum systems of feeding, differences between the voluntary intake of food by castrates and gilts (Bowland and Berg 1959: Bell 1965) may well be a contributory cause to inconsistency of results, while diet x sex interactions, as found by Bowland and Berg (1959), Robinson et. al. (1964) and in the present work, must also be of significance.

4. The effect of meal level -

The reader is referred to pages 139 and 152 for summaries of the results of each experiment.

(a) Energy Intake

The performance of pigs fed the higher daily allowance of meal supplement was superior to that of pigs receiving the lower level of meal. This observation is in agreement with the results of other work (re Chapter 2) involving pigs fed fresh whey, either to appetite or in restricted amounts.

The results of Experiment II showed that the mean daily intakes of digestible energy for pigs fed either the higher or lower allowance of meal supplement were similar. It may be concluded therefore, that the inferior performance of pigs fed the larger quantities of whey, was a reflection of "losses" of energy occuring subsequent to digestion.

These "losses" may have occurred via any one, or all of three routes:

First, "losses" occurring in the urine and related to low renal tolerance for certain components of whey, e.g. lactose or galactose.

Second, "losses" associated with the demand on available energy, accompanying the ingestion of comparatively large volumes of water, at a temperature below that of the body.

Third, "losses" related to assimilation of the metabolites of whey.

The final two of these three possible avenues of loss, are virtually identical to the residual fraction of energy loss defined by Leroy (1965) as losses " ... related to the changes undergone by the ingested metabolites while they are being digested and assimilated and also to the extra expenditure of energy which accompanies the act of eating".

No reference could be found relating specifically to the urinary loss of energy accompanying the ingestion of fresh whey, i.e. to the metabolizable energy value of whey. Diggs et. al. (1959: 1965) found the metabolizable energy values of a variety of feeds to equal about 92% of digestible energy. The actual value obtained for dried whey fed to pigs of 30 lb. liveweight was 94%. Shearer (1967), feeding meal diets,

containing from 0 to 45% lactose, to pigs weighing 50 - 120 lb., found that total reducing sugars voided in the urine, accounted for only 1 - 2% of the lactose consumed at all levels of intake. Thus unless transformation of energy occurred to forms other than those in which it was absorbed, lactose intake appeared to have little detrimental effect upon the metabolizable energy content of the diet. From the work cited, related evidence suggests that the metabolizable energy value of fresh whey may not be grossly inferior to that of other foodstuffs (although the validity of this conclusion might well be influenced by the level of whey in the diet, or the amount ingested).

It seems therefore that the apparently low "productive" energy content of whey, a reflection of energy losses associated with the concomitant intake of large volumes of water and/or with changes undergone by the ingested metabolites.

The additional calorific requirement to raise the temperature of the greater volume of whey consumed/day (15 lbs.) by pigs in the present experiments, receiving the lower daily allowance of meal, in comparison with those on the higher meal diets, was estimated as 120 k.cals/day - taking the specific heat of whey as 1 cal/gm. and assuming that the temperature of the whey when fed had to be raised 18°C. to reach that of the body.

The mean digestible energy intake of pigs fed the higher level of meal, throughout the total growth period, was approximately 5660 k.cals/day (re Table 6/40), giving a mean metabolizable energy intake of 5200 k.cals/day (taking ME as 92% of DE - Diggs et. al. 1959: 1965). The mean body weight of pigs during the entire growth period approximated to 40 kg., and thus in accordance with the data of Leroy (1965) would have had an energy requirement for maintenance of approximately 1400 k.cals/day. Consequently

the mean metabolizable energy intake, over and above maintenance, of pigs fed the higher meal diets was estimated to be about 3800 k.cals/day - a value not greatly different from those reported by Leroy (1965) and Oslage and Fliegel (1965) for pigs fed to appetite. In reference to the results of Brierem (1939); Lund (1938); Nehring and Schiemann (1963) - all cited by Oslage and Fliegel (1965) - and Oslage and Fliegel (1965), the efficiency of utilization of metabolizable energy available for production, approximates to 75%.

On this basis, the daily intake of "stored" energy by pigs fed the higher allowance of meal was calculated as 2850 k. cals. As a proportion of this value, the 120 k. cals. estimated as the additional energy expenditure of pigs receiving the greater amounts of whey, represents 4 - 5%. In view of the fact that pigs fed the higher level of meal performed approximately 10% better than those on the lower meal diets (both in terms of rate of gain, feed efficiency and N retention), the above calculations suggest that the "cooling effect" of whey was unlikely to be solely responsible for the inferior performance of pigs consuming the greater amounts (even after making some allowance for inefficiency in heat production).

Consequently, the specific dynamic effect of the metabolites of whey may, in part, be responsible for the reduction in pig performance accompanying increases in the whey:meal ratio of the diet. In view of the fact that whey dry matter contains 60 - 70% lactose, and on consideration of the effects of the level of dietary lactose in all-meal diets on pig performance (re Chapter 2), the above contention seems quite possible.

Irrespective of the nature of the "loss" of digestible energy, provided by the diets in the current experiments involving the higher intake of whey, comparison of the performance of pigs fed such diets with that of pigs receiving the lower allowance of whey, represents an evaluation of the

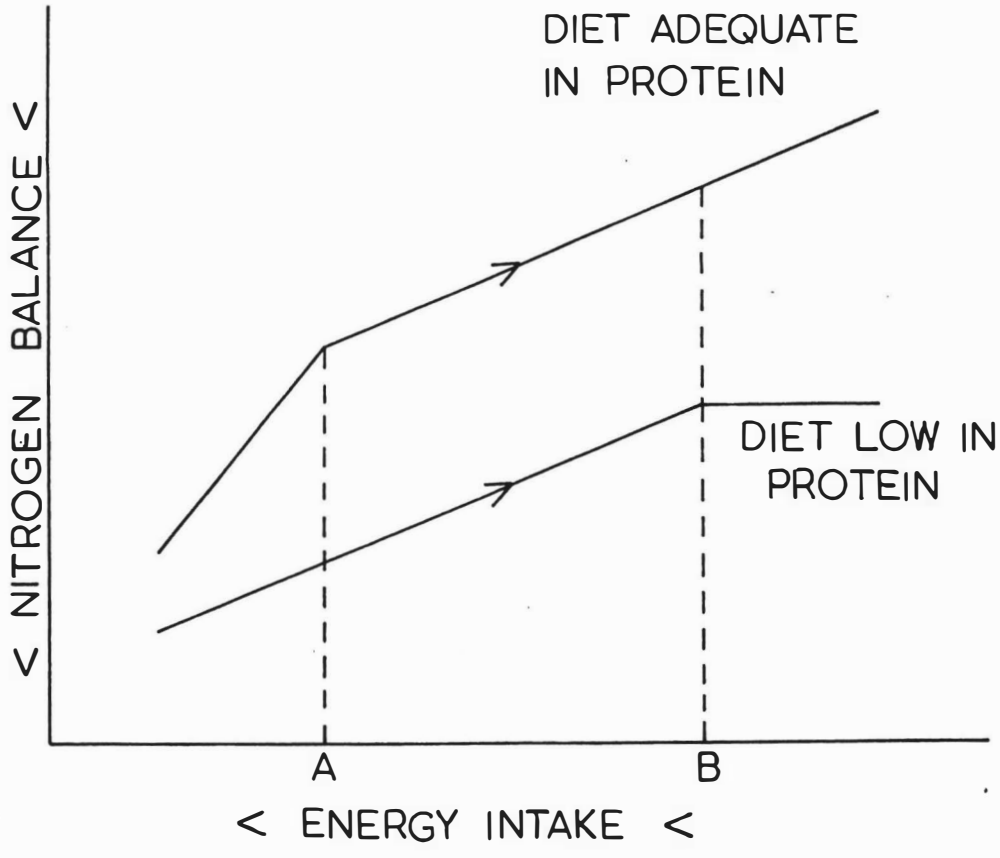
influence of energy intake on the performance of pigs having virtually the same mean daily intakes of digestible N. Although the "quality" of N provided by the two types of diet may have differed, it is unlikely that any severe amino-acid deficiencies or imbalances existed, in view of the fact that all diets contained some milk protein. For purposes of discussi it will be assumed that differences in protein quality were small and of little effect.

From henceforth, diets involving the higher level of meal supplement will be termed the higherenergy diets, and those involving the lower meal level, the lower energy diets.

Over the entire growth period, both castrates and gilts on the higher energy diet grew significantly faster and utilized their food more efficiencly, than their counterparts receiving the lower level of dietary energy. These observations are in general agreement with published results on the effects of increasing energy intake when protein intake remains constant (re App. 2/1).

(b) N Balance

Despite the fact that pigs having the higher daily intake of energy grew 10% faster and utilized their food 10% more efficiently, than pigs on the lower energy diet, differences between indices of carcass composition for the two groups of animals failed to reach significance, wit the exception of carcass specific gravities. (The slightly higher mean specific gravity of carcasses from pigs fed the higher energy diet suggeste that they contained a little more lean than those from pigs receiving the lower level of dietary energy). The above results suggest that the higher rate of energy intake stimulated a greater rate of N retention. The results of Experiment II support this contention for castrates at least,



igure 7/1: The interrelationship between dietary energy (metabolizable) and protein, for diets adequate or low in protein (from Munro 1964).

whereby pigs on the higher energy diet retained significantly more N (13 - 14%) than animals receiving the lower energy diet. In view of the positive response of gilts to higher energy intake, in rate of gain and feed efficiency, but the lack of response in carcass composition, one may speculate that in their case, higher energy intake likewise induced greater N balance.

The interrelationships of dietary energy and protein are discussed by Miller and Payne (1963) and Munro (1964). To summarize, Munro states ".... under normal nutritional conditions, N balance is improved by either an increase in energy intake or in protein intake. However, the beneficial effect of a rise in energy intake can be modified or prevented by an inadequate protein intake and, conversely, an increased protein intake may not be fully effective because of insufficient energy in the diet". The above statement is presented diagramatically in Figure 7/1. For the diet adequate in protein, energy intake below A is restrictive to protein synthesis, while increases in energy intake above B, for the diet low in protein, are without effect on N balance, as in this case protein intake is inadequate. It should be pointed out that energy intake is classified by both Miller and Payne, and by Munro, in metabolizable terms.

In the present experiments it may be concluded that the observed response of castrates and gilts to higher energy intake was "normal", probably represented in Figure 7/1 by the area encompassed by A and B.

5. <u>The effect of the Level of DBMP</u> -

In the light of what has been said, the addition of DBMP to diets involving the higher and lower level of meal supplement, may be regarded as the addition of protein to diets providing a higher and lower level of energy. It should be borne in mind, that although DBMP incorporation was without significant

effect on the daily digestible energy intake of pigs fed the lower meal diets, it resulted in a significant positive linear trend in mean daily digestible energy intake in the case of pigs receiving the higher meal diets (a maximum of 3 - 4%). It seems improbable however, that the relatively small increases in daily digestible energy intake as the proportion of DBMP was increased, could have accounted solely for the observed response of pigs fed the higher allowance of meal, although they may have resulted in some slight modification of response.

Summaries of the results of each experiment are found on pages 139 and 153. In general terms, castrates responded positively in rate of gain as the DBMP content was increased from 0 to 30% at either level of energy. Gilts on the other hand showed a negative linear trend at the lower energy level, and a negative curvilinear trend at the higher, rate of gain being maximum when DBMP was incorporated at the rate of 10%. From analysis of variance, the response of both castrates and gilts, was shown to be restricted largely to the growth period from 50 - 85 lb. liveweight. Similar trends in carcass lean content and feed efficiency, for both castrates and gilts, followed those described above for rate of gain.

The response of castrates agreed well with the statement of Munro (1964), suggesting that under "normal" nutritional conditions when energy intake is not limiting, N balance is improved by an increase in protein intake. This was in fact demonstrated positively in Experiment II, although the response at the higher level of energy intake failed to reach significance. Furthermore, reference to Figure 6/7 suggests that increases in N balance as protein intake increased, were greatest during the early stages of growth. This agrees with the trends in growth performance found in Experiment I, and in view of the declining relative requirement for protein on ageing (Lucas 1958; Braude 1958), might have been expected.

From the negative growth response of gilts to increasing proportions of DBMP, and from the trends evident in indices of carcass lean content, it may be postulated that at the lower energy intake, each increment in DBMP resulted in reduced N balance. Similarly, each addition of DBMP, in excess of 10%, at the higher level of energy intake, probably depressed N retention. Thus in contrast to castrates, the pattern of response of gilts was indicative of a surfeit of dietary protein, or conversely, of an inadequacy of energy. As Munro (1964) states ".... there is a threshold below which energy intake becomes a factor in protein utilization", which in turn is supported by Robinson et. al. (1964), who drew attention to a certain minimum critical level of calorie intake.

Miller and Payne (1963), and Munro (1964) show that when energy is limiting to protein biosynthesis, N balance remains constant as protein intake increases. It was suggested above, that any deterioration in the growth performance and carcass lean content of gilts could be translated into terms of reduction in N balance, which at first sight appears contradictory to the views of Miller and Payne, and Munro. The apparent anomaly is explicable on consideration of different terminology used for identification of energy intake. Thus Miller and Payne, and Munro, describe isocaloric diets in terms of metabolizable energy, while in the experiments described here, digestible energy values were used. As the protein content of the diet increases beyond the point where amino-acids are utilized for protein synthesis, and are non-preferentially catabolized for energy-yielding purposes, the metabolizable energy content of diets, isocaloric in digestible terms, diminishes (Blaxter 1962; Vercoe 1964). It follows therefore, that any suggested reduction in N retention for gilts, accompanying increases in N intake, may be considered a function of diminishing metabolizable energy intake, as protein was consumed in supra-optimal amounts. Similar decreases in N retention (for castrates) at high levels of protein intake were found by Jones et. al. (1961) and Likuski et. al. (1961). Jones

et. al. speculated that this may have been due to an inadequate supply of non-protein sources of energy - this is essentially what has been said above.

It should be borne in mind that as DBMP contains approximately 50% lactose, it is possible that reductions in the metabolizable energy intake of gilts, as the protein (DBMP) content of the diet increased, may have been aggravated by further residual loss of energy, related to the specific dynamic effect of lactose per se or its metabolites. Such loss was suggested as a possible contributory cause for the relatively low yield of "productive" energy from whey.

In summary, the interactions found between sex and diet indicated, that for the most part, the protein contents of the diets fed exceeded the optimum requirement of gilts at each level of energy intake, but fell below that of castrates. In other words, the results suggested that the dietary protein requirement of castrates is greater than that of gilts.

6. The Protein requirement of the female and castrated male pig -

Ludvigsen and Thorbek (1955) and Piatkowski and Jung (1966) found that gilts retained significantly more N than castrates when fed the same diet, but provided no information on the relationship between N balance and sex at different levels of protein or energy intake. The results of the experiments described here agree with the work cited, in so far as gilts, on average, grew faster and were leaner than castrates, suggesting that they retained a greater proportion of the N consumed (the mean daily intakes of protein by castrates and gilts being similar). However the results also suggested that the magnitude of the difference is dependent upon the intake of protein. The same conclusion was reached by Bowland and Berg (1959).

Bell (1965) found a significant protein x sex interaction for liveweight gain, whereby castrates significantly outgained gilts on low protein (13%)

diets, but showed less advantage on high protein (16%) diets. The interaction applied to the growth period of 100 - 200 lb. liveweight and to pigs fed all-meal diets to appetite.

In support of the results of Bell, are those of Adam (pers. comm.), who found that castrates grew faster than gilts on low protein (11.8%) diets, but that little difference existed between the rates of gain of castrates and gilts fed a diet containing 14% crude protein. The interaction applied to the period from 150 - 200 lb. liveweight and to pigs fed cereal diets in restricted amounts.

The findings of both Bell and Adam imply that gilts have a greater dietary protein requirement than castrates for maximum rate of gain, which one might perhaps expect, in view of the fact that gilts retain more N than castrates and produce leaner carcasses. This conclusion is supported by the present policy of workers at Nottingham University U.K. (Lodge, pers. comm.), who conduct experiments involving aspects of protein nutrition with gilts only, on the presumption that they are more responsive to higher levels of dietary protein than castrates.

The results of the experiments described here, suggested that gilts have a lower protein requirement than castrates, and in this respect were contrary to other results reported in the literature.

It is possible that the contradictory observations from the present experiments, could have arisen if the range of protein levels selected was grossly different from the ranges used in other experiments, which tend to centre around current recommendations.

For this reason, Table 7/1 has been compiled, to show the apparent digestible protein contents (%) of the diets consumed in the current experiments, expressed on a meal-equivalent basis (88% DM) - obtained from the total intakes of protein and dry-matter recorded in Experiment I and the coefficients of apparent digestible N from Experiment II.

Table 7/1: Apparent digestible protein contents (%) of the seven experimental diets consumed, in relation to stage of growth and expressed on a meal-equivalent basis (88% DM).

Tr. / Period	1	2	3	4	5	6	7
50 - 85 lb.	11.5	12.8	14.3	10.4	11.4	13.0	14.8
85 - 120	12.1	12.8	13.9	11.1	12.0	12.8	14.3
50 - 120	11.9	12.8	14.0	10.8	11.7	13.0	14.6

Current recommendations for the protein requirement of the growing pig range from 15 - 18% (re Chapter 2). In terms of digestible protein, this range is equivalent to 11.6 - 14.4%, taking coefficients of apparent digestibility for the lower and higher levels as 77 and 80% respectively (Jones et. al. 1961: Barber et. al. 1964). It is apparent therefore, that the digestible protein contents of the experimental diets, covered the range of those recommended in the literature. For this reason it was concluded that the contradictory results of the current work, relating to the nature of the protein x sex interaction were unlikely to have been associated with the levels of dietary protein selected.

The major difference between the experiments of Bell and Adam, referred to above, and those described here, was that whereas whey provided a large proportion of the non-protein fraction of the diet in the current experiments, the diets fed in the other trials were based on cereals. It was tentatively concluded that differences between the experiments cited and those described here, with regard to the type of non-protein dietary ingredients, were largely responsible for the conflicting results, concerning the dietary protein requirement of castrates and gilts. Possible ways in which such differences may influence the nature of protein x sex interactions are discussed more fully

in Section B of this chapter.

For reasons outlined above, it seems prudent to restrict the results of the experiments described, concerning the response to dietary protein, specifically to pigs fed whey diets. Extrapolation of the observations, to include all types of diet may be unjustifiable.

7. Comments on some observations from the experiments -

No increase was noted in the absolute amount of N retained/day by castrates on ageing, or as they increased in weight from approximately 25 to 50 kg. Throughout the experiment, pigs retained 12 - 13 gms. N/day, having a mean intake of 34 gms. N/day.

Barber et. al. (1964) found that pigs consuming from 18 to 25 gms. N/day retained from 6 to 10 gms. at about 50 lb. liveweight. Pigs weighing 30 - 60 lb. were found by Jones et. al. (1961) to retain from 3 - 10 gms. N/day, but no intake data were presented. Fuller (1965) reported that at 68°F, pigs weighing about 25 kg. and consuming 48 to 55 gms. N/day, retained 15 - 20 gms/day. Robinson et. al. (1964) reported that at 27 kg. liveweight pigs retained 16 gms. N/day when consuming 40 gms/day, and that although intake of N rose to 54 gms/day at 47 kg., the amount retained remained constant. With self-fed pigs, consuming 30 gms. N/day at 25 kg. and 46 gms. at 50 kg. liveweight, Oslage and Fliegel (1965) found N retained/day to fall slightly from 18.4 to 16.7 gms.

From the work cited it will be apparent that the amount of N retained by pigs in the current experiments, compared favourably with levels obtained in other experiments, particularly on consideration of N intake. Furthermore, constant N balance with age, appears to be the rule rather than the exception. This contention is upheld by the statement of Piatkowski and Jung (1966), in summary of an experiment on N balance with "boars, sows and geldings". They

concluded by saying that "The theory of equal protein retention for the weight range between 25 and 110 kg. cannot be extended to boars ..."

Reference to Figure 6/9 shows that pigs fed diets involving the lower level of meal supplement, exhibited a substantial (20%) but not significant, fall in N retention during collection period B, when compared with either period A or C. Furthermore, Figure 6/6 shows this to have been a feature of pigs fed each of the lower meal diets, irrespective of protein content, while reference to Appendix 6/5 reveals that five of the six pigs involved showed this pattern of response. It seems therefore, that the phenomenon was a true biological response, possibly related to the particular combination of meal and whey associated with collection period B. It may be that some "critical point" exists, associated with the meal:whey ratio, or with whey intake, and possibly related to the physiological age of the pig, when temporarily at least, the animal is unable to make efficient use of the energy and/or protein ingested. It may be of some significance that the data of Experiment I suggested some deviation (cubic) from the "normal" linear or curvilinear relationship between protein intake and performance, for pigs fed the higher amount of meal supplement. The cubic pattern of response applied only to castrates and not to gilts. It is possible that the causes of the cubic response pattern were essentially the same as those suggested for decreased N balance during collection period B.

It was mentioned in Chapter 2 that the protein requirement for maximum carcass lean content has been found to be greater than that for maximum rate of gain. In the present experiments, and for castrates considered alone, the reverse situation was found for pigs fed the lower meal diets. The other experiments referred to in Chapter 2 applied to data of castrates and gilts considered together. If interactions occur between sex and the level of

dietary protein, then any trends evident from the means of the pooled data of castrates and gilts, may well be the mathematical resultant of two distinct biological responses, rather than a true biological response in itself.

8. Application of the results of the experiments -

The commercial producer follows a policy which involves penning and feeding mixed groups of female and castrated male pigs. For this reason the results of the experiments described will be interpreted first in reference to such systems of production.

The results indicated that for mixed populations of gilts and castrates, weighing at least 50 lb./pig, little benefit will be gained from the addition of protein concentrates to meal supplements fed at the rate of $1\frac{1}{2}$ lb./pig/day, in association with lactic casein whey. This conclusion is in agreement with the results reported by Dunkin (1961 - re p.43), for pigs fed similar levels of meal supplement with restricted amounts of cheese whey.

When meal supplements were fed at the rate of $2\frac{1}{2}$ lb./pig/day, the experiments showed that from 50 - 85 lb. liveweight (but not subsequent to 85 lb.), incorporation of DBMP at 10, 20 and 30% resulted in a significant linear increase in rate of gain and feed efficiency. A similar trend in carcass lean content was found, following slaughter at 120 lb. liveweight. However, as carcass quality may well have been influenced by protein intake after 85 lb. liveweight, and because improvements in carcass lean content were relatively small, and in fact not detectable from fat-depth measurements taken on the mid-line, the trend is probably of no more than academic interest. This view is strengthened by the fact that the New Zealand pork market involves no objective grading system.

Taking the costs of barley meal, DBMP and whey, as 3c/lb., 7.5c/lb. and 0.5c/gallon respectively, the total food costs/pig, fed meal supplements containing 0, 10, 20 and 30% DBMP from 50 - 85 lb. liveweight, may be

calculated, using the actual consumption data obtained. These are found to be £2.50, 2.60, 2.79 and 2.85 respectively. Thus the incorporation of DBMP at 10, 20 and 30% into meal supplements fed at the daily rate of 2½ lb./pig, increased total food costs by 4, 12 and 14%. The associated improvements in rate of gain were 7, 9 and 15%. From these preliminary calculations it appears that little advantage is to be gained from adding DBMP to meal supplements fed at 2½ lb./pig/day, in association with restricted amounts of lactic casein whey. However it should be stressed that any recommendations made from the results of a single experiment are limited in themselves, and further that any such limited recommendations formulated from the results of the current experiments, must be restricted to pigs growing from 50 - 120 lb. liveweight and to supplementary protein provided in the form of DBMP. It is possible that some real benefit might accrue from feeding high protein diets to pigs being taken through to bacon-weight (re Robinson and Lewis 1964), while if the same response arose from feeding alternative, less-expensive sources of protein than DBMP, then recommendations could well be different.

The results indicated that gilts and castrates respond differently to increases in dietary protein. It seems, that where circumstances permit, considerable advantage may result, under whey-feeding systems at least, from segregating gilts and castrates and feeding them different diets for growing and probably finishing purposes.

When 1½ lb. meal supplement/pig/day is fed, the results suggested that for optimum growth performance gilts require no supplementary protein, and in fact that incorporation of protein into the diet is likely to cause deterioration in performance. At rates of meal supplementation of 2½ lb./day, gilts grew fastest when 10% DBMP was included. In comparison with gilts fed the meal supplement containing no additional protein, those receiving 10% DBMP in the diet grew approximately 7% faster from 50 - 120 lb. liveweight. The associated

increase in total food costs/pig was nearly 4%, suggesting that some financial benefit may result from incorporating 10% DBMP in the diet, under the conditions outlined.

Over the entire growth period, the rate of gain of castrates increased linearly as the proportion of DBMP increased in meal supplements fed at either $1\frac{1}{2}$ or $2\frac{1}{2}$ lb./pig/day. At the lower level of meal, the incorporation of 15 or 30% DBMP, resulted in an 8 or 10% increase in growth rate, and an increase in total food costs/pig of 4% or 11%. These results suggest that no advantage is likely to be gained from adding more than 15% DBMP to meal supplements fed to castrates at the rate of $1\frac{1}{2}$ lb./pig/day. The inclusion of DBMP at 10, 20 or 30% in meal supplements fed at $2\frac{1}{2}$ lb./pig daily, promoted faster rates of gain of about 1, 2 or 11% respectively, but total food costs were raised by 10, 19 or 16%. In this case therefore the incorporation of DBMP into the meal supplement would not appear to be warranted.

In conclusion, brief economic appraisal of the diets involved in the experiments, suggests that probably little benefit will result from adding DBMP to meal supplements fed at either $1\frac{1}{2}$ or $2\frac{1}{2}$ lb./pig/day, in association with restricted amounts of casein whey, to pigs of 50 - 120 lb. liveweight, whether the animals are fed as mixed or separate groups of castrates and gilts. If this is so, then there is little to be said in favour of segregating castrates and gilts. However it should be realized as already mentioned, that these tentative recommendations might be subject to considerable modification, if alternative, less-expensive sources of protein initiate the same responses as those found when DBMP was used.

The lactic casein whey fed in the present experiments contained, on average, 17 - 18% crude protein on a dry-matter basis. This is considerably higher than values published in the literature (see Chapter 2). Consequently

any recommendations made from the results must be translated with extreme care and a certain degree of reservation, before applying them to general commercial practice.

B. AN HYPOTHESIS ON THE INTERRELATIONSHIP BETWEEN DIETARY ENERGY AND PROTEIN IN THE N METABOLISM OF THE FEMALE AND CASTRATED MALE PIG:

1. General -

It is unlikely that any major differences occur in the biochemical processes involved in the protein synthesis of gilts and castrates. Kielanowski (1964) showed that the energy cost of protein deposition has been found to be similar for a number of species, while Miller and Payne (1963) and Munro (1964) considered that the principles underlying the interrelationship between dietary energy and protein, could be extended to include mammals in general.

It is well established that when fed the same diet as castrates, gilts retain more N and produce leaner carcasses. However, although it has not been positively demonstrated, it is probable (in view of the incidence of protein x sex interactions in growth-performance experiments) that the magnitude of the difference between castrates and gilts, in the amount of N which they retain, is not constant, but varies with intake. Furthermore, as the nature of protein x sex interactions can apparently be reversed (as evident from the results of the experiments described here, in comparison with those reported elsewhere) it seems likely that the threshold value, at which N intake becomes limiting to protein synthesis, differs for castrates and gilts. Consequently, as protein synthesis is an energy dependant process, one might expect that the threshold value at which energy becomes limiting to protein syntheis, also differs for castrates and gilts. The interactions between energy and sex found by Bowland and Berg (1959) and Robinson et. al. (1964) suggest this to be so.

Absolute differences in N balance, and in threshold values for both N and energy, are a feature of protein synthesis in animals of the same "type" fed diets classified as either adequate in protein or inadequate (either quantitatively or qualitatively) in protein (Miller and Payne 1963: Munro 1964).

The hypothesis to be outlined, suggests that differences between the N metabolism of gilts and castrates, may be likened to the differences between the N metabolism of a single animal fed a diet adequate in protein, or inadequate in protein. Dietary adequacy is after all, simply a reflection of how closely the intake of nutrients meets the metabolic requirements of the animal - "complete adequacy" being synonymous with metabolic requirement. It is not unreasonable to suggest therefore, that if the principles underlying body protein synthesis are similar for two metabolic systems having different "requirements" or "capacities", then the response curves of the two systems to the same diet, will be similar to the response curves of either system to different diets. Throughout the hypothesis, the response curve of the gilt, to variations in protein and energy intake, is paralleled to that of a single animal-type fed a diet adequate in protein, while the response curve of the castrate is likened to that of the same animal-type fed a diet inadequate in protein.

At the cellular level, the consequence of feeding a protein of low quality is a relatively high concentration of an imbalanced array of free amino-acids, susceptible to deamination (Pol and Hartog 1966). In view of the reduced rate of uptake of amino-acids (Kincl 1965), one might expect to find a similar situation in the case of the castrated animal, except perhaps that the free amino-acids need not necessarily comprise an imbalanced array. Ludvigsen and Thorbek (1955) found that compared with gilts, a comparatively large proportion of the total heat produced by castrates was of protein origin, indicating a relatively high rate of deamination. It will be evident therefore that there

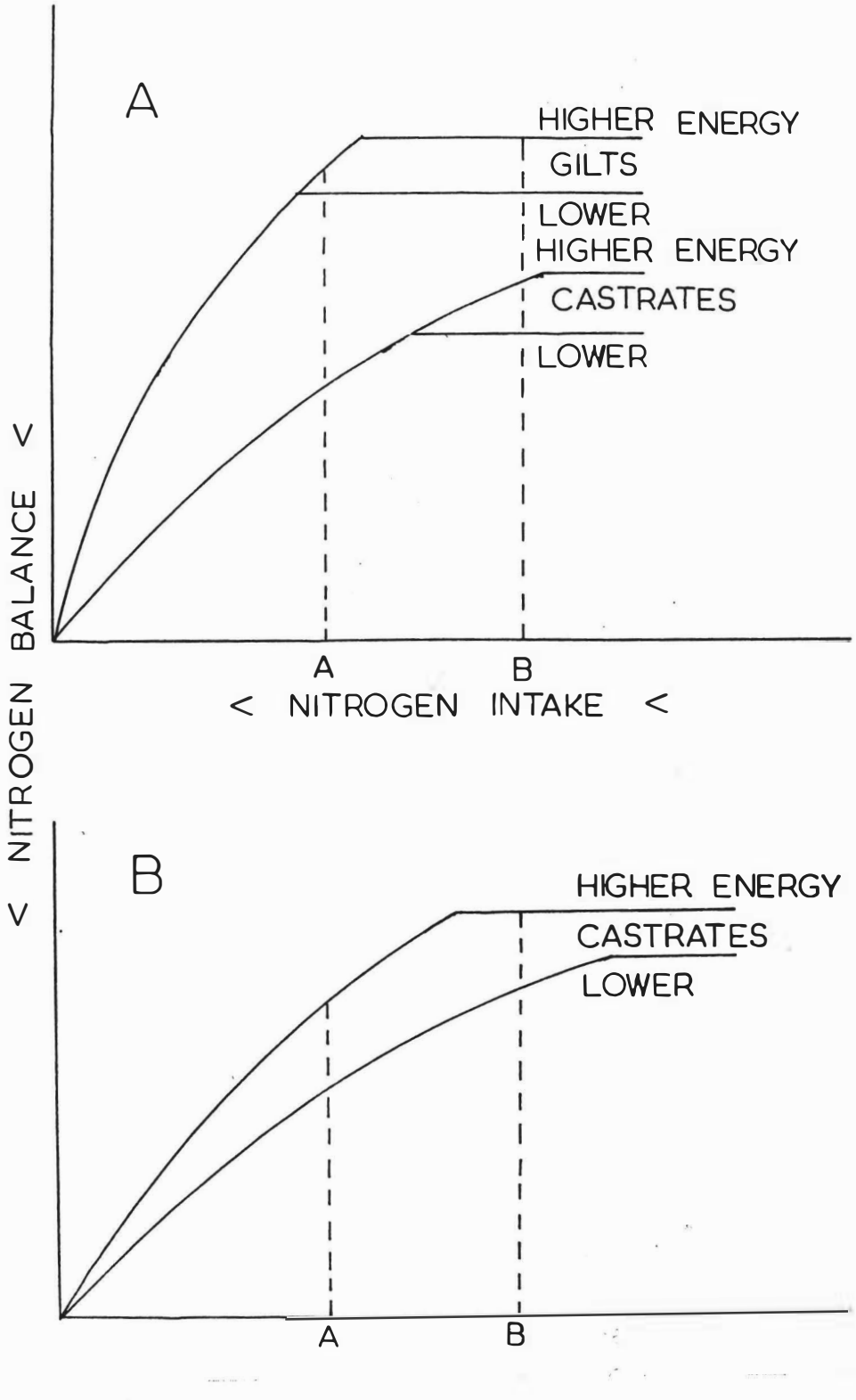


Figure 7/2: An hypothetical representation of the interrelationship between dietary energy and protein, in the N metabolism of the female and castrated male pig. (N retained/kg $^{0.73}$/day in relation to N intake/day) - Energy intake constant.

is some basis for drawing a comparison between dietary protein inadequacy and castration, at the sub-animal level. The hypothesis virtually rests on the supposition that deficiences in the substrate (dietary amino-acid imbalance) and deficiences in the metabolic system (resulting from castration) are essentially the same in any effects they may have on the interrelationship between dietary energy and protein in N metabolism.

Due to the complexity of energy:protein interrelationships, the hypothesis will be outlined under four headings. Throughout, N balance or retention refers to N retained/kg. $^{0.73}$ and energy intake to energy available for production. For simplicity of presentation, the hypothesis has been constructed around the results of the present experiments, and it has been assumed that N intake covered the same range at the lower level of dietary energy as at the higher. Reference to the relevant data shows this not to be strictly correct, but for purposes of speculation, the relatively small deviation is of little consequence. No attention has been payed to qualitative differences which may have existed between the protein supplied by the various experimental diets.

2. <u>The effect of variation in N intake at constant energy intake</u> -

Figure 7/2A shows the hypothetical response curves of castrates and gilts to increasing N intake (A to B) at the two levels of dietary energy involved in the experiments. Although it is appreciated that N balance cannot be translated directly into rate of gain etc., it is probable that at a fixed level of energy intake, increases in N balance will result in faster growth, leaner carcasses and improved feed efficiency.

Comparison of the results of Experiment I with the "expected" responses of castrates and gilts depicted in the graph, reveals a high correlation. Any deterioration in performance, indicative of declining N balance, but where the graph suggests N balance should have remained constant, is explicable in terms

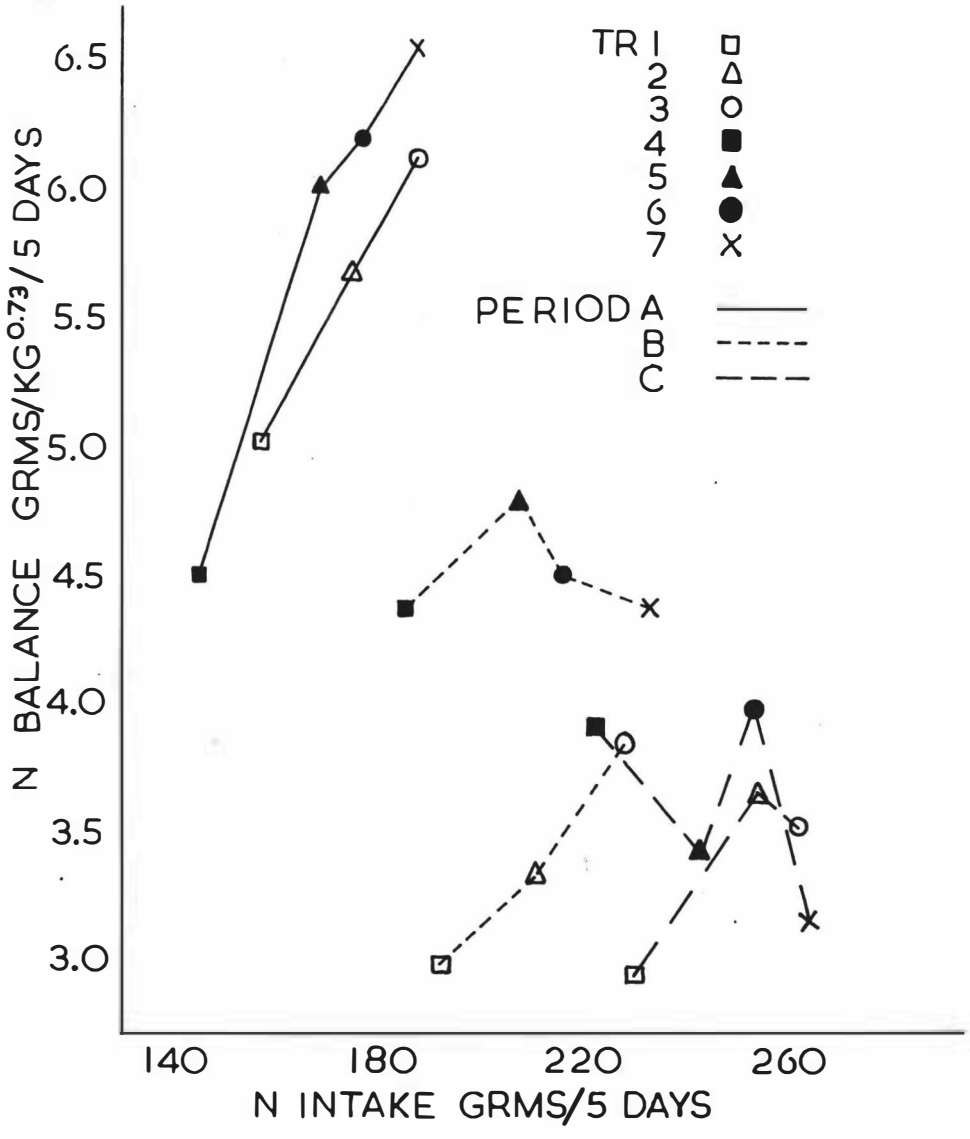


Figure 7/3: Experiment II : N retained/kg$^{0.73}$/5 days in relation to N intake, treatment and collection period.

body-protein synthesis. Under these circumstances energy intake cannot be regarded as constant.

It should be noted that for castrates fed the lower energy diets, the "expected" response would have been an initial positive trend, followed by constant N balance, as N intake approached B. Trends in carcass lean content agreed well with this pattern of response (any "unexpected" decline being a reflection of reduced available energy), but the positive linear trend in rate of gain did not. However, as carcass lean content is an absolute measure of protein synthesis, it probably affords a more accurate estimate of N balance than growth rate. If this is so, then all the results of Experiment I agree exactly with the responses predictable from the graph.

Positive information is available on N balance for castrates, from the results of Experiment II. Figure 7/3 shows the results of the experiment expressed in terms of N retained/kg. $^{0.73}$/5 days, i.e. using the same terminology pertinent to the hypothesis, in relation to treatment and collection period. Results of analysis of variance of these data are presented in Appendix 6/5. For the pooled data of the three collection periods, N retained/kg. $^{0.73}$ increased linerarly ($p < 0.10$) as the N content of the lower energy diets increased, while the negative curvilinear response at the higher level of energy failed to reach significance. These trends not only differ from those postulated in Figure 7/2A but also disagree with the observations from Experiment I. Thus whereas the response of castrates of Experiment I fed the lower energy diets was negatively curvilinear, that of castrates of Experiment II was positively linear. This difference in response can be explained if it is assumed that the energy intake of the animals in Experiment II was higher, or their expenditure of energy lower, thus effectively increasing the energy available for production. Under these circumstances energy may no longer have been limiting to protein synthesis and thus the continuing positive response as N intake increased to B

might well have occurred.

Considering the responses of the castrates of Experiments I and II fed the higher energy diets, it will be seen that whereas those of the first experiment showed a positive linear trend as N intake increased from A to B, there was some suggestion that the response of castrates in Experiment II was negatively curvilinear. This difference cannot be explained in terms of difference in "energy status" of the two groups, as outlined above for pigs fed the lower energy diets. Although it is realized that the negative curvilinear response of the Experiment II animals did not reach statistical significance and in any case was based on relatively few observations, Figure 7/2B has been compiled in compliance with the results of Experiment II. Figure 7/2B suggests that for castrated male pigs the effects of dietary energy and protein on N balance are never truly independent of each other, and in this respect is contrary to all information provided by Miller and Payne (1963) and Munro (1964) on mammalian protein metabolism, and more specifically to that directly applicable to the castrated male pig (Kuryvial and Bowland 1962: Robinson et. al. 1964). For this reason it is concluded that Figure 7/2A probably represents a more accurate picture of the true situation, but perhaps the alternative (Fig. 7/2B) should not be entirely discarded.

It was mentioned earlier, that other experiments in which protein x sex interactions have been isolated, have suggested that the dietary protein requirement of gilts is greater than that of castrates. This conclusion has been reached from the observation that gilts often elicit a greater response to increases in dietary protein than castrates, and further that they retain more N and produce leaner carcasses, suggesting that they require more dietary protein. From Figure 7/2A it is apparent that gilts would be expected to show greater response to increases in dietary protein than castrates, provided that energy

was not limiting, or that the range of protein levels selected did not exceed, in part, or in total, the requirement of either sex for the maximum genetically possible rate of protein synthesis, i.e. the responses would follow the curved portions of the graphs. The graphs however indicate that when energy is restrictive to protein synthesis, the protein requirement of gilts for maximum N balance is less than the corresponding requirement of castrates.

It is concluded that the apparent contradictory results obtained in the current experiments, suggesting gilts to have a lower protein requirement than castrates for maximum performance, arose primarily from the fact that the type of diets fed provided comparatively low levels of available energy, and that for the range of protein levels selected, energy intake was a limiting determinant in N balance, particularly in the case of gilts. As no reference could be found to protein x sex interactions, of a similar nature to those reported here, it may be that under all-meal feeding conditions, deficiencies in energy intake are seldom likely to arise - this would be undoubtedly so under ad libitum systems of feeding.

It should be borne in mind, however, that if the interrelationships between dietary energy and protein in the N metabolism of the female and castrated male pig, are similar to those relating to diets adequate or inadequate in protein (as has been postulated), then the type of carbohydrate consumed may differentially influence the utilization of protein by castrates and gilts. Thus Chang (1962) found that protein utilization by the growing rat was effected more by carbohydrate type when the protein fed was of low quality, i.e. inadequate, in comparison with the effect when a high quality protein was consumed. On this basis it may be that N balance in castrated male pigs is influenced more by the type of non-protein calories consumed than in the case of the gilt. If this were so, then a direct comparison between the results of the present experiments, where whey (lactose) formed a large portion of the non-protein fraction of the

diet, with the results of other experiments involving cereal diets, may not be entirely justifiable. Reference to Chapter 2 shows that, when consumed in large amounts, lactose is poorly utilized by the pig, in comparison with other sources of energy.

Finally it will be apparent from the graph, that to achieve maximum N balance at any particular level of N intake, gilts require proportionally more energy than castrates. If energy, as defined in the hypothesis, can be translated into terms of gross or digestible energy, then the hypothesis implies that gilts require diets of wider calorie:protein ratio than castrates, contrary to the popular belief that gilts require higher levels of dietary protein than castrates.

3. The effect of variation in energy intake at constant N intake -

At a N intake of $\frac{A + B}{2}$ i.e. the mean of the range of N intake involved in the experiments, both gilts and castrates would have been expected (from Figure 7/2A) to show an increase in N balance as energy intake increased from the lower to the higher level. Experiment II showed this to be so for castrates, while the results of Experiment I suggested it to be so for gilts.

As the lower level of energy intake was restrictive to protein synthesis for gilts at each level of N intake involved in the experiments, but not for castrates, gilts might have been expected to show a relatively greater increase in N balance, on raising energy intake to the higher level. Thus in reference to Figure 7/7 (derived from Fig. 7/1) the "expected" response of castrates and gilts is apparent if the two levels of energy intake involved in the experiments are taken to fall, either below, or around B. Although not reaching statistical significance, differential response of gilts and castrates to changes in energy intake was suggested from the results of Experiment I (re p.139). Thus whereas gilts fed the higher energy diet were slightly leaner than those receiving the

lower level of energy, the reverse situation appeared true for castrates.

It is firmly established that in general gilts produce leaner carcasses than castrates. This evidence is in support of the hypothesis. Thus, reference to Figures 7/2A and 7/7 indicates that under "normal" nutritional conditions, when neither protein nor energy intake is severely limiting to protein synthesis, gilts will retain more N than castrates over all levels of N and energy intake. However if the threshold value, at which energy becomes a determining factor in protein synthesis, differs for castrates and gilts, then under "abnormal" nutritional conditions, energy intake may restrict protein synthesis in one sex but not the other. Under these circumstances, as was demonstrated in the experiments described, increases in N intake may have opposite effects on the N balance and performance of castrates and gilts. The hypothesis implies that the "energy-threshold" value is lower for gilts than castrates, and thus that when opposite trends in gilt and castrate performance are found, in response to increases in protein intake, they are likely to be exemplified only by negative response of gilts and positive response of castrates.

In view of the fact that gilts retain more N than castrates, and thus have a greater energy requirement for protein synthesis, it is quite feasible that energy intake is more likely to be a limiting factor in the N metabolism of gilts than of castrates.

4. The effect of plane of feeding -

Alterations in the plane of nutrition involve concomitant and proportional changes in the intake of protein and energy. No positive information is available from the results of the experiments described, on the response of gilts and castrates to such dietary changes. However, if as postulated, gilts and castrates respond to dietary energy and protein in a similar fashion as a single "type" of animal to different dietary protein regimes, then it may be

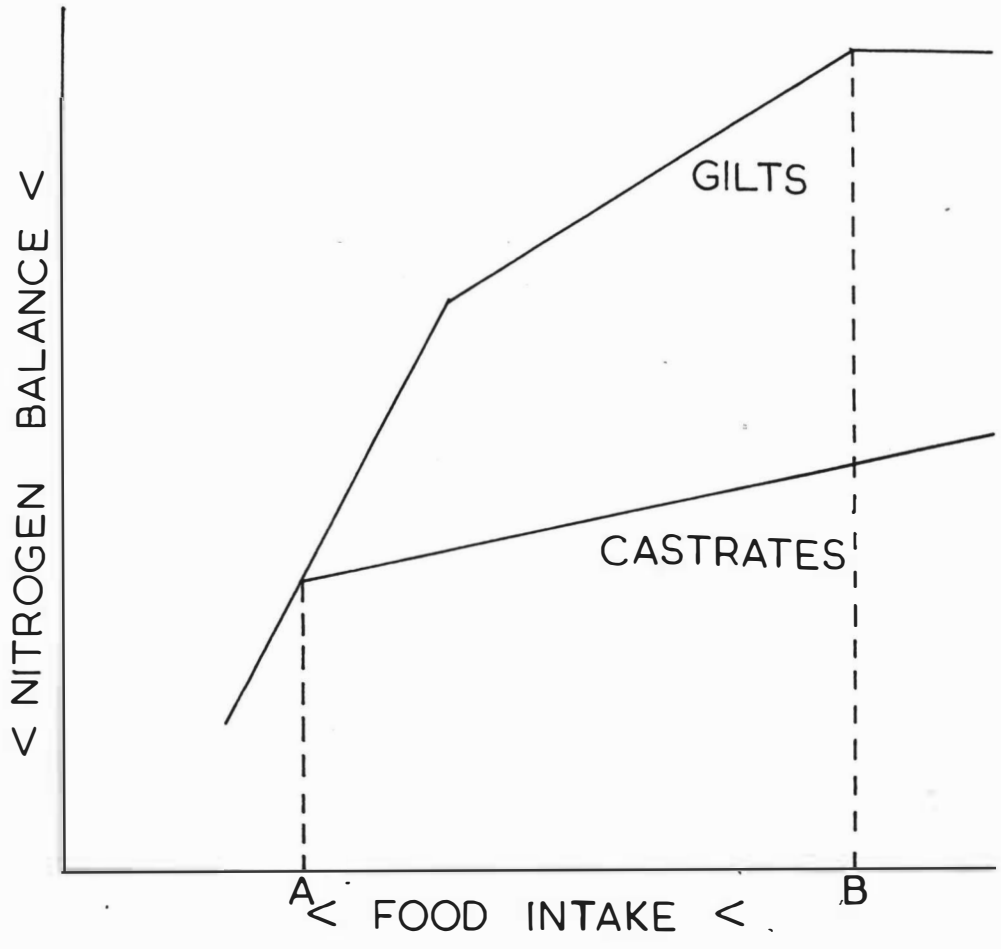


Figure 7/4: An hypothetical representation of the effects of food intake on the N balance (per kg $^{0.73}$/day) of the female and castrated male pig.

further speculated that their response to changes in food intake would be similar to that of a single animal to diets adequate or inadequate in protein. In accordance with Miller and Payne (1963), the hypothetical response of gilts and castrates is shown in Figure 7/4. Food intake B represents that when the associated intake of protein is just adequate to meet the maximum genetically possible rate of body protein synthesis for gilts. Thus any further increase above B would, in the case of gilts be deposited as fat, but in the case of castrates as both lean and fat. It follows therefore that reduction in food intake to B would have a relatively greater beneficial effect on the carcasses of gilts compared with those of castrates. Such an effect has been observed in experiments involving variations in plane of feeding (Lucas et. al. 1960: Dunkin and Carr 1966 unpubl.). The effect of reductions in food intake below B is difficult to assess, but as the process of protein synthesis in fast growing animals is usually accompanied by a concomitant deposition of fat (Blaxter 1962), the relatively rapid decline in N balance of gilts might well be accompanied by a relatively rapid decrease in carcass fat content.

5. The effect of age -

It was apparent from the results of both experiments that as the animal aged so the response to protein intake changed. In general, the response was greatest over the earlier stages of the experimental period. This may be considered a reflection of the greater capacity of the young animal to synthesise relatively large amounts of protein. Ignorning, for the moment, the effects of either protein or energy intake on N balance, one would expect a gradual decline with age in the genetically controlled amount of N which the animal is able to retain/kg. $^{0.73}$. Oslage and Fliegel (1965) presented the results of N balance experiments with pigs fed approximately to appetite, over the weight range from 20 to 170 kg. Their results have been recalculated in terms of N retained per/kg.$^{0.73}$

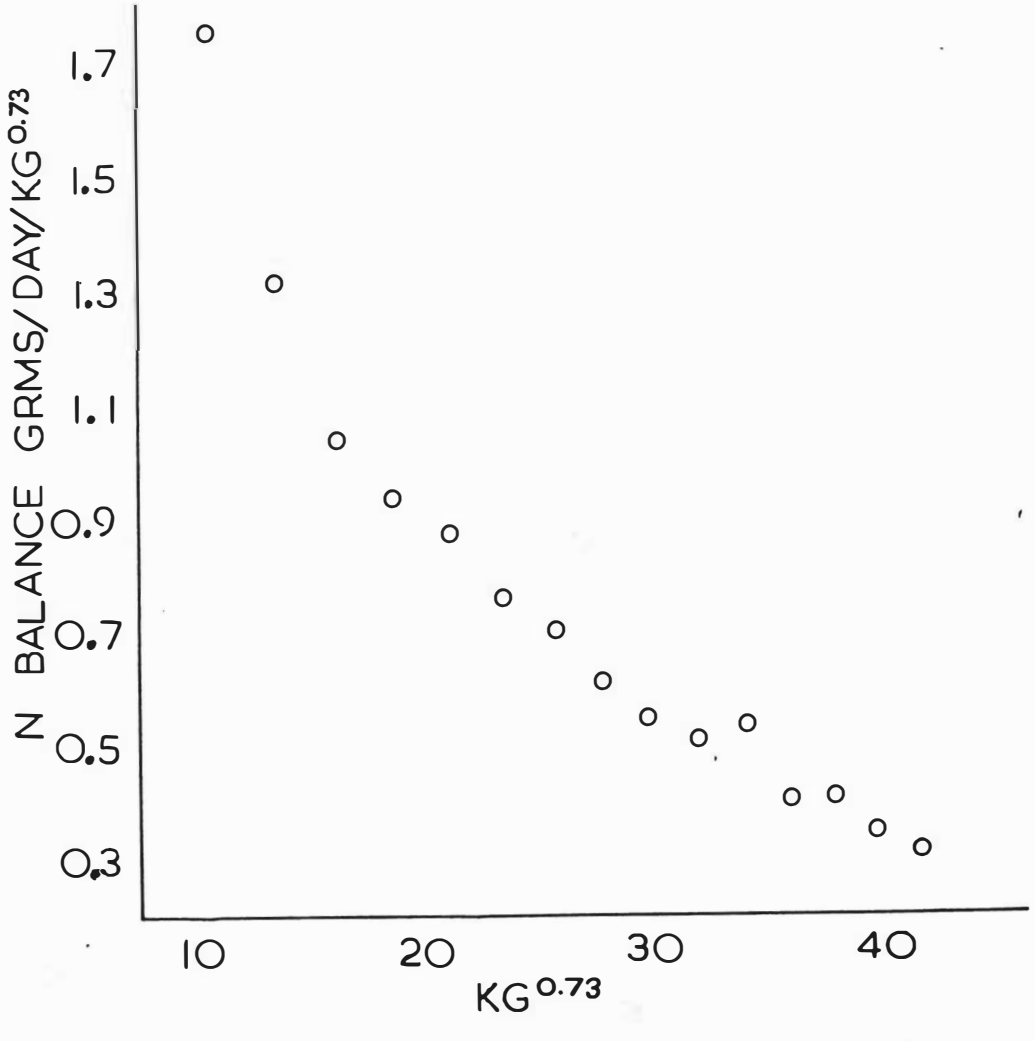


Figure 7/5: N balance (gms/day/kg $^{0.73}$) in relation to metabolic body weight (kg $^{0.73}$) - derived from the data of Oslage and Fliegel (1965).

and these are presented diagramatically in Figure 7/5. It appears therefore that on ageing, the maximum possible amount of N which the pig can retain/kg. $^{0.73}$, decreases curvilinearly and would presumably approximate to zero on attainment of mature body weight. This curvilinear decrease was noted in the present experiments over the comparatively small weight range of 10 to 17 kg. $^{0.73}$ (see App. 6/5).

From the above information Figure 7/6 has been compiled to show the possible relationship between N balance, N intake and age, for a single "type" of animal. One would expect therefore that as the animal aged, providing the energy available for production was not limiting, increases in N intake, e.g. A - B would be more likely to elicit a positive response in N balance, although in absolute terms at a lower level than the balance achieved by the younger animal. Reference to Figure 7/3 shows that in absolute terms N balance was greatest during the earlier collection period, and increased to a greater extent as N intake increased, when compared with the responses during later collections. In this respect therefore the results of Experiment II agree with the postulations on the effects of age on N balance. However there was little evidence to support the contention that increases in N intake are more likely to promote positive N balance in older animals compared with younger ones. Figure 7/3 suggests that for the most part, changes in N intake had little effect on N balance in the older animals. Although these conclusions are based on relatively few observations and treatment x collection period interactions failed to reach significance, it is possible that over later collection periods, pigs were "unable" to respond in the manner suggested in Figure 7/6, because either protein intake exceeded that required to meet the maximum genetically possible rate of protein synthesis, or else energy intake was limiting. If this was so, then the results emphasise the need to widen the calorie:protein

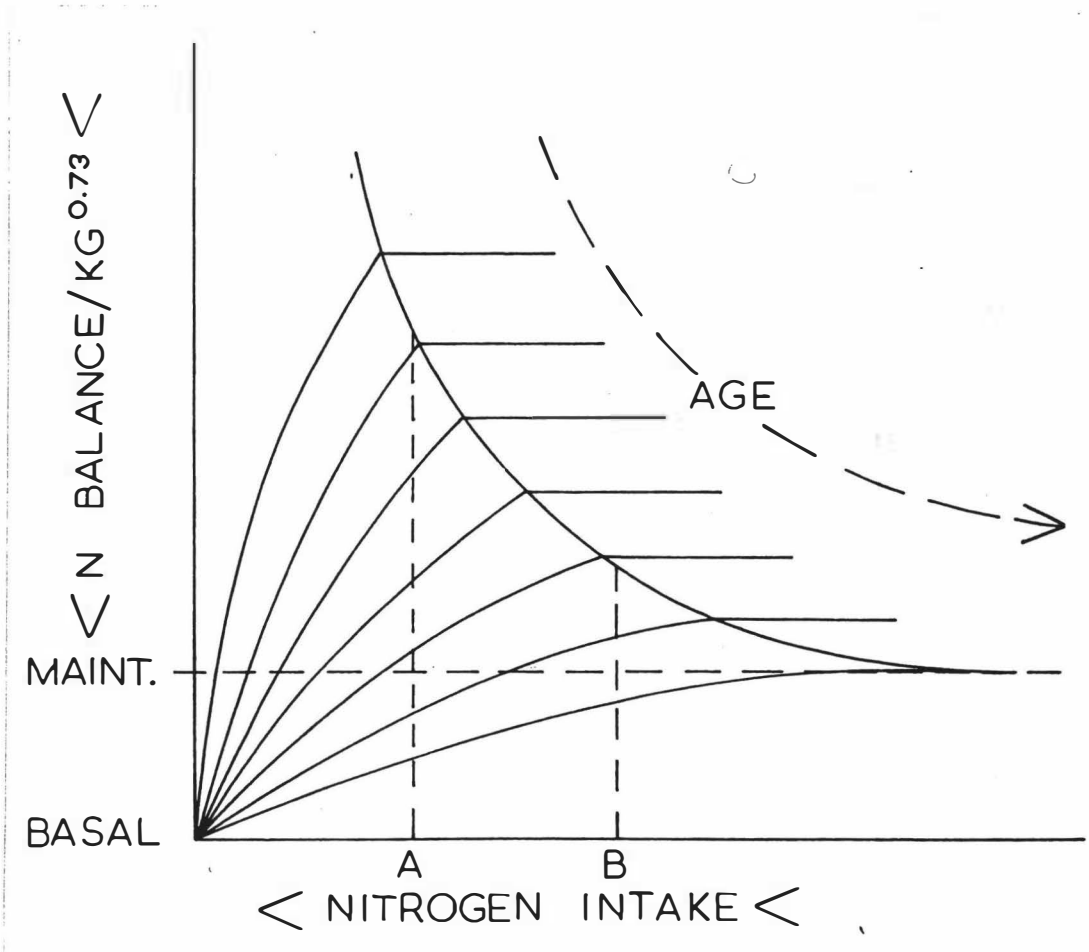


Figure 7/6: An hypothetical representation of the relationship between N balance/kg $^{0.73}$, N intake and age.

ratio of the diets fed to older animals, at least as far as rations containing whey are concerned. It is possible that under whey-feeding systems, where whey forms an increasing proportion of the diet as the animal ages, energy is more likely to be the factor limiting performance in the older animal compared with either the younger animal or with older pigs fed all-meal diets.

C. IMPLICATIONS OF THE HYPOTHESIS AND SUGGESTIONS FOR FUTURE EXPERIMENTAL WORK:

If the hypothesis represents an approximation of the truth, it may be concluded that little positive information exists on the interrelationships of dietary protein and energy in the metabolism of female and male castrated pigs.

Inconsistencies occur throughout the literature on the incidence of treatment x sex interactions and also protein x energy interactions. This would be expected from the hypothesis. Referring to Figure 7/2A and considering castrates only, protein x energy interactions would be expected only within the range of N intakes A - B. Within this same range one might also expect protein x energy x sex interactions. Figure 7/7 illustrates when sex x energy interactions might be expected viz. within the two ranges of energy intake A - B and C - D. In general, interactions might be expected when the range of protein and energy intakes lies around the point at which either becomes limiting to protein synthesis, or when protein intake exceeds that required for the maximum possible rate of protein deposition. The hypothesis suggests that the threshold values for dietary energy and protein are different for gilts and castrates and thus the probability of treatment x sex interactions occuring is likely to be greater than that of protein x energy interactions.

It is suggested therefore that experiments involving any aspect of protein or energy metabolism, which may be taken to include dietary supplementation with a multitude of accessory ingredients (see 2A), should be so designed that isolation

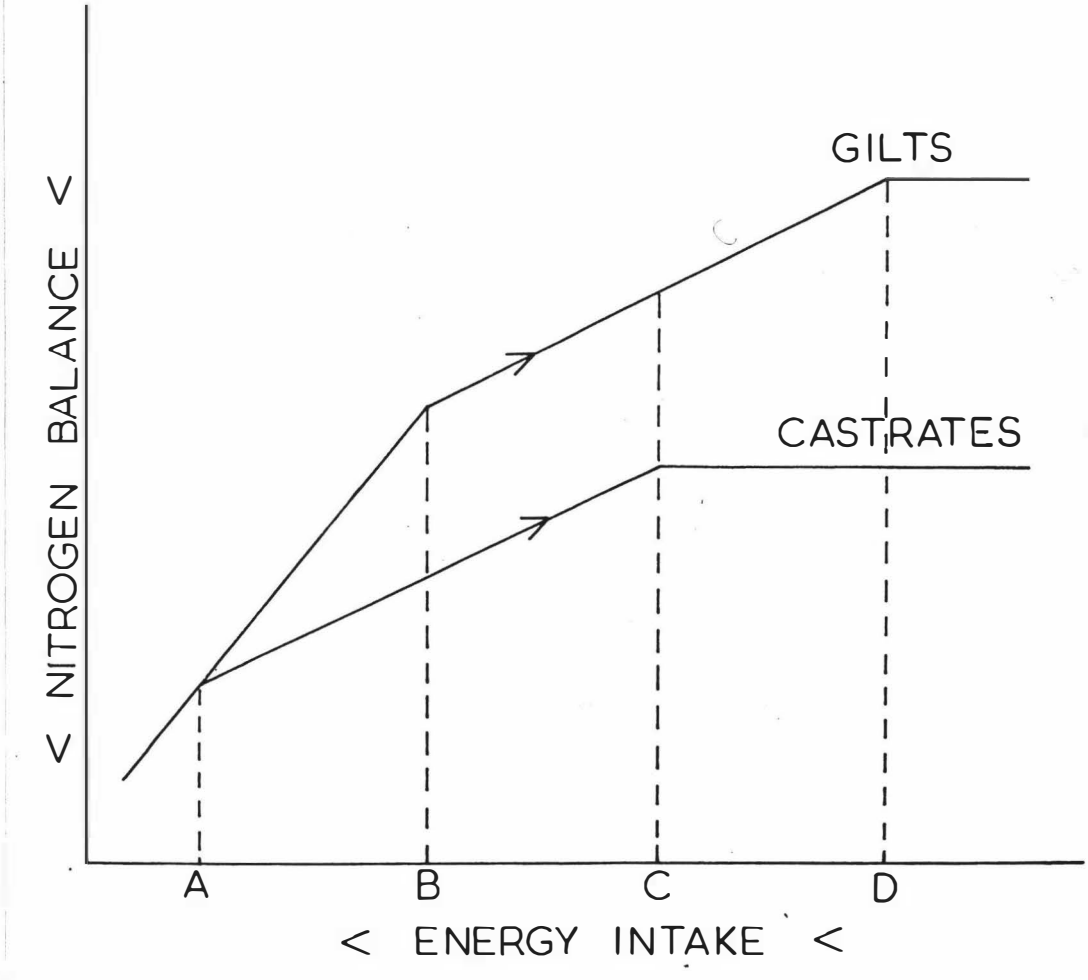


Figure 7/7: An hypothetical representation of the interrelationship between dietary energy and protein in the N-metabolism of the female and castrated male pig (N retained/kg $^{0.73}$/ day in relation to energy intake/day) - N intake constant.

of treatment x sex interactions is possible. If not, it is possible that a true response of one sex may be modified or obliterated by differential response of the other.

Experiments should be conducted to elucidate the exact relationship between dietary energy and protein in gilt and castrate nutrition. Irrespective of the hypothesis, marked differences must occur, but to date no information is available on whether the differences are constant over varying levels of intake. The hypothesis suggests they are not. The response curves of gilts and castrates to dietary protein (preferably amino-acid) content, at energy intakes varying from maintenance to appetite should be established for pigs of varying ages. Once these are defined they should provide valuable information for computer-derivation of feeding regimes giving maximum return, in the light of rate of gain, feed efficiency, carcass quality and market requirement.

It has been suggested that in a marketing environment dictating the castration of male pigs, gilts and castrates should be segregated and fed on different planes of feeding, in an attempt to improve overall carcass grading (NRC 1964: Boaz 1964: Blair and English 1965). The hypothesis indicates that a more efficient method of accomplishing this objective may be not to feed different amounts of food, but to feed qualitatively different diets. Present feeding recommendations have been established using mixed populations of gilts and castrates. It may well be that recommended protein allowances are a compromise between the opitimum requirement of the castrate and that of the gilt, and that consequently the potential of neither sex is being fully exploited.

The experiments described should be repeated, using a more economically acceptable form of protein concentrate, and in view of the comparatively greater consequence of deficiencies in carcass composition at heavier weights, should be followed through to bacon-weight.

Finally, it would be of interest to ascertain the significance of the non-protein fraction of the diet on the performance of growing/finishing pigs. The majority of work of this nature has to date been largely restricted to studies with baby pigs, in relation to the development of the digestive enzyme system and the suitability of various foodstuffs for inclusion in weaner rations. The object of the work suggested should be aimed not at the digestive system per se. but at the metabolic system in general.

D. SUMMARY:

1. Experiments are described which were designed to evaluate the requirement of pigs weighing 50-120 lb. liveweight, for additional protein, when fed diets comprising a fixed daily allowance of meal supplement and lactic casein whey, fed in restricted amounts in accordance with liveweight.

2. The experimental diets involved two levels of meal supplement - $1\frac{1}{2}$ and $2\frac{1}{2}$ lb./pig/day - plus whey fed to adjusted scales, such that the estimated TDN intake of all pigs of the same weight was equal. Buttermilk powder (DBMP) was incorporated in the lower level of meal supplement at 0, 15 and 30% and in the higher at 0, 10, 20 and 30%. Adjustments in daily meal allowances were made to counteract the higher TDN value of DBMP compared with that of barley meal.

3. The work was conducted as two experiments, each involving the same seven dietary treatments. Experiment I, the performance experiment, involved two similar sub experiments, each comprising 14 female and 14 castrated male pigs, of Large White x Landrace origin. Records of growth rate, food consumption and carcass composition were kept. Experiment II, involved 14 castrated male Large White x Landrace pigs. N balance was determined for each pig at three stages during the total growth period, namely when the animals weighed about 25, 40 and 55 kg.

4. Gilts on average, grew significantly faster than castrates, utilized their food more efficiently and produced leaner carcasses.

5. Pigs fed the higher amount of meal supplement grew significantly faster and utilized their food more efficiently than pigs receiving the lower level of meal, but differences in carcass composition for the most part proved non-significant. As the digestible energy intake of the two groups of pigs was equal, the limitation of TDN or digestible energy as a basis for feeding systems was demonstrated.

6. Analysis of the growth data of Experiment I by regression technique disclosed a highly significant treatment x sex interaction. This was not evident on analysis of the data by analysis of variance methods.

7. When fed the lowest protein diets, irrespective of meal level, gilts performed better than castrates, but at the highest levels of dietary protein the position was reversed. The implications of this interaction were discussed.

8. At the lower level of meal supplement, gilts and castrates considered together, showed no significant response to added protein, in terms of rate of gain or carcass composition (except a negative curvilinear response in carcass specific gravities), but a positive linear trend in feed efficiency from 50 - 85 lb. liveweight. Castrates exhibited a positive linear response in rate of gain and a negative curvilinear response in carcass lean content. Similar trends were apparent in feed efficiency. Gilts showed a negative linear response in rate of gain which was accompanied by similar non-significant trends in feed efficiency and indices of carcass lean content.

9. At the higher level of meal, castrates and gilts considered together displayed significant linear increases in rate of gain, feed efficiency and carcass lean content as the protein content of the diet increased. There were of particular significance over the 50 - 85 growth period. Considering the sexes separately, the growth rate and carcass lean content of castrates increased linearly, and similar trends were evident in the feed efficiency data. Gilts displayed a significant negative curvilinear response in rate of gain and similar non-significant trends were apparent from the feed efficiency and carcass composition (lean content) data.

10. The N balance data, in general agreed well with the observations of castrate performance obtained from Experiment I.

11. At either level of meal supplement, increases in dietary protein stimulated higher N retention, but this only reached significance at the lower meal level.

12. Pigs fed the higher level of meal, retained significantly more N than those fed the lower level.

13. Increases in the dietary content of DBMP resulted in significant increases in the coefficient of apparent digestible energy.

14. Increases in N intake were accompanied by increases in the coefficient of apparent digestible N, but this only reached significance at the higher level of meal.

15. The coefficients of apparent digestible energy and N were significantly lower for pigs fed the higher level of meal supplement, than for those fed the lower.

16. The coefficient of apparent digestible energy of whey dry-matter was estimated to be 96% and the TDN value as approximately 85%.

17. Brief economic appraisal of the diets fed, in relation to the responses obtained, suggested that little benefit is likely to result from the incorporation of DBMP into barley meal supplements, fed at the rates of either $1\frac{1}{2}$ or $2\frac{1}{2}$ lb./pig/day in association with restricted amounts of lactic casein whey, over the period 50 - 120 lb. liveweight. It was pointed out that recommendations could be different if less expensive sources of protein gave the same response as DBMP, or if pigs were taken through to bacon-weight on the same diets.

18. An hypothesis was put forward on the interrelationships of dietary energy and protein in the metabolism of female and castrated male pigs.

19. The implications of the hypothesis were discussed and suggestions made for future experimental work.

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APPENDIX 6/5: (Contd)

ANALYSES OF VARIANCE (data/5 day period)

Source	df	N Intake (gms) Mean sqs/F tests	ADN Intake (gms) Mean sqs/F tests	E Intake (k/cals -25000 ÷ 1000) Mean sqs/F tests	ADE Intake (k/cals -22000 ÷ 100) Mean sqs/F tests	ADN % Mean sqs/F tests
T	6	1543.33 ***	1570.97 ***	1430 ***	5875 *	22.55 ***
(1-3)v(4-7)	1	59.04 *	241.95 **	6944 ***	16	20.40 *
Lin. 1 - 3	1	2901.63 ***	2581.33 ***	502	527	11.00
Quad. 1 - 3	1	55.25 †	0.64	68	3413	4.50
Lin. 4 - 7	1	6039.26 ***	6559.37 ***	675 †	24000 **	77.00 ***
Quad. 4 - 7	1	132.07 **	1.31	200	6787 †	21.90 †
Cub. 4 - 7	1	73.79	41.30	189	4509	0.60
C	2	20470.75 ***	14619.05 ***	375286 ***	3259998 ***	3.85
Lin. A - C	1	40919.86 ***	29237.97 ***	750572 ***	6507289 ***	3.90
Quad. A - C	1	21.64	0.13	2258 ***	12707 *	3.80
TC	12	8.88	21.40	123	946	6.39
A:TC	21	13.60	24.91	190	2142	3.61

Source	df	ADE % Mean sqs/F tests	N Retained (gms) Mean sqs/F tests	N Retained % Mean sqs/F tests	N Retained/kg (gms) Mean sqs/F tests	N Retained/kg$^{0.73}$ (gms) Mean sqs/F tests
T	6	19.32 ***	242.98	51.29	0.14476	1.05
(1-3)v(4-7)	1	54.50 ***	733.46 *	204.32 **	0.35505 †	2.81 **
Lin. 1 - 3	1	8.70 *	509.60 †	14.30	0.27180 †	2.07 †
Quad. 1 - 3	1	1.30	44.00	4.77	0.00518	0.08
Lin. 4 - 7	1	47.90 ***	17.63	64.09	0.12982	0.61
Quad. 4 - 7	1	2.20	139.20	15.51	0.10494	0.71
Cub. 4 - 7	1	1.30	14.01	4.76	0.00176	0.00
C	2	8.80 **	72.44	579.71 ***	4.85255 ***	18.90 ***
Lin. A - C	1	17.40 ***	54.02	1068.89 ***	8.89992 ***	34.49 ***
Quad. A - C	1	0.20	90.85	90.53	0.80517 **	3.31 **
TC	12	1.32	101.78	17.87	0.08822	0.58
A:TC	21	1.45	121.02	25.30	0.08541	0.56

† $p < 0.10$: * $p < 0.05$: ** $p < 0.01$: *** $p < 0.005$

where no level of significance is shown $p > 0.10$

ADN : Apparent digestible nitrogen

ADE : Apparent digestible energy

APPENDIX 6/5:

EXPERIMENT II - RAW DATA AND ANALYSES OF VARIANCE

RAW DATA/5 DAYS

Pig	Tr.	Period	Mean L.wt. (kg)	DM Intake (gms)		E Intake (k/cals)		N Intake (gms)		Faecal Energy (k/cals)	Faecal N (gms)	Urinary N (gms)	ADE Intake (k/cals)	ADN Intake (gms)	N Retained (gms)
				Meal	Whey	Meal	Whey	Meal	Whey						
54/68	1	A	26.6	2980	3561	12822	13850	59.7	97.0	3300	28.3	75.9	23372	128.4	52.5
56/7		A	25.9	2993	3561	12878	13850	59.9	97.0	3510	31.8	67.7	23218	125.1	57.4
54/68		B	40.9	2980	5117	12822	19902	59.7	140.1	3347	29.9	123.6	29377	170.0	46.4
56/7		B	39.7	2966	4851	12762	18867	59.3	130.4	3590	36.8	110.8	28039	152.9	42.1
54/68		C	52.1	2970	6167	12779	23986	59.5	172.5	3555	33.0	148.5	33210	199.0	50.4
56/7		C	51.5	2978	6015	12813	23395	59.7	169.1	3669	35.4	139.2	32539	193.4	54.2
43/8	2	A	30.7	2802	3586	12364	13947	76.8	100.1	3195	31.1	66.9	23116	145.8	78.8
54/67		A	26.3	2758	3561	12169	13850	75.6	97.0	2982	28.6	91.4	23037	144.0	52.7
43/8		B	40.9	2825	4654	12465	18101	77.4	127.7	3207	37.0	116.0	27359	168.1	52.1
54/67		B	40.7	2793	5117	12323	19902	76.6	140.1	3406	35.5	133.8	28819	181.2	47.4
43/8		C	52.2	2804	6418	12372	24962	76.8	182.7	4161	50.1	146.1	33173	209.6	63.3
54/67		C	52.1	2782	6167	12276	23986	76.3	172.5	3366	38.1	142.9	32896	210.6	67.7
43/57	3	A	31.3	2732	3628	12179	14111	88.5	100.5	2778	30.4	98.1	23512	158.7	60.5
56/57		A	25.3	2680	3561	11947	13850	86.9	97.0	2271	25.1	81.1	23526	158.1	77.7
43/57		B	40.8	2700	5055	12036	19661	87.5	138.7	3228	37.4	131.4	28469	188.8	57.4
56/57		B	41.4	2680	5117	11947	19902	86.9	140.1	2807	31.2	137.8	29042	195.8	58.1
43/57		C	53.1	2741	6222	12219	24200	88.8	174.2	3697	45.6	175.8	32722	217.4	41.6
56/67		C	53.3	2744	6167	12232	23986	88.9	172.5	2939	36.1	139.4	33279	225.3	85.9
44/67	4	A	31.6	4913	1605	21307	6242	101.7	44.7	4805	32.3	57.0	22744	114.1	57.1
54/79		A	26.3	4841	1583	20994	6157	100.2	43.1	3712	27.3	68.3	23439	116.1	47.8
44/67		B	41.6	4770	3111	20687	12100	98.7	85.4	5089	38.1	73.5	27698	146.0	76.6
54/79		B	41.8	4841	3149	20994	12248	100.2	86.2	4254	34.6	95.6	28988	151.9	56.3
44/67		C	53.2	4864	4390	21094	17074	100.7	124.4	5415	40.7	100.7	32753	184.4	83.7
54/79		C	54.0	4823	4240	20916	16491	99.9	118.6	4482	37.6	121.6	32925	180.8	59.2
44/58	5	A	29.9	4825	1601	20996	6227	125.9	44.4	4125	32.3	57.0	23098	134.4	75.9
56/56		A	26.0	4754	1583	20688	6157	124.1	43.1	4392	27.3	68.3	22453	128.4	61.2
44/58		B	40.5	4735	3111	20605	12100	123.6	85.4	4571	38.1	73.5	28134	168.7	76.0
56/56		B	40.9	4743	2986	20640	11614	123.8	80.2	4345	34.6	95.6	27989	164.7	67.2
44/58		C	53.2	4806	4277	20914	16635	125.4	119.8	4696	40.7	100.7	32853	202.7	62.1
56/56		C	53.3	4756	4135	20696	16083	124.0	116.3	4619	37.6	121.6	32160	194.1	63.0
44/57	6	A	30.8	4760	1490	20907	5795	134.2	41.5	2839	26.3	80.9	23863	149.5	68.6
56/8		A	26.8	4767	1583	20938	6157	134.4	43.1	3504	27.1	75.7	23591	150.4	74.7
44/57		B	41.4	4713	3095	20700	12038	132.9	84.6	4643	52.6	91.0	28095	164.9	73.9
56/8		B	42.6	4775	2986	20973	11614	134.6	80.2	4119	37.7	113.7	28468	177.1	63.4
44/57		C	52.8	4735	4262	20797	16577	133.5	120.9	4303	43.1	145.3	33071	211.3	66.0
56/8		C	51.1	4758	4240	20898	16491	134.3	118.6	4114	45.2	132.0	33275	207.7	75.7
44/568	7	A	28.8	4637	1488	20591	5787	144.7	41.5	2540	22.7	84.4	23838	163.5	79.0
54/7		A	26.1	4601	1583	20431	6157	143.5	43.1	3048	27.0	92.0	23540	159.7	67.7
44/568		B	41.3	4609	3209	20467	12481	143.8	91.4	3880	34.6	126.2	29068	200.6	74.4
54/7		B	40.5	4621	3149	20520	12248	144.2	86.2	3229	33.5	140.1	29539	196.9	56.8
44/568		C	51.6	4633	4262	20573	16577	144.6	120.9	3694	39.0	170.0	33456	226.5	56.5
54/7		C	51.5	4685	4240	20804	16491	146.2	118.6	4277	45.4	163.9	33018	219.3	55.4

ADN : Apparent digestible nitrogen
ADE : Apparent digestible energy

A P P E N D I X 6/4: (Contd)

COVARIANCE ANALYSIS

"C" (mm) ADJUSTED TO EQUAL CARCASS WEIGHT (lbs)

Source	df	Sums of Squares and Products			Tests of Adjusted Means		
		Sx^2	Sxy	Sy^2	df	$Sdy.x^2$	Mean sqs/F tests
T	6	23.88	-13.10	36.69	6	28.45	4.74
E	1	23.10	25.10	27.10	1	36.34	36.34
B:E	6	32.90	-18.22	46.70	5	36.61	7.32
TE	6	13.40	35.60	52.80	6	58.76	9.79
TB:E	36	172.60	-33.02	260.50	35	254.18	7.26
S	1	28.60	-39.30	54.00	1	36.43	36.43 *
TS	6	18.90	23.50	62.40	6	62.86	10.48
SE	1	2.60	- 2.78	3.10	1	2.46	2.46
TSE	6	42.40	-33.92	33.20	6	20.72	3.45
A:TSE	28	113.02	-12.50	154.50	27	153.12	5.67

* $p < 0.05$: Where no level of significance is shown, $p > 0.10$.

A P P E N D I X 6/4: (Contd)

"C" (mm), ANALYSIS OF VARIANCE BY CONSTANT FITTING.

S o u r c e	df	Mean sqs/F tests
Reduction in SS through fitting mean (m)	1	
Fitting Blocks (b)	7	10.55
Fitting Treatments (t)	6	5.45
Fitting mean (m), blocks (b), treatments (t) and sex (s)	15	
Sex effect	1	52.59 **
Fitting (m), (b), (t), (s) and Sex x treatment Interaction (s x t)	21	
Sex x Treatment Int.	6	8.73
Residual	35	5.95
Total	56	

** $p < 0.01$: where no level of significance is shown, $p > 0.10$.

A P P E N D I X 6/4: (Contd)

ANALYSES OF VARIANCE

(castrates and gilts separately)

		CASTRATES ONLY		
		"C" (mm)	Specific Gravity (-1 x 1000)	Loin Joint Lean:Fat ratio (-0.5 x 1000)
Source	df	Mean sqs/F tests	Mean sqs/F tests	Mean sqs/F tests
T	6	13.20 †	7999.0 **	47138 †
(1-3)v(4-7)	1	0.00	4845.8	11842
Lin. 1 - 3	1	50.00 **	9112.5 *	66613 †
Quad. 1 - 3	1	24.00 †	16748.0 **	136353 *
Lin. 4 - 7	1	1.50	11520.0 *	30604
Quad. 4 - 7	1	0.10	2256.3	314
Cub. 4 - 7	1	3.60	3511.3	37105
E	1	24.10 †	1443.0	25658
TE	6	7.57	4124.3 †	17487
A:TE	14	5.64	1592.6	20179
			GILTS ONLY	
T	6	2.65	2606.2	34207
(1-3)v(4-7)	1	2.50	7543.1	65766
Lin. 1 - 3	1	8.00	4232.0	42954
Quad. 1 - 3	1	0.20	28.2	2726
Lin. 4 - 7	1	4.50	3025.8	48452
Quad. 4 - 7	1	0.60	225.0	44817
Cub. 4 - 7	1	0.10	583.2	528
E	1	6.00	2527.0	33120
TE	6	6.78	1704.8	18638
A:TE	14	5.39	2884.4	29318

† $p < 0.10$: * $p < 0.05$: ** $p < 0.01$: Where no level of significance is shown, $p > 0.10$.

A P P E N D I X 6/4: (Contd)

ANALYSES OF VARIANCE

(Castrates and gilts combined)

Source	df	"A" (mm) Mean sqs/F tests	"Eye" Muscle Area (cm^2) Mean sqs/F tests	"C" (mm) Mean sqs/F tests	EMA:"C" Mean sqs/F tests
T	6	6.92	2.80	5.45	0.06310
(1-3)v(4-7)	1	2.63	0.43	1.00	0.01714
Lin. 1 - 3	1	22.56	0.01	9.00	0.01716
Quad. 1 - 3	1	1.69	0.20	14.10	0.04344
Lin. 4 - 7	1	1.23	8.65	5.60	0.20192
Quad. 4 - 7	1	12.50	4.35	0.50	0.07144
Cub. 4 - 7	1	0.90	3.14	2.50	0.02751
E	1	4.60	9.80	27.10	0.36241
B:E	6	19.65	17.65	7.78	0.29208
TE	6	3.40	6.10	8.80	0.15610
TB:E	36	19.78	4.23	7.24	0.10920
S	1	73.10 *	62.60 ***	54.00 ***	1.37188 ***
TS	6	16.65	2.93	10.40	0.13946
SE	1	25.80	0.00	3.10	0.00014
TSE	6	7.95	5.37	5.53	0.13049
A:TSE	28	17.14	5.21	5.52	0.09615

Source	df	Specific Gravity (-1x1000) Mean sqs/F tests	Loin Joint Lean % Mean sqs/F tests	Loin Joint Fat % Mean sqs/F tests	Loin Joint Lean:Fat ratio (-0.5x1000) Mean sqs/F tests
T	6	6253.3 †	15.41	23.76	31674
(1-3)v(4-7)	1	12240.0 *	8.43	5.35	10897
Lin. 1 - 3	1	462.3	1.21	6.55	1292
Quad. 1 - 3	1	9075.0 †	21.23	37.56	50259
Lin. 4 - 7	1	13176.9 *	35.43 †	51.02 †	78035 †
Quad. 4 - 7	1	1953.1	5.79	21.53	26318
Cub. 4 - 7	1	616.2	9.57	20.56	23244
E	1	3899.0	8.43	64.48	58541
B:E	6	2528.5	62.11	46.68	97713
TE	6	1962.0	8.12	10.12	17722
TB:E	36	2691.4	11.15	13.30	19902
S	1	17330.0 *	131.43 **	106.95 *	201096 **
TS	6	4351.7	28.78	25.45	49672 †
SE	1	71.0	0.74	0.00	238
TSE	6	329.2	7.01	16.82	18403
A:TSE	28	2377.7	15.26	14.24	24748

† $p < 0.10$: * $p < 0.05$: ** $p < 0.01$: *** $p < 0.005$:

Where no level of significance is shown, $p > 0.10$.

A P P E N D I X 6/4: (Contd)

ANALYSES OF VARIANCE

(castrates and gilts combined)

Source	df	Carcass Weight(lbs) Mean sqs/F tests	Killing-out % Mean sqs/F tests	Length (cm) Mean sqs/F tests	
T	6	4.82	0.47	126.67	
(1-3)v(4-7)	1	4.0	0.04	268.79	
Lin. 1 - 3	1	6.3	-	-	
Quad. 1 - 3	1	0.3	-	-	
Lin. 4 - 7	1	2.5	-	-	
Quad. 4 - 7	1	10.1	-	-	
Cub. 4 - 7	1	5.6	-	-	
E	1	23.10 †	19.90 †	1623.00	
B:E	6	5.48	3.95	1142.83	
TE	6	2.23	0.45	34.50	
TB:E	36	4.79	1.01	145.61	
S	1	28.6 *	2.30	146.00	
TS	6	3.15	0.47	184.00	
SE	1	2.60	4.20 †	0.00	
TSE	6	7.07	2.40	79.83	
A:TSE	28	4.04	1.30	370.35	

		Third Vertebra (mm)	Mid-Back (mm)	Max. Loin (mm)	Min. Loin (mm)
T	6	5.58	3.48	2.29	2.56
(1-3)v(4-7)	1	1.62	0.43	2.04	5.18
E	1	36.16	2.17	0.08	4.57
B:E	6	10.47	12.61	23.99	16.19
TE	6	1.00	2.87	7.40	5.49
TB:E	36	8.15	5.14	6.43	8.30
S	1	46.45 *	15.03	1.15	34.57 †
TS	6	7.95	10.06	8.48	8.41
SE	1	0.16	1.43	8.63	0.29
TSE	6	10.24	1.24	5.15	2.45
A:TSE	28	10.87	6.30	10.14	10.57

† $p < 0.10$: * $p < 0.05$: Where no level of significance is shown $p > 0.10$: - not analysed.

APPENDIX 6/4: (Contd)

RAW DATA

LOIN JOINT WEIGHT (gms)

Tr. \ Bl.	1	2	3	4	5	6	7	8	Total
1	3288	2370	3215	2957	2893	3013	2859	3145	23740
2	2684	2664	3164	3267	2817	2866	2674	2841	22977
3	2940	2725	2974	2900	2907	2853	2986	3100	23385
4	2526	3003	2986	3017	2993	3242	2890	3021	23678
5	2882	2636	2678	3048	3146	2711	2779	2838	22718
6	3227	2667	3048	2695	3206	2999	2841	2878	23561
7	2658	2483	2705	2758	3004	2895	3045	2941	22489
Total	20205	18548	20770	20642	20966	20579	20074	20764	162548

TOTAL DISSECTABLE FAT WEIGHT (gms)

1	1780	960	1520	1588	1230	1364	1240	1721	11403
2	1165	1365	1405	1555	1081	1161	1088	1390	10210
3	1288	1328	1523	1296	1332	1192	1390	1509	10858
4,	1158	1490	1378	1563	1424	1488	1396	1574	11471
5	1468	1047	1102	1348	1368	1084	1244	1402	10063
6	1693	1335	1393	1184	1215	1159	1334	1329	10642
7	1275	1043	1244	1223	1081	1321	1431	1339	9957
Total	9827	8568	9565	9757	8731	8769	9123	10264	74604

TOTAL DISSECTABLE LEAN WEIGHT (gms)

1	1109	1133	1208	1023	1286	1283	1180	1035	9257
2	1194	1001	1279	1239	1331	1257	1185	1058	9544
3	1270	1105	1104	1154	1229	1199	1127	1135	9323
4	1087	1100	1238	1104	1228	1305	1112	1045	9219
5	1071	1237	1170	1186	1367	1320	1111	1005	9467
6	1087	1150	1169	1133	1547	1409	1148	1070	9713
7	1241	1094	1113	1157	1451	1156	1136	1152	9500
Total	8059	7820	8281	7996	9439	8929	7999	7500	66023

A P P E N D I X 6/4:

EXPERIMENT I - CARCASS DATA

RAW DATA AND STATISTICAL ANALYSES

R A W D A T A

SPECIFIC GRAVITY

Tr. \ Bl.	1	2	3	4	5	6	7	8	Total
1	1.0409	1.0595	1.0535	1.0460	1.0629	1.0564	1.0618	1.0490	8.4300
2	1.0654	1.0528	1.0568	1.0542	1.0602	1.0641	1.0591	1.0547	8.4673
3	1.0617	1.0496	1.0480	1.0546	1.0565	1.0594	1.0557	1.0531	8.4386
4	1.0612	1.0520	1.0603	1.0476	1.0554	1.0549	1.0580	1.0502	8.4396
5	1.0569	1.0629	1.0636	1.0556	1.0566	1.0598	1.0597	1.0578	8.4729
6	1.0532	1.0616	1.0561	1.0634	1.0625	1.0619	1.0578	1.0615	8.4780
7	1.0611	1.0662	1.0636	1.0547	1.0679	1.0514	1.0581	1.0633	8.4863
Total	7.4004	7.4046	7.4019	7.3761	7.4220	7.4079	7.4102	7.3896	59.2127

"C" (m.m.)

1	24	13	15	21	15	15	12	19	134
2	13	17	14	17	12	14	15	13	115
3	13	14	19	17	15	12	16	16	122
4	14	16	14	22	16	15	17	14	128
5	14	10	15	16	16	14	16	18	119
6	20	19	17	14	12	10	15	15	122
7	16	13	18	13	11	15	17	14	117
Total	114	102	112	120	97	95	108	109	857

"EYE" MUSCLE AREA (cm^2)

1	19.9	25.3	20.3	14.8	20.8	20.5	19.9	15.7	157.2
2	18.0	15.9	18.5	18.8	23.3	23.4	19.3	18.3	155.5
3	22.9	20.7	16.8	17.0	19.7	20.1	18.3	21.4	156.9
4	21.6	19.9	20.1	15.9	19.9	18.6	17.2	15.1	148.3
5	20.7	20.5	18.2	20.9	22.4	22.9	19.6	17.2	162.4
6	18.2	20.1	19.5	17.8	23.1	25.4	18.2	17.1	159.4
7	20.8	18.9	17.0	20.0	24.2	19.5	19.9	21.4	161.7
Total	142.1	141.3	130.4	125.2	153.4	150.4	132.4	126.2	1101.4

APPENDIX 6/3: (Contd)

ANALYSES OF VARIANCE

		Period 50 - 120 lb. Liveweight				
		Whey Intake (lbs - 1000)	DM Intake (lbs)	DM Intake/ day (lbs)	CP Intake (lbs)	CP Intake/ day (lbs)
Source	df	Mean sqs/F tests	Mean sqs/F tests	Mean sqs/F tests	Mean sqs/F tests	Mean sqs/F tests
T	6	1938325 ***	773.75 ***	0.0151 ***	43.32 ***	0.01480 ***
(1-3)v(4-7)	1	11571263***	2940.05 ***	0.0343 ***	119.69 ***	0.00006
Lin. 1 - 3	1	40000 †	555.78 †	-	34.81 *	-
Quad. 1 - 3	1	176	0.29	-	0.04	-
Lin. 4 - 7	1	13672	1073.30 *	-	102.40 ***	-
Quad. 4 - 7	1	185	0.45	-	0.21	-
Cub. 4 - 7	1	4655	72.63	-	2.76	-
E	1	48734	1794.40 †	0.0001	47.36	0.00008
B:E	6	46723	527.15	0.0059	19.03	0.00025
TE	6	8374	60.37	0.0039	1.84	0.00015
TB:E	36	13804	176.71	0.0032	5.52	0.00010
S	1	105444 *	1566.70 **	0.0005	45.18 **	0.00007
TS	6	35006 *	324.85	0.0019	11.02	0.00015
SE	1	4573	42.82	0.0002	1.12	0.00003
TSE	6	10648	195.84	0.0070	6.25	0.00012
A:TSE	28	14048	171.10	0.0034	5.82	0.00012

- not analysed : † $p < 0.10$: * $p < 0.05$: ** $p < 0.01$: *** $p < 0.005$

where no level of significance is shown $p \geq 0.10$.

A P P E N D I X 6/3: (Contd).

ANALYSES OF VARIANCE

		Period 85 - 120 lbs. Liveweight				
		Whey Intake (lbs - 600)	DM Intake (lbs)	DM Intake/ day (lbs)	CP Intake (lbs)	CP intake/ day (lbs)
S o u r c e	df	Mean sqs/F tests	Mean sqs/F tests	Mean sqs/F tests	Mean Sqs/F tests	Mean sqs/F tests
T	6	514028 ***	141.32	0.0186 †	14.15 ***	0.01293 ***
(1-3)v(4-7)	1	3078021 ***	773.79 ***	0.0178	28.34 ***	0.00003
Lin. 1 - 3	1	4225	42.58	-	10.89 †	-
Quad. 1 - 3	1	61	3.26	-	0.03	-
Lin. 4 - 7	1	176	15.07	-	44.94 ***	-
Quad. 4 - 7	1	221	1.32	-	0.15	-
Cub. 4 - 7	1	1464	11.94	-	0.55	-
E	1	2392	170.40	0.0350	3.81	0.00053
B:E	6	16080	146.43	0.0110	5.74	0.00136
TE	6	4662	36.57	0.0077	0.97	0.00014
TB:E	36	6325	61.62	0.0075	3.12	0.00020
S	1	33909 *	394.80 *	0.0000	13.02 *	0.00013
TS	6	12795	117.62	0.0091	4.02	0.00050
SE	1	11	11.91	0.0003	0.08	0.00011
TSE	6	5226	60.43	0.0079	1.70	0.00023
A:TSE	28	6505	57.93	0.0083	2.18	0.00038

- not analysed : † $p < 0.10$: * $p < 0.05$: ** $p < 0.01$: *** $p < 0.005$

where no level of significance is shown $p \geq 0.10$.

A P P E N D I X 6/3: (Contd)

ANALYSES OF VARIANCE

		Period 50 - 85 lbs. Liveweight				
		Whey Intake (lbs - 300)	DM Intake (lbs)	DM Intake/ day (lbs)	CP Intake (lbs)	CP Intake/ day (lbs)
S o u r c e	df	Mean sqs/F tests	Mean sqs/F tests	Mean sqs/F tests	Mean sqs/F tests	Mean sqs/F tests
T	6	458410 ***	308.23 ***	0.0203 ***	8.49 ***	0.014326 ***
(1-3)v(4-7)	1	2713350 ***	701.52 ***	0.0352 ***	31.55 ***	0.000041
Lin. 1 - 3	1	18292 *	300.16 *	-	6.76 *	-
Quad. 1 - 3	1	450	1.51	-	0.14	-
Lin. 4 - 7	1	16954 *	817.22 **	-	11.66 **	-
Quad. 4 - 7	1	1	4.06	-	0.05	-
Cub. 4 - 7	1	898	24.96	-	0.84	-
E	1	29578	839.30 †	0.0098	24.31	0.000596
B:E	6	10815	149.27	0.0087	4.58	0.000196
TE	6	3454	44.20	0.0007	1.23	0.000124
TB:E	36	3033	48.07	0.0031	1.41	0.000065
S	1	19725 *	378.60 *	0.0019	9.69 *	0.000005
TS	6	7206 †	83.83	0.0009	2.48	0.000021
SE	1	4132	19.71	0.0000	0.59	0.000034
TSE	6	1263	42.31	0.0067	1.63	0.000098
A:TSE	28	3551	52.54	0.0042	1.55	0.000098

- not analysed : † $p < 0.10$: * $p < 0.05$: ** $p < 0.01$: *** $p < 0.005$

where no level of significance is shown $p \geq 0.10$.

APPENDIX 6/3:

FOOD INTAKE - EXPERIMENT I

RAW DATA

TOTAL WHEY INTAKE (lbs)

Period 50 - 85 lbs. liveweight									
Bl. / Tr.	1	2	3	4	5	6	7	8	Total
1	1075	752	884	935	774	824	804	991	7039
2	974	852	903	848	710	718	832	858	6695
3	788	894	882	822	761	708	832	811	6498
4	387	422	456	462	430	443	419	434	3453
5	487	349	421	379	395	371	380	427	3209
6	531	409	406	343	361	357	365	386	3158
7	429	307	360	373	337	324	406	385	2921
Total	4671	3985	4312	4162	3768	3745	4038	4292	32973

Period 85 - 120 lbs. liveweight									
Bl. / Tr.	1	2	3	4	5	6	7	8	Total
1	1313	1078	1155	1304	1124	1185	1145	1353	9657
2	1208	1260	1137	1304	1126	1118	1197	1204	9554
3	1194	967	1199	1165	1361	1081	1312	1118	9397
4	633	727	690	829	725	658	727	735	5724
5	905	625	665	734	715	631	666	745	5686
6	889	699	734	657	718	691	694	766	5848
7	796	655	719	738	651	718	793	656	5726
Total	6938	6011	6299	6731	6420	6082	6534	6577	51592

TOTAL DRY-MATTER INTAKE (lbs)

Period 50 - 85 lbs. liveweight									
1	112.3	82.8	94.5	98.9	81.6	85.6	84.3	103.3	743.3
2	103.1	89.9	97.2	93.2	74.6	74.9	90.5	89.5	712.9
3	82.7	98.7	92.8	87.0	77.8	74.2	84.2	76.6	674.0
4	83.3	89.8	94.2	96.8	87.8	88.8	84.7	87.7	713.1
5	98.9	73.0	84.9	80.5	80.9	75.5	78.2	86.7	658.6
6	102.6	83.2	83.4	73.5	74.4	72.4	74.6	77.3	641.4
7	87.6	64.3	73.7	76.4	68.1	71.6	80.3	76.3	598.3
Total	670.5	581.7	620.7	606.3	545.2	543.0	576.8	597.4	4741.6

Period 85 - 120 lbs. liveweight									
1	113.2	97.4	100.2	112.9	96.1	101.4	97.2	113.8	832.2
2	104.4	107.9	96.5	111.8	96.4	94.6	100.6	100.7	812.9
3	102.8	89.0	101.9	98.7	116.5	90.3	107.6	99.3	806.1
4	85.9	99.5	93.0	110.6	95.9	87.8	96.1	96.1	764.9
5	121.7	85.6	88.7	96.8	94.5	83.6	87.6	96.0	754.5
6	113.8	92.6	96.1	87.4	94.0	90.1	90.4	98.3	762.7
7	103.4	87.0	94.3	95.3	85.5	93.0	101.8	85.5	745.8
Total	745.2	659.0	670.7	713.5	678.9	640.8	681.3	689.7	5479.1

TOTAL CRUDE PROTEIN INTAKE (lbs)

Period 50 - 85 lbs. liveweight									
1	17.8	13.1	15.0	15.8	12.9	13.6	13.3	16.5	118.0
2	17.9	15.7	16.9	16.3	13.2	13.2	15.8	15.5	124.5
3	15.5	18.7	17.5	16.4	14.8	14.1	15.7	15.7	128.4
4	12.3	13.3	14.0	14.4	13.0	13.0	12.5	13.0	105.5
5	16.1	12.0	13.9	13.2	13.2	12.3	12.8	14.2	107.7
6	18.5	15.0	15.1	13.2	13.4	13.0	13.4	13.9	115.5
7	17.2	12.6	14.5	15.0	13.3	14.1	15.7	14.9	117.3
Total	115.3	100.4	106.9	104.3	93.8	93.3	99.2	103.7	816.9

Period 85 - 120 lbs. liveweight									
1	18.6	15.8	16.4	18.4	15.5	16.5	15.7	19.7	136.6
2	18.3	18.8	16.9	19.6	16.6	16.2	17.6	18.6	142.6
3	19.2	16.7	18.9	18.4	21.6	16.5	20.4	18.1	149.8
4	13.2	15.3	14.3	17.2	14.8	13.7	14.8	15.4	118.7
5	20.4	14.2	14.9	16.2	15.7	13.9	14.6	16.5	126.4
6	20.7	16.6	17.2	15.8	16.8	16.2	16.2	18.2	137.7
7	19.7	116.7	18.1	18.3	16.2	17.7	19.5	17.0	143.2
Total	130.1	114.1	116.7	123.9	117.2	110.7	118.8	123.5	955.0

		Days 50-85 lbs. (C+G)	Days 85-120 lbs. (C+G)	Days 50-120 lbs. (C+G)			
Source	df	Mean Sqs/F Tests	Mean Sqs/F Tests	Mean Sqs/F Tests	Mean Sqs/F Tests	Means Sqs/F Tests	Mean Sqs/F Tests
T	6	35.62 ***	13.07 *	81.17 ***			
(1-3)v(4-7)	1	133.93 ***	75.33 ***	410.16 ***			
Lin. 1 - 3	1	14.06	0.06	16.00			
Quad.1 - 3	1	0.19	1.69	0.75			
Lin. 4 - 7	1	62.50 **	0.31	54.06 †			
Quad.4 - 7	1	0.50	0.28	0.03			
Vub. 4 - 7	1	2.50	0.76	6.01			
E	1	126.00 *	0.45	179.00 †			
B:E	6	20.23	7.97	45.00			
TE	6	1.33	1.42	12.67			
TB:E	36	7.12	4.89	16.33			
S	1	41.10 *	28.50 *	138.00 **			
TS	6	9.18	5.58	24.33			
SE	1	2.60	1.30	7.00			
TSE	6	11.32	3.95	12.17			
A:TSE	28	7.54	4.89	17.64			
		Days 50-85 lbs. (C)	Days 50-85 lbs. (G)	Days 85-120 lbs. (C)	Days 85-120 lbs. (G)	Days 50-120 lbs. (C)	Days 50-120 lbs. (G)
T	6	29.14 †	15.66 *	5.50	13.14 *	57.64 *	47.73 ***
(1-3)v(4-7)	1	78.11 *	56.68 ***	17.65	65.19 ***	170.00 ***	243.44 ***
Lin. 1 - 3	1	28.13	0.00	10.13	8.00	72.00 *	8.00
Quad.1 - 3	1	3.38	6.00	1.04	0.67	8.17	2.67
Lin. 4 - 7	1	54.45 *	14.45 †	1.01	3.20	70.37 *	4.05
Quad.4 - 7	1	9.00	16.00 †	3.06	1.00	22.56	25.00
Cub. 4 - 7	1	1.80	0.80	0.11	0.80	2.81	3.20
E	1	82.29 *	46.29 **	5.14	0.57	128.57 *	57.14 *
TE	6	10.29	2.37	2.48	2.91	46.57	6.89
A:TE	14	10.86	4.21	5.86	3.93	14.86	8.21

† $p < 0.10$: * $p < 0.05$: ** $p < 0.01$: *** $p < 0.005$

where no level of significance shown $p > 0.10$

A P P E N D I X 6/2:

GROWTH DATA (DAYS TAKEN) : ANALYSES OF VARIANCE - EXPERIMENT I

R A W D A T A

50 - 85 lb. L.Wt.									
Block / Tr.	1	2	3	4	5	6	7	8	Total
1	39	30	33	34	28	29	29	27	259
2	37	32	35	33	26	26	32	32	253
3	30	38	33	31	27	26	29	30	244
4	29	31	32	33	30	30	29	30	244
5	34	26	29	28	28	26	27	30	228
6	36	29	29	26	26	25	26	27	224
7	31	23	26	27	24	26	28	27	212
T O T A L	236	209	217	212	189	188	200	213	1664
85 - 120 lb. L.Wt.									
1	30	28	27	30	26	28	27	31	227
2	28	29	26	30	27	26	28	28	222
3	28	28	28	27	34	25	30	26	226
4	23	26	25	29	26	24	26	26	205
5	33	23	24	26	26	23	24	26	205
6	31	25	26	24	26	25	25	27	209
7	28	24	26	26	24	26	28	24	206
T O T A L	201	183	182	192	189	177	188	188	1500

A P P E N D I X 6/1:

REGRESSION ANALYSIS (LIVEWEIGHT ON TIME) - EXPERIMENT I

DETAILS OF ANALYSIS

		df.	Sx^2	Sxy	Sy^2	b	Sy^1	df.	Regression Equations
T.1	C	6	28	209.50	1571.92	7.4821	4.41	5	Y = 7.4821X + 44.61
	G	6	28	249.13	2220.21	8.8975	3.58	5	Y = 8.8975X + 46.59
T.2	C	6	28	233.37	1947.78	8.3346	2.72	5	Y = 8.3346X + 48.14
	G	6	28	233.49	1949.47	8.3389	2.41	5	Y = 8.3389X + 46.59
T.3	C	6	28	235.65	1983.64	8.4161	0.39	5	Y = 8.4161X + 47.13
	G	6	28	228.64	1868.66	8.1657	1.65	5	Y = 8.1657X + 47.29
T.4	C	6	28	235.90	1996.34	8.4250	8.88	5	Y = 8.4250X + 45.70
	G	6	28	249.11	2225.50	8.8968	9.22	5	Y = 8.8968X + 46.15
T.5	C	6	28	241.50	2087.16	8.6250	4.22	5	Y = 8.6250X + 48.11
	G	6	28	276.61	2738.40	9.8789	5.79	5	Y = 9.8789X + 43.89
T.6	C	6	28	240.84	2073.96	8.6014	2.39	5	Y = 8.6014X + 46.30
	G	6	28	267.86	2564.27	9.5664	1.81	5	Y = 9.5664X + 47.52
T.7	C	6	28	266.13	2530.15	9.5046	0.68	5	Y = 9.5046X + 46.43
	G	6	28	258.77	2393.48	9.2418	1.98	5	Y = 9.2418X + 46.30
TOT.		84	392	3426.50	30150.94		50.13	70	
T.1		6	28	229.33	1882.00	8.1904	3.71	5	Y = 8.1904X + 45.60
T.2		6	28	233.41	1948.06	8.3361	2.34	5	Y = 8.3361X + 47.41
T.3		6	28	232.13	1925.07	8.2904	0.63	5	Y = 8.2904X + 47.21
T.4		6	28	242.51	2109.11	8.6611	8.71	5	Y = 8.6611X + 45.93
T.5		6	28	259.08	2402.09	9.2529	4.86	5	Y = 9.2529X + 46.04
T.6		6	28	254.35	2312.35	9.0839	1.85	5	Y = 9.0839X + 46.91
T.7		6	28	262.45	2460.91	9.3732	0.91	5	Y = 9.3732X + 46.37
TOT.		42	196	1713.26	15039.59		23.01	35	
C		6	28	237.54	2017.44	8.4836	2.25	5	Y = 8.4836X + 46.66
G		6	28	251.94	2269.95	8.9979	3.03	5	Y = 8.9979X + 46.33
TOT.		12	56	489.48	4287.39		5.28	10	

C Castrates

G Gilts

A P P E N D I X 6/1:

REGRESSION ANALYSIS (LIVEWEIGHT ON TIME) - EXPERIMENT I

RAW DATA : X = WEEKS : Y = MEAN WEIGHT OF PIGS (lbs)

T.1			T.2			T.3			T.4			T.5			T.6			T.7			All T's		Wks
C	G	C+G	C	G	C+G	C	G	C+G	C	G	C+G	C	G	C+G	C	G	C+G	C	G	C+G	C	G	
53.50	56.50	55.00	57.38	55.88	56.63	55.75	56.25	56.00	55.75	56.63	56.19	58.00	55.13	56.56	55.63	57.88	56.75	56.25	56.25	56.25	56.04	56.36	1
59.13	64.50	61.81	64.75	63.13	63.94	63.50	63.38	63.44	62.75	64.13	63.44	65.38	63.63	64.50	63.75	66.50	65.13	65.38	64.75	65.06	63.52	64.29	2
66.13	72.13	69.13	73.13	70.88	72.00	72.50	71.25	71.88	69.38	71.63	70.50	73.38	72.38	72.88	71.38	75.63	73.50	74.63	73.75	74.19	71.50	72.52	3
73.88	81.25	77.56	80.63	79.25	79.94	81.00	79.75	80.38	78.25	80.50	79.38	81.75	82.38	82.06	80.25	85.13	82.69	84.63	82.63	83.63	80.05	81.55	4
81.50	91.25	86.38	89.38	88.38	88.88	89.25	87.75	88.50	87.38	89.38	88.38	90.75	93.13	91.94	88.75	95.63	92.19	93.38	92.13	92.75	88.63	91.09	5
90.00	100.38	95.19	98.13	96.50	97.31	97.38	96.13	96.75	96.13	100.13	98.13	100.00	102.88	101.44	97.86	104.75	101.30	103.75	101.50	102.63	97.60	100.32	6
97.63	109.25	103.44	107.50	105.63	106.56	106.13	105.13	105.63	106.13	109.75	107.94	109.63	114.25	111.94	107.38	115.00	111.19	113.13	111.88	112.50	106.79	110.13	7
521.77	575.26	548.51	570.90	559.65	565.26	565.51	559.64	562.58	555.77	572.15	563.96	578.89	583.78	581.32	565.00	600.52	582.75	591.15	582.89	587.01	564.13	576.26	28

C Castrates

G Gilts

APPENDIX 4/1:

PUBLISHED DATA ON THE COMPOSITION OF FOODSTUFFS USED IN THE EXPERIMENTS

	%							%			ppm				
	Moisture Content	Crude Protein	Ash	Ether Extract	Crude Fibre	N.Free Extract	TDN	Ca	P	Na	Mn	Fe	Cu	Zn	Source
BARLEY MEAL:															
	13.7	12.5	2.3	2.0	4.4	65.1		-	0.33	0.01	22	58	4.2	34	)
	13.2	10.3	2.7	2.3	3.9	67.7		-	0.33	-	19	58	4.3	30	)
	13.8	10.4	2.6	1.7	4.9	66.8		0.05	0.35	0.04	12	52	4.3	23	)
	13.0	8.8	2.3	0.9	4.3	70.8		0.04	0.30	0.02	18	44	4.6	27	) Massey University
	14.2	9.1	3.1	1.1	6.7	66.0									)
	13.9	9.3	2.6	1.1	4.3	69.1									)
	10.9	12.1	3.2	2.1	7.4	64.3	69.0								Morrison (1956)
	13.6	10.7	2.6	1.9	4.6	66.6	69.9								Schneider (1947)
	14.0	10.5	2.6	1.5	4.8	66.6	70.9								Evans (1960b)
	11.0	11.5	-	1.9	5.0	-	70.0								N R C Pub. 659
	-	11.5	-	2.0	6.0	68.0	78.0	0.05	0.40						Feed Bag Red Book (1966)
	13.0	11.4	2.3	1.9	5.0	-	70.0	0.08	0.42			53	7.8	15	N R C Pub. 1192
VALUES USED:							71	0.05	0.33		18	53	4.4	30	
BUTTERMILK POWDER:															
	5.1	36.5	7.4	7.1		43.9		0.93	0.89		1.4	23	1.9	32	)
	4.7	36.0	7.6	10.0		41.7		1.16	0.81		1.2	18	1.8	31	)
	9.0	31.7	6.8	7.8		44.9		1.11	0.83		6.0	11	2.6	37	) Massey University
	5.9	36.1	-	-		-		0.92	0.85		3.0	26	1.4	36	)
	6.8	31.6	7.4	6.1		48.1									)
	7.6	32.2	9.1	1.8		49.3	77								Schneider (1947)
	7.6	32.4	10.0	6.4		43.3	84								Morrison (1956)
	10.0	35.3	7.7	7.0		40.0	99(Liquid)								Evans (1960b)
	7.0	32.0	-	5.8		-	77(83 for ruminants)								N R C Pub. 659
	-	32.0	9.5	5.0		44.0	85								Feed Bag Red Book (1966)
	6.9	11.1	3.6	2.7		-	26(= 89 on DM Basis)								N R C Pub. 1192
VALUES USED:							85	1.03	0.65		3	17	2	33	
WHEY: FRESH AND DRY:															
	3.7	17.5				62.8	78.7	0.87	0.72		5	210	53		Morrison (1956)
	93.4	0.9				5.0	5.9(=89 on DM BASSIS)								Morrison (1956)
	93.4	0.7				5.0	6.1(Starch equiv.)								Evans (1960b)
	6.0	13.1	9.7	0.8			78.0	0.87	0.79			155	44		N R C Pub. 1192 (1964)
CHEESE	Dried	13.0	8.0	1.0		72.0	78.0	0.90	0.75						Feed Bag Red Book (1966)
LACTIC CASEIN	93.8	0.8	0.7			4.1		0.15	0.20	0.06					McDowall and Thomas (1961)
	93.1	-	0.6					0.05	0.05	0.05					Webb and Whittier (1948)
	94.9	0.9						0.04	0.06						Mitchell (1963)
												53-260			Massey University
VALUES USED:	(D.M Basis)						83	0.8-1.1	0.75		5	50-210	53	30 ?	
BONE FLOUR:															
								25.9	12.3	0.63	32	375	2.8	120	)
								28.2	13.3	0.60	12	412	2.8	108	)
								28.8	13.6	0.80	8	335	3.1	107	) Massey University
								28.4	13.5	0.80	8	393	2.8	107	)
VALUES USED:								28.5	13.5		9	380	3	107	

APPENDIX 2/1:

SUMMARY OF SOME EXPERIMENTS CONDUCTED TO EVALUATE THE IMPORTANCE OF DIETARY ENERGY AND PROTEIN IN PIG NUTRITION

SOURCE	"ENERGY" LEVELS	PROTEIN LEVELS	Systems of Feeding	Growth Period	Effect of increasing energy			Effect of increasing Protein			C x P interactions	Tr.xSex interactions	Effect on N retention		
					LWG	% LEAN	FCE	LWG	% LEAN	FCE			Energy	Protein	CxP
Abernathy et al(1958)	0,5,10% FAT	14, 18%	Ad. lib.	40-110	+	- NS	+	+				?			
			Ad. lib.	110-190	+		+					?			
Kennington et al(1958)	0-20% FAT	14 - 20%	Ad. lib.	30-125	+	-	+					?			
Baird et al (1958)	0-10% TALLOW	13, 19%	Dry lot	40-200			+				+ ?	?			
Lowrey et al (1958)	0, 10% FAT	13,16,19%	Ad. lib.	20-60	+		+	+			+ ?	?			
Clawson et al (1959)			Ad. lib.	40-	+		+					?			
Noland and Scott (1960)	950, 1050, 1200 k/cals	12,16,20%	Ad. lib.	40-75				+			+	?			
	Product En/lb			40-200	+	-	+					?			
Clawson et al(1962)	0,5,10% FAT	C:P Ratios	Ad. lib.	40-70				+		+		?			
				40-200	+		+					?			
Wagner et al (1963)	950, 1170, k/cals.	13,19,25%	Ad. lib.	40-200	+	-	+	+	+	+		?			
	Prod. En/lb														
Creeley et al (1964)	0 - 12% TALLOW	13-19%	Ad. lib.	45-90	+	-	+					?			
Searly et al (1964)	0,4,8% GREASE	12.5,14.5%	Ad. lib.	40-200		-	+	+	+			?			
Bowland and Berg (1959)	65,79% TDN	17,21%	Ad. lib.	40-110	+ NS					+		+			
				110-200											
				40-200		-			+ NS						
Likuski et al(1961)	*[a]64,80% TND	14,18%	Ad. lib.	8 kg.											+
				20 kg				•							
				50 kg											
Kuryvial et al(1962)	*0,15,30% FAT	14,18,22%	Semi-Rest	15-195	+	-	+	+	+	+	+				
Kuryvial and Bowland (1962)	*[a]0,15,30% FAT	14,18,22%	Ad. lib.	7 kg.										+ NS	
				45 kg.										-	+
				87 kg.	+	-	+	+	+	+	+				
Costain and Morgan (1961)	66,78% TDN	15.5, 18.5%	Rest.	50-100		-					+	?			
Robinson et al(1964)	2640, 2860, 3120 3260, K/cals DE/kg.	14, 16, 18, 20%	Rest.	50-120	+-NS		+ -	+ -?	+ ?	+ -		+			
				120-200											

* CASTRATES ONLY a Nitrogen balance only + positive effect - negative effect

+- negative curvilinear effect. NS not significant ? not tested or mentioned +? response unsure

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