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THE USE OF WHEY POWDER IN
MEAL MIXTURES FOR EARLY
WEANED PIGS

A Thesis Presented in Partial Fulfilment
of the Requirements for the Degree
of Master of Agricultural Science
in the University of New Zealand

by
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Massey Agricultural College
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REQUIEM

On Monday, when the sun is hot,
I wonder to myself a lot:-
"How is it true or is it not
That what is which and which is what?"

On Tuesday, when it hails and snows
The feeling on me grows and grows
That hardly anybody knows,
If those are these and these are those.

On Wednesday, when the sky is blue,
And I have nothing else to do,
I sometimes wonder if its true
That who is what and what is who.

On Thursday, when it starts to freeze
And hoar-frost twinkles on the trees
How very readily one sees
That these are whose - but whose are these?

On Friday

.....A.A. Milne

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CHAPTER I

INTRODUCTION

1. General
2. Scope of Study

INTRODUCTION

1. GENERAL

Considerable interest has been shown in the last ten years in the early weaning of litters from the sow before they reach the "traditional" 8 week weaning age. The attention of commercial pig producers and research workers has been drawn to the possibility of improving the efficiency of the reproductive phase of pig production, by the use of early weaning techniques.

A number of arguments have been advanced in support of the use of this method. Namely, that the feed consumed by the litter directly from the trough, is converted more efficiently than that fed through the sow and that sow weight losses are reduced as the lactation period is shortened. Furthermore, in countries where feed is available all the year round, early weaning can be used as a means of improving the productivity of the sow by increasing the number of litters born each year.

In New Zealand, dairy by-products constitute the bulk of feed used for pigs. The output of these by-products is seasonal, they are perishable in nature and are produced irrespective of the requirements of the pig herd. In terms of the most efficient production with a minimum of wastage of feed, early weaning allows the planning of more suitable farrowing dates and balance of stock numbers, to fit in with the supply of food.

This interest in early weaning has provided a stimulus to studies on the nutrition of the young pig and the formulation of ;

suitable post weaning diets.

These studies have indicated that lactose is the preferred source of energy over the other carbohydrates during the first few weeks of life. This would suggest that foodstuffs rich in lactose, such as whey, might be useful for rearing young pigs.

Whey is produced in New Zealand in quantities far in excess of its demand for pig feeding purposes. Consequently a growing whey disposal problem confronts many cheese and casein manufacturers. The concentration of some of this surplus has been carried out by a few Dairy Companies in the hope that the dried product could be conserved for local use and export.

Knowledge on the use of dried whey products in pig feeding in New Zealand, is limited, although some local and overseas trials have indicated that the young pig can tolerate higher levels of dried whey than at later stages of growth. Furthermore, the high production costs of whey powder in N.Z., makes it additionally important that this knowledge be extended, so as to determine the conditions under which the product must be used to realize its maximum value.

2. SCOPE OF STUDY

The present trial was designed to obtain information on the effect of different levels of substitution of lactic casein whey powder for barley meal, in an early weaning mixture for young pigs.

Comparisons of rates of gain, feed conversion efficiency and thrift of the animals on the different experimental treatments,

were supplemented with data on the apparent digestibility of feed constituents. These digestibilities were determined by the chromium oxide reference-marker technique. Observations were made on the use of this method in pig nutrition studies, and results and discussion are presented on the chemical analytical procedures used.

Further observations were made on the managerial factors involved and the feeding habits of young pigs fed whey powder in their meal mixtures.

CHAPTER II

REVIEW OF LITERATURE

- PART I : THE NUTRITION OF THE YOUNG PIG
- PART II : THE ESTIMATION OF APPARENT DIGESTIBILITY
- PART III: THE HENNEBERG ANALYSIS AND OTHER CHEMICAL
PROCEDURES INVOLVED IN NUTRITION STUDIES.

REVIEW OF LITERATURE

PART I: THE NUTRITION OF THE YOUNG PIG

1. INTRODUCTION

The pig, by comparison with other species of farm livestock, is born at a relatively early stage of its development. For example, at birth the pig weighs less than 1% of the average adult size whereas the foal weighs about 9% of the average adult size (Braude 1954).

The subsequent rapid growth rate is unique. At birth the average piglet weighs between 2½ and 3 lbs (Bellis, 1957; Duncan and Lodge, 1960) and at 8 weeks of age may weigh 50-60 lbs.

It is thus no wonder that the young pig is extremely sensitive to inadequacies in its nutrition and environment. An adequate and balanced supply of nutrients are required to support such rapid growth.

2. THE GROWTH CURVE AND FEED ENERGY RELATIONSHIP

The growth rate of the young pig depends largely on the digestible energy intake from its feed. With suckled pigs, this will of course depend on the energy yield of the sow's milk. Braude (1954), Lodge and Lucas (1956, 1958), Smith (1952, 1960) and others have reported that the sow's output of milk solids declines markedly from about the 3rd-4th week of lactation. In the absence of any other source of dietary energy, the growth rate of the litter can be expected to fall off. This is illustrated

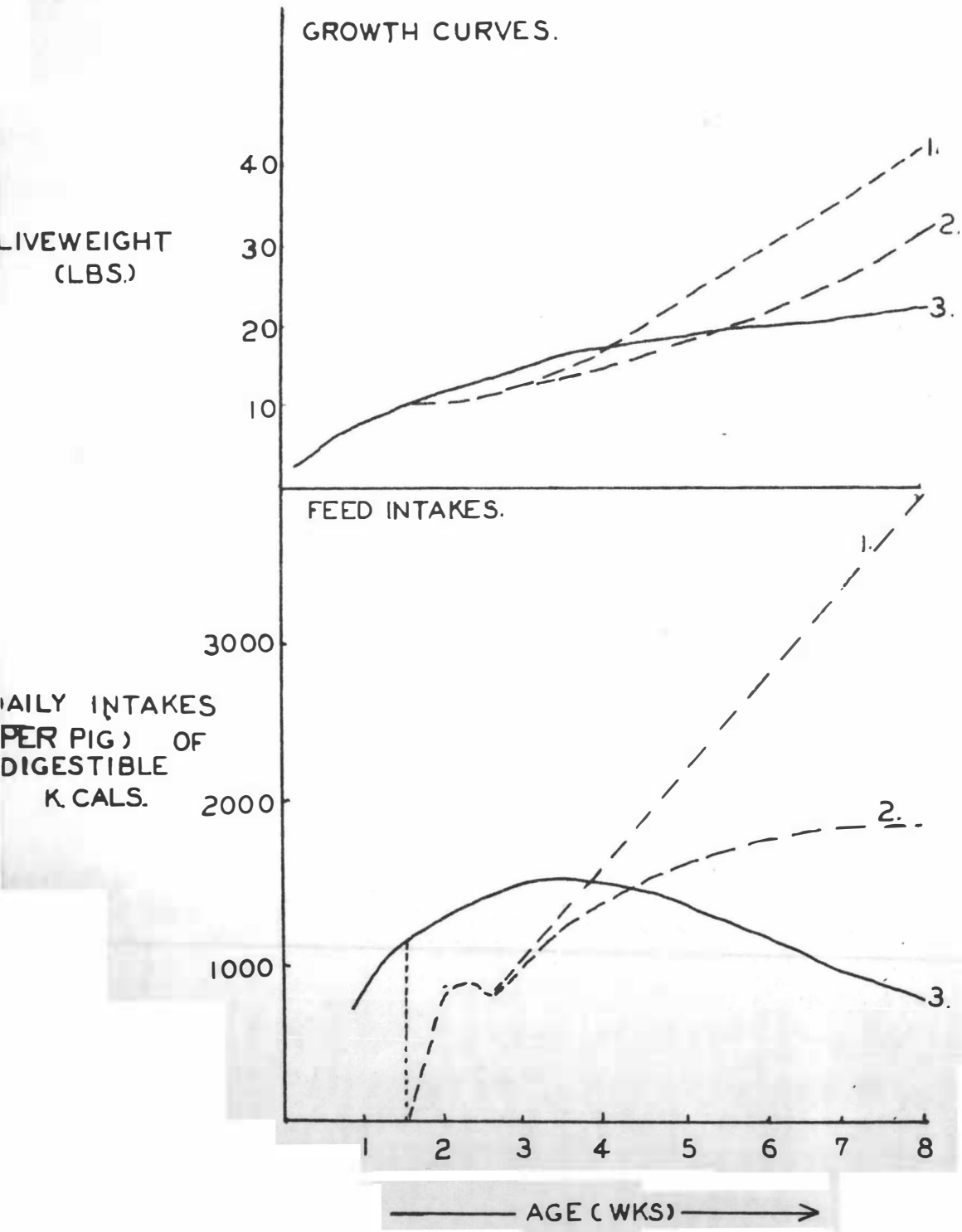


FIG. 1.

KEY TO FIGURE 1

GROWTH CURVES AND FEED INTAKES

OF EARLY WEANED PIGS

(Lodge and Lucas, 1958)

- Line 1 : Early weaned pigs, full-fed.
Line 2 : Early weaned pigs, restricted feed.
Line 3 : Sow-reared pigs, not creep fed.

diagrammatically in Fig. 1 from data compiled by Lodge and Lucas (1958) from a trial where no alternative source of energy to sow's milk was given.

Berge and Indrebø (1953) showed that the younger the piglet, the more valuable was milk from the dam. The weight increase of piglets during the first and second weeks of lactation, represented 60% of the caloric content of sow milk; during the third week 36% and during the fourth only 28%.

This factor was further clarified by Braude (1954) who found that up to about 3 weeks of age the growth curves of litter mates reared artificially on a sow milk substitute, were very similar to those of mates of the same litter reared on the sow. After this time the artificially reared piglets had a faster growth rate than the other group. Braude concluded that pigs reared on the sow received an insufficient supply of milk to enable them to grow at their full potential rate from the age of 2-3 weeks. In this trial, both lots of pigs received the same creep feed, which suggested that the milk substitute (fed ad lib) satisfied a nutritional requirement not catered for by the limited amount of milk the sow was giving to her pigs.

These findings have indicated the need for the feeding of a supplement to the young pig during the suckling period and particularly after the 2nd-3rd week of lactation. The provision of supplementary feed for suckling pigs in an area of the pen called a "creep", to which the litter, but not the sow, has access is now commonly practised in many countries. Development of

- Line 1: Energy intakes of early weaned pigs which reached 45 lb at 8 weeks of age.
- 2. Energy intakes from milk and creep feed of sow reared pigs which reached 38 lb at 8 weeks.
- 3. Estimate of energy requirement from milk + creep for pigs reaching 40-45 lb at 8 weeks of age.
- 4. Mean energy intakes from sow's milk over 24 recorded lactations.

DAILY
INTAKES
(PER PIG) OF
DIGESTIBLE
CALCS.

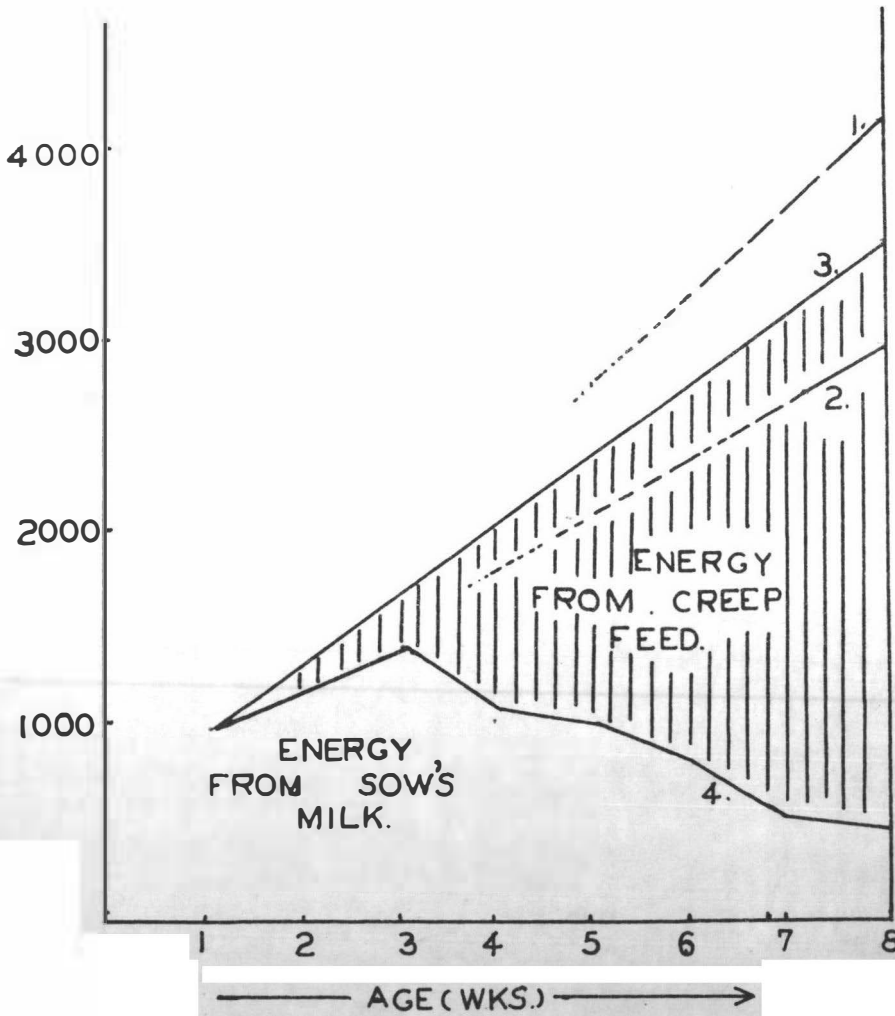


FIG. 2.

Requirements for digestible energy from sow's milk and creep feed (Lodge and Lucas, 1958).

suitable supplements has stimulated much interest in recent years, in the specific nutritive requirements of the young pig and into the nature of the delicate nutritional balance between piglet and dam.

From an energy efficiency point of view Lodge (1959) in U.K., and Smith (1959a, b; 1960) in N.Z. found that provision of supplementary feed to suckled pigs, resulted in heavier pigs at weaning and that the intake of supplementary feed by the litter led to an increase in the energetic efficiency of litter production. Smith (1960) showed that this higher efficiency was due (a) to the lower weight losses of the sows (dams of litters receiving no supplement produced more milk over the last four weeks of lactation and lost more weight); and (b) to the greater efficiency with which the creep fed energy obtained directly from the trough, was converted to weight gains by the litter, compared with the feed energy which was fed through the sow to produce milk for the suckers. In some earlier work Smith (1959) indicated that between 30 and 50% of the food consumed by a litter up to 8 weeks of age, could be derived from the creep feed.

In a review, Lodge and Lucas (1958) presented data from some of their studies on these energy aspects of creep feeding. Some of this data is shown in Table 1 and Fig. 2.

Several workers have referred to the relationship between creep consumption by a litter and their milk intake from the sow, as a compensatory relationship. Whether this is in fact the case and whether such an effect acts automatically, is open to question.

Most of the factors governing the amount of creep food eaten by a litter and the time that the litter starts eating it, are still unknown. It is believed that a number of factors such as the shape of the lactation curve as well as palatability of the creep food, and site of the creep trough, are important.

TABLE 1

Energy required from creep feed. Lodge
and Lucas (1958).

Age (Weeks)	Approx. body wt. (lbs)	Energy, digestible K.cals.			Calculated Daily Amount of Creep Feed (Air Dry Basis) (lb.)
		Daily Requirements	Supplied by Sows Milk	Required from Creep Feed	
1	6	950	950	-	-
2	9	1250	1250	-	-
3	13	1625	1400	225	0.2
4	17	2000	1250	750	0.5
5	22	2375	1250	1125	0.8
6	28	2750	1150	1600	1.1
7	35	3125	900	2225	1.5
8	42	3500	800	2700	1.8

3. EARLY WEANING

During the last ten years, considerable interest has been shown in the rearing of young pigs away from their dams as a means of increasing the efficiency of the reproductive phase of pig production.

Investigations have developed along two broad lines:-

(a) The development of sow milk substitutes for the artificial raising of newborn or very young piglets.

(b) The development of dry meal mixtures for piglets weaned from 7-10 days onwards.

(a) Johnson (1948) was one of the first to produce a sow milk substitute. He was followed by many others. From a practical point of view however, the artificial raising of very young pigs has been restricted to litters threatened by starvation in the event of death or illness of their dam. Dyrendahl (1953, 1958) reported that artificial raising of very young piglets had given results comparable with those of natural methods. The feeds used however, were of very high nutritional value and in consequence, expensive. In addition the younger the pigs, the higher the standard of hygiene and management required.

Furthermore Dyrendahl et al. (1958), Grummer (1953) and others showed that the majority of sows, even after their litters had been removed at a very early age, would not conceive until approximately 3 weeks after parturition.

The piglet is dependent on the colostral transfer of antibodies (Foster et al. 1951). Thus piglets that have not suckled their dam, are very susceptible to disease. The newborn pig, which is devoid of antibodies, absorbs them within minutes of obtaining colostrum. Catron et al. (1958) found that most antibody transfer took place during the first 12 hours of the piglet's life. Under artificial rearing conditions (from birth) this would be a difficult problem to overcome.

(b) From a practical point of view, weaning at a later stage, when it is possible to dispense with sow milk substitutes and feed a dry meal mixture, is a more satisfactory proposition. The purpose of developing early weaning techniques from 7-10 days of age and onwards has been to take advantage of a shortened nursing period. Early removal of piglets from their dam can increase the food conversion efficiency of the reproductive phase.

Smith (1960) supported this argument with data showing that feed consumed by the litter directly from the "creep" or trough was converted twice as efficiently as that fed to them through the sow. In addition sow weight losses were reduced as the lactation period shortened and the sows could consequently be kept on a more uniform plane of nutrition, reducing the amount of feed required during the dry period. Smith produced further evidence to show that when lactation efficiency alone was being considered, the feed energy required per pound gain for litters of ten pigs, was reduced by as much as 30% as a result of weaning at 20 days instead of the traditional 56 days. Even when the minimum energy requirements for gestation were added to those for lactation, there was a 21% saving in feed energy per pound of gain.

It is of equal importance in explaining the reasons for these results, to remember that early weaning can coincide with the period of falling sow milk energy, which occurs during the 2nd or 3rd week of lactation.

Furthermore an early weaning programme shortens the period between farrowings and it is thus possible to get an increased

number of litters per sow per year.

Early weaning holds a special place in pig rearing under New Zealand conditions. These may be summarised as follows:-

(Smith 1952, 1960)

- i. Dairy by-products constitute the bulk of feed used for pigs in N.Z.. Due to the perishable nature of these products there must be simultaneous production and consumption if their full value is to be exploited.
- ii. Due to the seasonal production of these products irrespective of the requirements of the pig herd, stock numbers must be adjusted to meet fluctuations in feed supply. Early weaning allows earlier farrowing of summer litters, giving a greater chance for these pigs to be marketed before milk supplies fall at the end of the season.
- iii. The savings effected by an early weaning programme, in food requirements over the reproductive phase, allow extra stock to be carried.

Very early weaning is subject to the difficulties already mentioned. Grummer (1953), summarised present knowledge by stating that the earlier weaning took place the higher were the requirements for nutrition, environment and care. Under most farm conditions it was impracticable to remove litters from their sow earlier than two or three weeks after parturition. There is general agreement in the scientific literature (Braude, 1954, 1957; Lodge and Lucas, 1958, Smith 1952 and many others)

that 2-3 weeks of age is satisfactory for weaning. Many commercial producers in the U.K., in N.Z. and other countries have found however, that later weaning at 3-5 weeks of age is preferable under their conditions of management.

With increasing age, the requirements of young pigs for feeds of high nutritional value is reduced and the economic factors governing raising are much more favourable than is the case with newborn piglets. On the other hand the longer weaning is delayed, the smaller the advantage of the technique. The "point of balance" depends on economic factors and management standards.

4. THE SPECIFIC NUTRITIVE REQUIREMENTS OF THE YOUNG PIG.

The development of early weaning as a practical method of rearing litters has awaited, and followed, the evolution of baby pig rations. (Smith, 1960)

The studies described in section 2 of this review have also led to much of the present interest in baby pig nutrition. Developments in the general field of animal physiology and nutrition have made further contributions. While an appreciable amount of information on the subject is available however, this particular field of research is by no means exhausted.

Limitations of Feeding Requirements

Braude (1958) in reviewing current knowledge on feeding standards stated that:-

....Feeding standards of today are one of the most misinterpreted concepts in animal husbandry. With the advancement of the science of nutrition in general...it

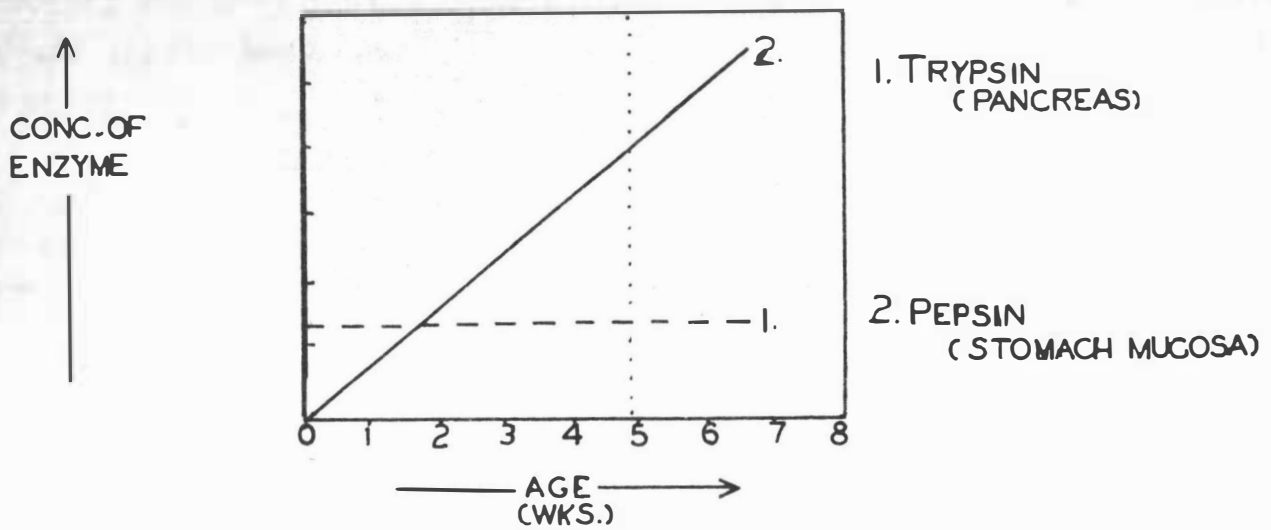


Fig. 3. Proteolytic enzyme development in the young pig (Catron, 1957).

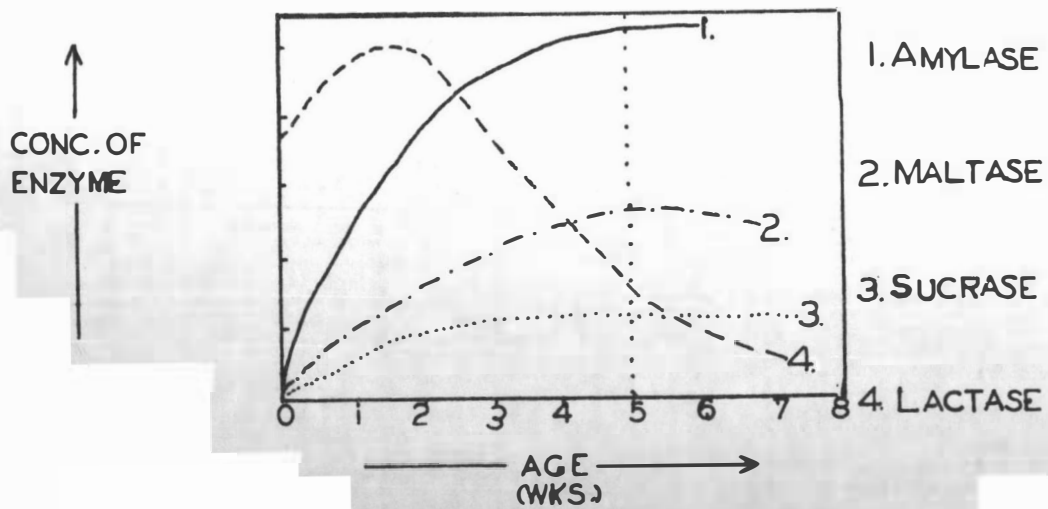


Fig. 4. Amylolytic enzyme development in the young pig (Catron, 1957).

has become abundantly clear that no single yardstick can cover all the contingencies that may arise in practical feeding....Feeding standards should be treated only as guides....with the interactions between nutrition and either hereditary, environment, management, stage of development or type of production and superimposing on all of these the economics of feeding, it becomes obvious that no feeding standards are capable of covering every possibility.

(a) Protein

Reports in the literature on protein requirements vary considerably. This is not surprising since a number of factors affect these requirements. These include (apart from environmental factors or disease, which may restrict growth):-

- i. The development of the digestive enzyme system.
- ii. The amino acid composition of the feedstuff and the availability of these acids.
- iii. The ratio of protein to the total energy content of the ration.
- iv. The source of dietary constituents.

- i. The development of the digestive enzyme system.

Catron (1957), claimed that in pigs of less than 5 weeks of age, the proteolytic enzymes are poorly developed and remain relatively inactive until the pH of the stomach falls below a level not normally reached until 20-30 days of age. Casein was the protein of choice for pigs at least prior to 5 weeks of age. This is shown diagrammatically in Fig. 3.

Catron further reported that the fortification of the diet

with proteolytic enzyme extracts, improved the digestibility of the protein. Calder et al. (1959) and several other workers were unable to confirm these findings and expressed doubt as to whether the complex digestive processes could be so simply speeded up.

ii. Amino acid content.

Rose (1948) classified the 10 essential amino acids required by the pig. Braude (1953) indicated that the modern use of the term "protein supplement", implies an ingredient which is called upon to meet the animals amino acid requirements. In the past, protein requirements have often been confused with accessory substances which can, with modern developments, be supplied separately.

Very few amino acid requirements have been confirmed for pigs under 20 lb liveweight. The problem is further complicated by interactions between different amino acids. Amino acids should be present in the diet not only at levels to meet minimum requirements but also in correct proportions to each other, as well as in a form which is available to the animal.

iii. Ratio of protein to the total energy content of the ration.

Sewell et al. (1953) found that the nutritive economy during the early stages of growth depended primarily on a correct adjustment between the proportion of protein and the total energy supplied. They found the most efficient and rapid gains occurred on diets with a nutritive ratio approaching 1 : 3.

(Maynard (1956) defined nutritive ratio as:-

$$\text{N.R.} = \frac{(\text{digestibility fat} \times 2.25) + \text{dig. N.P.F.} + \text{dig. Cr. Fibre}}{\text{dig. protein}}$$

McCrea and Tribe (1956), developing semi-synthetic diets for very young pigs (1-3 days old) fed three different levels of protein (mainly from casein and dried milk, - 20, 27 and 34% protein). Maximum weight gain to 56 days of age occurred on the 20% level (av. weight 35.7 lbs) and lowest gain on the 34% protein level (av. weight 32.5 lbs). When 10% of the sucrose in the 34% protein diet was replaced by lard these animals showed a 56 day weight of 39.4 lbs. The authors concluded that the calorific density of the diet had a considerable influence on the optimal protein level. They also suggested that the different calorific density of the diets used, and the biological values of the protein, used by various workers partially accounted for the lack of agreement in the results obtained.

iv. The source of dietary constituents.

Lodge and Lucas (1958) approached the problem of summarising existing knowledge on protein requirements by sorting the data out according to the type of diet used in the trial concerned. They found that these estimates fell into two categories - those where the protein was from cow's milk or casein ("synthetic" diets) and those where mixed proteins had been used ("non-synthetic" diets). On this basis the crude protein estimates for the synthetic diets were only about 66% of the non-synthetic diet estimates. Even so, the former were considerably above the

40-45 g. crude protein per 1000 digestible K. calcs. in sow's milk up to the 6th week of lactation. On an estimated digestible protein basis, the synthetic diets contained only 78% of that in the non-synthetic mixed protein diets.

The author's inferred from this that the value to the young pig of the digested protein of cow's milk was higher than that of the digested protein of a mixed ration containing dried cow's milk, fish meal or soya bean meal and cereals.

Catron's work, quoted earlier (see also Fig. 3) supported these findings. He suggested that milk proteins could be digested by trypsin with little or no help from pepsin. This was not true of plant proteins and thus young pigs were apparently unable to utilize soya bean or possibly fish and meat meal proteins until they were old enough to secrete pepsin in an active form. (Pepsin reaches its maximum active stage at about 6 weeks of age.)

The above factors account in no small part for the diversity of results obtained by different workers in recent years. Some of these are summarised in Table 2:-

TABLE 2

Summary of some baby pig protein requirement determinations

Authors	Age of Pig	Source of Protein in Diet Used.	% Protein for most efficient gains
Reber (1953)	3-4 weeks } 8 weeks }	Vitamin extracted casein	41% 20%
Sawell <u>et al.</u> (1953)	2-30 days	Soya bean protein	32%
Becker <u>et al.</u> (1954)	1-4 weeks } 5-9 weeks }	Skim milk	22% 12%
Crampton & Ness (1954)	10 days	Skim milk, soya bean, fish meal	30%
Jensen <u>et al.</u> (1957)	2-8 weeks	Maize and casein	17%

Lodge and Lucas (1958) summarised requirements for crude protein from mixed sources for early weaned pigs as follows:-

TABLE 3

Minimum crude protein requirements in meal mixtures containing fishmeal, soya bean meal, dried milk and cereals.
Lodge and Lucas (1958)

Liveweight (lb)	Crude protein	
	G. per 1000 Digestible K. Cal.	G. per 100 g. Dry Matter
10-20 (lb)	73	28.7
20-35 (lb)	58	21.5
35-45 (lb)	49	18.1

(b) Carbohydrates

The work of Porter and Dollar (1957); Bailey, Kitts and Wood (1956); Cunningham and Brisson (1957); Catron (1957); and Lodge and Lucas (1958, 1959) has shown that the development of the digestive enzyme system also plays an important part in carbohydrate digestion in the young pig.

In view of the high level of lactose in whey powder, carbohydrate digestion is of special interest in relation to the present trial.

Fig. 4 compiled from the Iowa data (Catron, 1957) shows the development of the amylolytic enzyme system. It follows that

this has an important bearing on the type of carbohydrate that should be fed at different stages of the animal's life.

Glucose and galactose are readily utilized by baby pigs and have been widely used as sources of carbohydrate in their diets.

Johnson and James (1948) found that baby pigs could be started very successfully after a preliminary nursing on colostrum with purified diets containing either glucose or lactose as the source of carbohydrate.

Most workers now support the contention that intestinal lactase activity is high at birth and declines sharply after the 3rd-4th week. This would follow, since lactose is the natural carbohydrate of milk.

Dollar et al. (1957) confirmed these findings and further reported that after about 10 days of age, amylase, sucrase and maltase become increasingly active and consequently starch, sucrose and maltose may be included in greater amounts in the diet.

Becker et al. (1954) found that sucrose and fructose were the least satisfactory sources of carbohydrate during the first week of life. The increase of sucrase activity with age, allowed pigs of 7-14 days of age to utilize 10-20% of sucrose in their diet. Becker also found that between the age of 7-35 days, glucose, dextrin and maize starch gave equal rates of gain when incorporated in the diet. This would support the theory that increasing quantities of starch (a cheaper source of carbohydrate) can be included in the diet as the pig gets older.

Lodge and Lucas (1958) reported that glucose was the only sugar which was tolerated by pigs of all ages, from 2 days to 8 weeks. They used diets with a glucose content of up to 60% successfully.

(c) Fat

It has been established that in spite of the ability of the pig to build fat from other nutrients, such as protein and carbohydrate, some fat is essential for normal development.

(Braude 1954)

There is little data on the minimum fat requirements of the young pig. In their review on pig nutrition, Lodge and Lucas (1958) indicated that most of the synthetic milk diets reported to have been used with very young pigs, contained approximately 27% of lard on a dry matter basis. In dry meals for pigs of over 10 lb liveweight, rises in fat level generally improved feed conversion efficiency, but over about 13%, increasing fat levels tended to produce an oily diet which made cleaning of equipment difficult.

Several workers have supported the theory that the level of protein in the diet has an important bearing on the utilization of fat. Speer et al. (1954) for example used a dry ration containing 24% protein and 7% fat successfully. Crampton and Ness (1954) obtained good results from a diet containing 30% protein and 8% fat. Mention has already been made of the contribution fat can make to the calorific density of the diet and the consequent utilization of protein.

Lloyd and Crampton (1957) at MacDonald College, showed that an inverse relationship existed between the molecular weight of fatty acids in fats and oils and their digestibilities in young pigs. They also showed that seven week old pigs could digest fat better than 3 week old pigs. This could possibly be explained by the work of Kitts et al. (1956) which showed that pancreatic lipase activity in pigs was of a high order at birth. They postulated that the increase in digestibility of fat with advancing age was due to an increase in bile secretion, which resulted in an increased absorptive capacity for fat.

(d) Minerals, vitamins and other growth factors.

Much work is still needed to elucidate the specific requirements of the young pig for minerals, vitamins and other growth factors. While details of deficiency symptoms, in many cases, are known, minimum requirements to prevent these symptoms appearing and to maintain healthy growth, are not at all clear.

5. THE USE OF WHEY POWDER IN MIXTURES FOR YOUNG PIGS.

Table 4 shows an analysis of a sample of unneutralised lactic casein whey powder, as used in the present trial.

TABLE 4

Henneberg analysis of unneutralised lactic casein whey powder. (Massey College Biochemistry Dept. 1959.)

Constituent	Air dry %	Oven dry %
Dry Matter	89.7	-
Ash	10.9	12.2
Protein	12.9	14.4
Fat	1.2	1.3
Crude Fibre	-	-
Nitrogen Free Extract	64.7	72.1

TABLE 5

Some data on constituents of unneutralised lactic casein
whey powder (Dairy Research Institute 1961)

(a) Mineral content:-

Mg.	Ca.	Na.	K
0.17%	1.86%	0.65%	2.40%

(b) Lactose and lactic acid content:- (approximate)

Moisture	:	10%
Protein	:	12%
Ash	:	10%
Lactic acid:		8%
Lactose	:	<u>60%</u>
		<u>100</u>

From Table 5, it is clear that whey is a rich source of lactose and contains about 60-70% of this sugar on a dry matter basis. That lactose, as the natural carbohydrate source of every mammalian infant, might hold a special place in the feeding of young animals, was noted by Duncan (1955) reviewing the physiological effects of this sugar. Lactose has however, certain physiological properties not characteristic of the other disaccharides or sugars. These may partly account for the diversity of opinions which exist in the literature, as to the value of lactose in foodstuffs.

Some of these physiological differences were listed by Duncan (1955):-

1. Some are due to the liberation of galactose when lactose is hydrolysed, some due to the other hexose sugar, glucose, which is also liberated on hydrolysis. (Both glucose and galactose can be utilized by the baby pig - see back.)
2. Some are specific to the lactose molecule itself.

These include: the effect of the sugar on gastro-intestinal

motility causing a beneficial laxative effect in some cases and diarrhoea (usually when fed in excess) in others; its favourable influence on the absorption, retention and utilization of calcium, phosphorous and magnesium; its value as a lipotropic agent and sparer of choline; its possible role in maintaining the natural intestinal flora in young animals; provision on hydrolysis of the energy-producing sugar, glucose and the "structural" sugar, galactose, which may be important in the formation of the cerebrosides and mucopolysaccharides of the nervous system; and possible others.

(a) Overseas

A number of research stations overseas have interested themselves in studies of whey feeding to pigs. With respect to the use of whey powder in rations for young pigs, reports in the literature are numerically insignificant.

There has been a hesitancy in the past to feed high levels of dried whey to pigs due to reports of ensuing diarrhoea. For example Krider et al. (1949) reported the occurrence of diarrhoea in weanling swine fed 4% to 8% of a dried whey product. Lactose was suggested as the causative factor. In recent years however, work on the levels of whey powder tolerated by pigs of different ages has thrown some light on the nutritive value of the product.

i) As a replacement for other carbohydrates in the ration.

Becker et al. (1954) reported a series of tests in which

the nutritive value of various carbohydrates was determined with pigs at different ages. In the baby pig, lactose fed at a level of 56.6% of the diet, gave a superior rate and efficiency of gain, to either glucose or starch, without any evidence of diarrhoea. Likewise with the finishing pig, 25% of its diet as lactose promoted satisfactory rate and efficiency of gain with the absence of diarrhoea.

In a further investigation, Becker et al. (1957) studied the effect of high levels of dried whey on pigs at various stages of growth. Dried whey fed to baby pigs weaned at 14 days of age, at levels of 0, 30 and 60% of the diet, had no significant effect on the rate or efficiency of gain, nor was there any evidence of a whey-induced diarrhoea during the four week trial period. With fattening pigs fed a semi-purified diet, a 60% whey ration produced severe diarrhoea and markedly depressed food intake and growth rate. Some diarrhoea occurred on a 40% whey powder diet, but growth rate was not significantly slower than those without the product in their diet.

In a subsequent group feeding trial, substitution of 20 and 30% dried whey in a practical ration of corn and soya bean meal fed ad libitum to weaning pigs, seriously reduced food consumption and growth rate during the 34 day trial period and produced a moderate diarrhoea.

Becker concluded that the pig had the ability to utilize higher levels of dried whey, without deleterious effect, than some workers had reported. The maximum advisable feeding rate appeared

to depend primarily on the remainder of the diet and the age of the pig.

Comparing the results of this whey powder trial with the results from the trial where lactose had been fed, the authors felt that the differences in response to the high levels of dried whey could not be explained solely in terms of the level of lactose fed. While lactose and dried whey tolerance showed an indirect relationship with the age of the pig, these tolerances were probably established by different mechanisms.

Daniel and Harvey (1947) suggested a possible mechanism involved in fixing dried whey tolerance. They reported that dialysis of whey produced a beneficial effect on its nutritive value in rats. In addition whey ash depressed the growth of rats fed dried whole milk and dialysed whey as the source of protein. These observations implied that the inorganic fraction of dried whey might be the growth retarding factor. The response from feeding high levels of whey might have depended upon the mineral composition of the remainder of the diet.

Meade et al. (1957) when studying dry meal formulas for baby pigs, used rations containing 10% of sugar with whey at levels of 5 to 30%. This addition of whey increased growth rates of the pigs from 3-11% respectively compared with those without whey powder in their diets.

ii. As a replacement for carbohydrate and protein concentrates.

Hudman et al. (1956) reported that lactose fed to baby pigs with soya bean meal, and sucrose with milk protein gave best growth

responses. They suggest that from the analyses listed by Morrison (1956) both dried skim milk and dried whey must be considered as a source of lactose, since on an average these products contain a high quality protein.

Crane (1953) observed that weanling pigs gained more rapidly on a ration containing 40% dried skim milk than on one containing 35% dried skim milk and 10% dried whey.

Hanson et al. (1957) claimed that dry skim milk improved a 50% dried whey diet for young pigs.

Lloyd and Crampton (1958) described a trial in which they attempted to replace the skim milk powder in a baby pig ration by a mixture of whey powder and meat meal. They considered that whey powder, which contains protein of a similar origin to skim milk, was possibly the less costly ingredient. According to the authors from the point of view of amino acid distribution, the protein of whey powder is as good as the protein of skim milk powder but the total content of the former is considerably lower than the latter. It was thus hoped to provide a similar protein level as that of skim milk by using a 50/50 mixture of whey powder and meat meal. Furthermore it was considered that a methionine deficiency would still exist in this mixture and quantities of this amino acid were included in some treatments.

This gave a ration with a 30% protein level and one with a 26% protein content. The overall substitution gave decreased feed conversion efficiencies and rate of gain and in no individual case did the addition of methionine significantly increase rate

of gain or F.C.E. Furthermore rate of gain of pigs on rations containing 26% protein was significantly greater than that of the 30% protein fed animals, but in terms of F.C.E. and nutrient digestibility, both levels of protein resulted in similar values. This result does indicate the effect of the other nutrients in the diet on the value of whey powder supplementation.

This reference is of particular importance to the present study due to the successful use of chromium oxide as a marker substance in the determination of digestibility. The authors presented digestibility data which threw some light on the reasons for the failure of the meat meal and whey powder rations to support growth to the same extent as the skim milk powder rations. The lower apparent digestibility of the crude protein and total carbohydrate in the whey powder rations at both 3 and 7 weeks of age contributed to the lower digestibility of both dry matter and gross energy thus decreasing the feeding value of this mixture.

The authors concluded by referring to the Iowa work (quoted earlier) on the development of the amylolytic and proteolytic enzyme systems, in support of the superior results obtained with the skim milk powder supplemented rations. Lewis et al. (1955) at Iowa had reported that the protein and carbohydrate of choice for pigs, at least prior to 5 weeks of age, was casein and lactose respectively.

Danielson et al. (1960) fed different combinations of dried skim milk powder and dried whey powder to baby pigs. Greatest

gains and food conversion efficiencies were made on a ration containing 30% dried skim milk and 10% dried whey. Gains and F.C.E. decreased when the whey powder was increased above this 10% ration. Pigs fed starter rations containing dried whey made greater gains during the subsequent period than those fed on a 40% dried skim milk starter ration. This work further emphasised the effect the remaining ingredients in the ration had on the overall nutritive value of whey powder. The authors concurred with much of the previous work regarding the value of lactose as the contributing compound to the greater efficiency of milk products to sustain healthy and efficient growth over the corn, soya bean or plant type of diet. They also offered the suggestion that not all this improvement could be attributed to lactose. This was evident from the reduction in gains and feed efficiencies observed when dried whey levels were increased above 10%, and was believed to have been due to the total protein coming from the milk product. Soya bean oil was used to keep the protein level constant and consequently as the whey powder level increased so the total soya bean protein increased.

(b) New Zealand

A growing whey disposal problem confronts the N.Z. Dairy Industry at the present time. New Zealand in the 1959-60 season was second only to the Argentine in world casein production (N.Z. Dairy Board Annual Report 1960). From figures obtained from Dairy Board Reports, Owtram (1961) and Henson

(pers. comm. 1961), it would appear that the production of cheese and casein whey has increased from about 975,000 tons to 1,730,000 tons annually over the past twenty years. This has primarily been due to the increase in casein production. This production of whey is far in excess of its demand for stock feeding purposes, and consequently a substantial proportion runs to waste. There is little economic pressure on dairy farmers necessitating them to fully exploit the value of dairy by-products. Due to the problems of river and stream pollution when they are used for whey disposal, pressure is being put onto Dairy Companies and Producer Boards to find alternative means of disposal.

Information permitting full exploitation of whey and whey products in this country is very limited. For this reason the Massey Research Figgery has been engaged for a number of years in a series of trials aimed at obtaining information on the utilization of whey and whey products by the pig.

A number of Dairy Companies have been producing small quantities of whey powder in an effort to find a means of disposal of whey as a stock food. This has principally been of the lactic casein variety.

The N.Z. Co-operative Dairy Co. (pers. comm. 1961) produced 109 tons of lactic casein whey powder in the 1957-58 season, 280 tons in 1958-59, and 360 tons in 1959-60. Concentration is expensive (powder must be sold at £35-40 to cover costs of production), little progress has been made in finding a suitable export market and local sales are very variable.

However, whey powder is probably cheaper in N.Z. relative to the price of cereals, compared with the situation in other countries and for this reason there is greater interest in this country in using relatively higher proportions of it, in pig rations.

A few trials with whey powder have been carried out at the Massey Piggery and the results of these are summarised in the following section. (Dunkin, pers. comm. 1961)

1. VALUE OF WHEY POWDER FOR FATTENING PIGS

(a) In an all meal ration

During 1958 an individual feeding trial was carried out in which lactic casein whey powder, supplemented with three different daily meal allowances (I, $\frac{1}{2}$ lb; II, 1 lb; III, 2 lb) was compared with an all meal ration. Pigs were fed the experimental mixtures from an initial liveweight of 47-50 lb until all animals weighed at least 140 lb liveweight. For the overall trial period whey powder constituted 84%, 71% and 43% of the total food eaten in treatments I, II and III above.

From 48-110 lb liveweight there was no significant differences in growth or food economy between the groups on the three whey powder treatments but all were significantly superior to the control group. Some scouring occurred in the earlier stages of the trial, especially in the case of the group of pigs on the highest whey intake. From 110-140 lb liveweight, the groups receiving the two highest levels of whey powder lagged

behind the controls and those pigs on the lowest whey powder treatments.

Because it was considered that the control's performance was sub-normal during the early phase of the trial, the trial was repeated, the only modification being that the control group was fed a mixture containing 10% whey powder so that there was no ^{qualitative} quantitative differences between the treatments. Over the liveweight range 48-110 lb the average growth rate for all four groups was very similar, confirming the results of the previous trial.

It was concluded that up to light pork weight, casein whey powder supplemented by as little as $\frac{1}{2}$ lb meal daily can support a daily gain of approximately 1 lb and that up to this stage the powder was fully equivalent in feeding value, to the barley meal used. The highest whey powder treatments did have the disadvantage of increasing the rate of scouring but this was not excessive. From 100 lb liveweight onwards, the results indicated a decline in growth rate and food conversion efficiency when the basic daily meal allowance was reduced below 2 lb.

(b) As a supplement for fodder beet

When compared with barley meal as the main ingredient of two levels of meal used to supplement sliced fodder beet fed to appetite, whey powder proved to be the superior concentrate.

(c) As a supplement for liquid whey

Whey powder was compared with barley meal as a supplement

for liquid whey at two levels of supplementation, viz. $1\frac{1}{2}$ and $\frac{1}{2}$ lb per day. Both the rations containing barley meal, gave faster growth rates than either of the whey powder rations, over the 15 week trial period.

(d) As a supplement for skim milk

In an individual feeding trial with 12 pigs, skim milk was fed to appetite and supplemented with a daily allowance of either 1 lb of barley meal or 1 lb whey powder per pig. After a 50 day trial period from 80 lb liveweight, pigs receiving whey powder averaged 146.3 lb liveweight, while those fed barley meal averaged 157.3 lb.

2. USE OF WHEY POWDER IN EARLY WEANING MIXTURES

During late 1958 to mid 1959, a total of 21 litters was used to evaluate the effect of including whey powder in the meal mixtures of pigs weaned at three weeks of age. Over the trial period seven litters were placed on each of three experimental treatments. Starter mixture was fed to the litters from 7 days of age, weaning took place at 21 days of age, and a "carry on" mix was fed from the 32nd to 56th day.

The principal ingredients of the experimental "starter" and "carry-on" meal mixtures are shown in Table 6.

TABLE 6.

Experimental feed mixtures (principal ingredients only). Early weaning trial (Dunkin 1959, pers. comm.)

Principal Ingredients Only	Treatments					
	I		II		III	
	Starter	Carry-on	Starter	Carry-on	Starter	Carry-on
% Buttermilk powder	60	30	40	30	40	20
% Whey powder	-	-	20	20	20	40
% Barley meal	13	45	10	25	10	15

Treatment I was in current use at the Piggery at that time and was consequently regarded as the control in this trial.

Over the 3-8 week period, the average total gains for the three groups, differed by a maximum of only 1.3 lbs. This difference was not statistically significant. The amount of meal consumed, decreased as the porportion of whey in the mixtures increased. It was considered that this was possibly due to the stickiness of the mixtures containing whey (due to its hygroscopic nature) which caused "caking" in the self-feeders and which could have had a restricting effect on intake.

3. CONCLUSIONS

From the results reported above, it appeared that whey powder was a useful concentrate food, roughly comparable to barley meal on a weight for weight basis. Its precise nutritive value depends upon the other ingredients of the ration, being greatest when used in rations containing no other milk products.

PART II: THE ESTIMATION OF APPARENT DIGESTIBILITY

1. INTRODUCTION

Crampton (1956) defined apparent digestibility of some constituent nutrient of a feed, as that fraction of the intake that was not recovered in the faeces. It is this unrecovered fraction expressed as a percentage of the total intake that is the apparent digestibility or coefficient of digestibility of that fraction.

While a simple comparative feeding trial may compare the results produced when a certain ration is fed, in terms of growth rate, food conversion efficiency, or some other productive process, it fails to answer the question as to why one particular feed was better than another. The estimation of apparent digestibility partly answers this question by determining the relative degree to which the individual nutrients in the ration are "digested".

Mitchell (1942) noted that there were marked differences among feeds and rations in the extent to which nutritive material was lost in the digestive process and among different species of animals in which digestive efficiencies differed. Even among animals of one species, the completeness with which nutrients were utilized in digestion showed considerable variation.

In a more recent review Crampton (1956) pointed out that digestion coefficients are not constants and consequently total digestible nutrient values are not constant. Maynard (1956) listed several factors which affected digestibility. These

included the nutritive ratio of rations fed, the ingredients of the ration, nutrient interrelationships, speed of passage of food through the digestive system, physical state of food fed and several others.

It is important therefore to measure digestibility accurately and to have some knowledge of its limitations. Despite these limitations digestion coefficients remain distinctly useful. Interpretation of digestibility data has been enhanced by modern developments in the field of statistical method and experimental design.

2. MEASUREMENT: TOTAL COLLECTION METHOD v. INERT REFERENCE SUBSTANCE METHOD.

The estimation of apparent digestibility depends on an accurate record of feed intake and faeces output. Methods involving total collection of faecal matter by means of a bag strapped to the animal have been used for many years. They are, however, cumbersome and time consuming; uncomfortable for the animal and unpleasant for the worker. Measurement of feed intake depends on the type of feed used and the animals concerned. The difficulties encountered in a quantitative estimate of pasture intake by grazing animals are numerous. With swine feeds, most of which can be hand fed, the problem is not so difficult.

The modern approach has been in the development of techniques which obviate the necessity of a total collection of faeces.

These range from the use of "tracer" substances which are a natural part of the feeds used to the incorporation of "indigestible" markers into the feed. It is possible on a ratio basis and provided these substances are "indigestible" to calculate the digestibilities of feeds used or of their constituents.

Chromium oxide (Cr_2O_3) has proved an effective marker substance in digestibility studies with several animal species including the pig. Detailed reference to its use in swine nutrition studies follows.

3. THE USE OF CHROMIUM OXIDE IN SWINE DIGESTIBILITY STUDIES

(a) GENERAL

Chromium oxide or chrome green, is the most used index substance at the present time. This compound is used in industry as a colouring pigment in paints.

Crampton (1956) described index substances as materials that could be consumed by or administered to an animal, but were (theoretically) entirely inert in the digestive system and were completely and regularly mixed with the faecal material. The apparent digestibility could be determined on a ratio basis from differences in the concentration of the index substance in the feed and its concentration in the corresponding faecal output.

Where the same combination of feed is fed at all feedings (or on an ad lib basis) the index substance may be mixed in fixed proportion with the batch as a means of getting it into

the animal (as in the present trial). With rations made up of combinations of roughages and grains in differing proportions, or in diets in which the supplements and the basal feeds are fed separately or in pasture feeding trials, it is usual to administer the index substance in a capsule. The quantity to be administered will depend on the amount of feed eaten, for the concentration of the index substance in the feed must remain constant over the test period.

Most workers with swine have used a level of about 1% Cr_2O_3 (by weight).

(b) USE

Edin (1926) in Sweden, was one of the first to describe the use of Cr_2O_3 as a reference substance and later published a series of papers embodying results obtained with the farm animals he used.

Barnicoat (1928) advocated the use of inert reference materials in digestibility work and in 1942 used Cr_2O_3 as an index in a pig nutrition study. He compared this with the standard bag collection method and obtained satisfactory results both in terms of the digestibility figures and the management of the trial.

Up to this time reports on the accuracy of the Cr_2O_3 method were diverse. Bergeim (1926); Hamilton et al. (1928); Heiller et al. (1928) and Gallup and Kuhlman (1931) for example reported favourable results. In a further trial

with a variety of animals Gallup and Kuhlman (1936) suggested the method had a limited applicability while Knott, et al. (1936) reported the method constituted "a serious sacrifice in accuracy" as compared with the more conventional methods.

In a further comparative trial, Barnicoat (1945) with lambs, calves, wethers and pigs, found that in most cases the index method gave lower results than those found by the total collection method. This was particularly so in the ruminants. He believed that this was due to lower recovery of the index substance than expected. Among the factors affecting this rate of recovery, he listed:-

- i. Losses through chemical estimation of Cr_2O_3 in feed and faeces.
- ii. Loss by solution or absorption of Cr_2O_3 in the digestive tract.
- iii. Stratification of Cr_2O_3 in the digestive tract.
- iv. Retention of Cr_2O_3 in the digestive tract.
- v. The time lag between feeding and excretion of Cr_2O_3 .

That the method, with certain improvements to techniques, could be a useful one, was becoming obvious to a number of workers. It was evident that the slightly lower accuracy of the reference method over the total collection method, could be compensated for by the fact that more animals could be used.

Kane et al. (1952) and Hardison and Reid (1953) showed that

with ruminants (in this case cattle) the complexity of the digestive tracts could be expected to contribute to the uneven excretion pattern of Cr_2O_3 and its variable rate of recovery.

Schurch et al. (1952) outlined a procedure for the determination of apparent digestibility in swine and recorded data which indicated that the rate of excretion of Cr_2O_3 was much less variable than in cattle.

They used a formula:-

$$\% \text{ apparent digestibility of nutrients} = \frac{100(a - b)}{a}$$

where a = parts of nutrient (D.M., protein, ether extract, etc.) per unit index material in the food.

b = parts of the nutrient per unit index material in faeces.

(c) EXCRETION PATTERN AND DIURNAL VARIATION

A study of excretion patterns of index substances and faecal components might be expected to help assess the accuracy and usefulness of index methods as well as suggest modifications or improvements to techniques.

During recent years therefore the diurnal variation in faecal composition has received attention from a number of workers in respect to the use of insoluble markers.

Diurnal variations in the faecal excretion of Cr_2O_3 were reported by Kane et al. (1952), Smith and Reid (1955) and Hardison et al. (1956) working with cattle; Raymond and Minson (1955) and

Pidgeon and Brisson (1956) with sheep; Dansky and Hill (1952) and Mueller (1956) with poultry and Clawson et al. (1955) with pigs.

Clawson reported that excretion of Cr_2O_3 by pigs self-fed a ration in which the indicator had been thoroughly mixed, regularly varied about 5% between samples taken at 10.30 a.m. and 8.30 a.m.. Samples taken at 5.30 a.m. and 3.30 p.m. more clearly approximated the levels of Cr_2O_3 calculated for 100% recovery than samples obtained at other times.

Digestion coefficients computed from the mean concentrations of Cr_2O_3 in faecal samples taken from pigs individually during one-day periods, agreed fairly closely with those determined in a total collection trial of 7 day duration. Table 7 shows some of these results.

Clawson further suggested that a rate of recovery of Cr_2O_3 as low as 90% could result in appreciable errors if the ration or nutrient in question is of low digestibility. With swine rations it could be expected that the error in the measurement of digestibility would be greater for crude fibre than for the other fractions.

Clawson also found that the Cr_2O_3 concentration in the faeces of his animals, became relatively constant after 3 to 4 days from initial feeding of the marker.

TABLE 7

Comparison of digestion coefficients determined conventionally with those derived from use of Cr_2O_3 - ratio method (Clawson et al. (1955))

Lot No.	Digestibility (%)			
	Dry Matter		Crude Protein	
	a [*]	b ⁺	a	b
1	81	80	81	79
8	79	79	77	77
3	80	79	77	76
7	81	80	78	76
4	74	72	72	70
5	75	71	76	72
2	67	67	68	68
10	69	67	74	72
6	77	74	74	71
9	74	69	71	65

* a: Digestion coefficients determined in conventional trials of 7-day duration.

+ b: Digestion coefficients derived from use of Cr_2O_3 - ratio method; faecal samples taken rectally twice daily on 3 consecutive days and compounded by lots.

It might well be possible for the type of feeding treatment imposed on the animal, to have an affect on faecal excretion patterns. Moore (1956) investigated the faecal

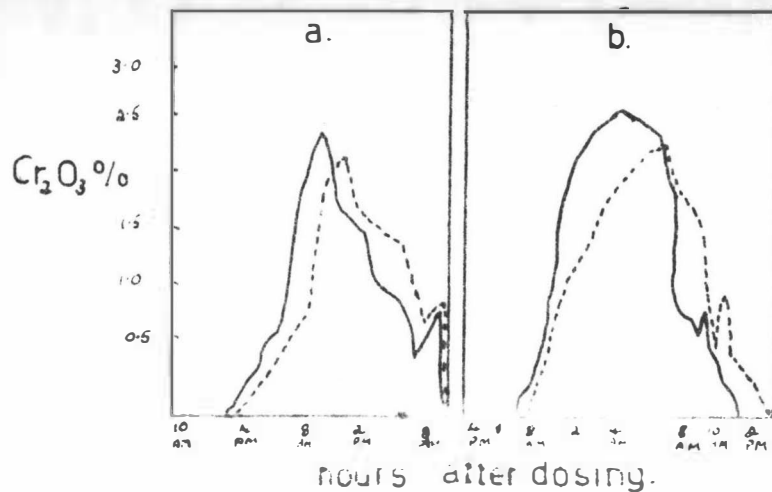


Fig. 5: Variations in the percentage of Cr_2O_3 in dry matter of faeces from two pigs after receiving single doses of Cr_2O_3 in (a) 9.30 a.m. feed and (b) 3.30 p.m. feed (Moore, 1957).

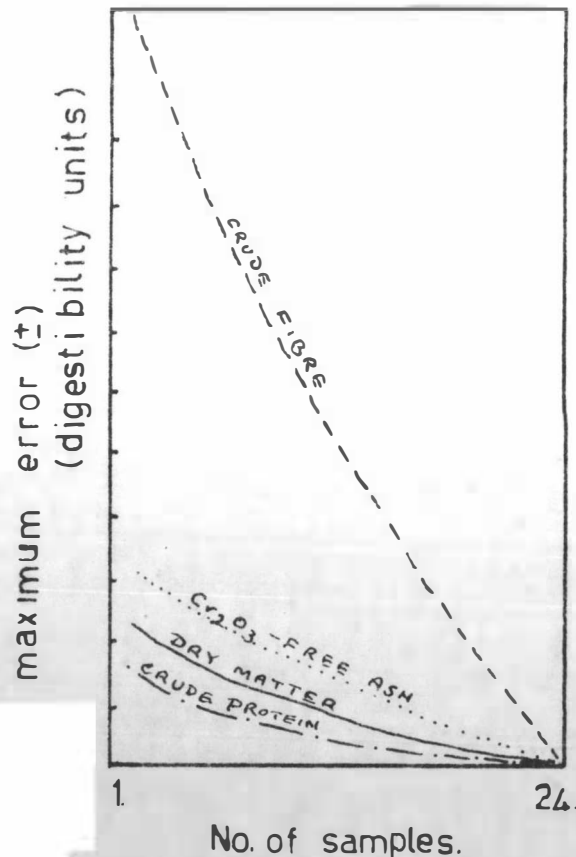


Fig. 6: Effect of the number of random samples of faeces collected, on the maximum error involved in the determination of the apparent digestibility coefficients of dry matter, crude protein, crude fibre and Cr_2O_3 - free ash (Moore, 1958).

excretion patterns of Cr_2O_3 , crude fibre, crude protein and ash.

In a series of three experiments, pigs were fed at different times of the day, viz. twice or three times daily.

Cr_2O_3 , crude protein, crude fibre and Cr_2O_3 - free ash were excreted in the faeces of pigs in regular daily patterns, which to a certain extent were characteristic for each pig and depended upon the length of time between feeds. (Fig. 5) Peaks in Cr_2O_3 concentration occurred between 24 and 29 hours after each feeding.

During the first 4 hours of digestion the rate of passage of nitrogenous material from the stomach into the small intestine was much greater than that of the dry matter. The dry matter was in turn removed from the stomach at a more rapid rate than crude fibre. Thus observed diurnal variations in faecal composition could be explained in terms of the differential rates of passage of food constituents from the stomach.

In one experiment Moore obtained recoveries of ingested Cr_2O_3 as low as 83% for no apparent reason.

In a further paper Moore (1957) evolved a reliable partial sampling technique for the Cr_2O_3 method, using the results from his previous report.

This involved the collection of a relatively small proportion of the daily output of faeces which on analysis would provide an accurate value for the digestibility coefficient of any particular nutrient.

Moore determined the effect of the number of random samples of faeces collected on the maximum error involved in the determination of the digestibility coefficients of the constituents. Results are shown diagrammatically in Fig. 6. A random sampling technique could be applied to the determination of the digestibility coefficients of dry matter, crude protein and Cr_2O_3 -free ash with a fair degree of accuracy. The sampling method consisted of collecting two samples of faeces each day, each amounting to about 10% of the total faeces for the day. Cr_2O_3 was, as in the previous trial, incorporated in the diet at a level of 1%.

To obtain a reliable value for the digestibility of crude fibre however, the number of random samples that must be taken, would amount almost to a complete collection of total daily faecal production. Moore found that an 80-90% collection of the daily faecal production was required to reduce the error to the vicinity of ± 2 digestibility units. He also calculated that with the conventional total collection method, because of the problem of quantitative faecal collection, a loss of 10% of the faeces would introduce a positive error of + 7.7 digestibility units.

Moore explained the above trends in terms of the diurnal variations of the digestibility coefficients as found in his previous trials. Diurnal variations were greatest for crude fibre digestibility coefficients.

In discussing the most suitable times of sampling, Moore

pointed out that faecal excretion patterns depended on the method of feeding, types of feed used and on the individuality of the pig. Unless the patterns were known for any particular combination of these factors, it would be difficult to predict a suitable time of the day in which faeces should be sampled.

The method does however, allow the use of more animals, in which case many of the variations observed can be compensated for.

In contrast to Moore's study, with hand-fed pigs, Horvath (1958) observed faecal patterns in swine which were self-fed. Whereas Moore found three peaks in excretion of faecal constituents when his animals were fed three times a day, Horvath found that in self-fed animals diurnal fluctuations overlapped with the increased frequency of eating, thus minimising variations in composition. He further suggested that any differential rate of passage, through the stomach would diminish with the mixing of food constituents as they passed through the upper large intestine.

PART III: THE HENNEBERG ANALYSIS OF FEEDS AND
OTHER CHEMICAL PROCEDURES INVOLVED IN NUTRITION
STUDIES

1. HENNEBERG ANALYSIS AND ITS LIMITATIONS

Devised at the Weende Experimental Station in Germany in 1860, the Henneberg analysis is the most generally used chemical scheme for describing foodstuffs, in spite of the fact that the information it gives in many instances, may be of the uncertain nutritional significance and often misleading.

According to the system a feedstuff is partitioned into six fractions: water, ether extract, crude fibre, nitrogen free extract, crude protein and ash.

Crampton (1956) in his book "Applied Animal Nutrition" draws attention to the limitations of the Henneberg system.

The Henneberg analysis is not as is sometimes erroneously supposed, an analysis of the nutrients of the food. Each of the components, except water, represents a combination of substances, some of which are nutrients or combinations of nutrients and some which are of no nutritional value to the animal at all---it is an index of nutritive value only because the fractions that it isolates are correlated with some of the properties of feeds that have nutritional significance.

It has long been recognised that digestibility of nutrients in feeds is related in part to chemical composition. Schneider (1952) stated that any increase in the accuracy of predicting digestibility coefficients could only occur when more information was available from digestibility experiments

in which the chemical analysis was more precise than the Henneberg analysis. An increasing number of workers are now carrying out a more complete analysis of the components of feedstuffs. Since these methods are often more difficult and time consuming than the Henneberg, their value has to be carefully studied.

The criticisms of Crampton (1956) on the Henneberg analysis can be summed up as follows:-

The difficulties lie:-

- (a) in demanding something from the analysis that with our expanding knowledge of nutrition we think desirable, but which the scheme was never intended to give.
- (b) in our failure, because of uncritical or erroneous thinking and deduction, to properly interpret the figures this analysis yields.

Modern knowledge of nutrition has been supplementary to digestibility data derived by the Henneberg, rather than a replacement for it.

2. THE ESTIMATION OF CHROMIUM OXIDE

The accurate estimation of the concentration of Cr_2O_3 in feeds and faeces where it is used as a digestibility index is obviously vital, if reliable estimates of digestibility are to be obtained.

Owing to certain facts which came to light during the present trial while attempting to standardise an analytical

procedure for determining Cr_2O_3 concentration, a review and discussion of this topic will appear in Chapters IV and V.

3. GROSS ENERGY DATA

In relating methods of expressing nutrient requirements to pig nutrition Part I of this Review indicated that with a well balanced ration and healthy animals in a good environment, that which limits growth is the intake of digestible energy.

Lodge and Lucas (1958) suggested that if energy intake were reduced the growth rate would be slower and in consequence, the requirements for the other nutrients would be less. It would appear therefore that a logical measurement for many, although not all, (e.g. minerals, vitamins) nutrients would be in terms of available or digestible energy.

Maynard (1956) recorded that the expression of a feeding standard in terms of the energy value of a food was useful, because the largest function of food was to furnish energy for body processes and to help form the non-nitrogenous, organic matter of tissues and secretions.

Many different measures of food energy exist, e.g. total digestible nutrients (T.D.N.) digestible energy, starch values, metabolizable energy. No measure of useful fuel energy can be exact in its application. Like most other feed standards, many variables are involved (particularly in drawing the line between the total amount available and the actual amount

utilized by the animal.) The field is however, an important one for research.

A Bomb Calorimeter was available in the present trial, for the determination of gross energy of feed and faeces. While appreciating that gross energy figures do not account for certain energy losses during metabolism of feeds, it was considered desirable to study a few gross digestible energy figures in the hope of finding some general relationship applicable to the results of the trial.

CHAPTER III

EXPERIMENTAL

- I: INTRODUCTION
- II: MATERIALS AND METHODS
 - PART 1: Preliminary Trial
 - PART 2: Main Trial
- III: STATISTICAL METHODS

EXPERIMENTALI. INTRODUCTION

The trial to be described, was carried out between June and September 1959 and the laboratory work during most of 1960.

From June to the early part of July 1959 a preliminary trial was conducted with a small number of animals. As this was the first time that a trial with young pigs had been carried out in the test fattening house, the purpose of the preliminary trial was to examine experimental techniques, to test equipment and to standardise laboratory analytical procedures, which might be used in the main trial.

The main trial was carried out from mid July to early September, 1959. Over a 5-week test period, piglets weaned at three weeks were fed the experimental feed mixtures.

Experimental design and management of the preliminary studies are described in Part 1 of Section II of this Chapter and that of the main trial in Part 2.



Fig. 7 Interior view.

TEST HOUSE



Fig. 8 Exterior view.

II. MATERIALS AND METHODSExperimental site

Both the preliminary and main trials were conducted in the test-house of the Massey Agricultural College Research Piggery. This totally enclosed and well insulated Danish type experimental fattening house was completed in 1956. (See Figs. 7 and 8) It contains 28 individual pens and is equipped with an automatic air temperature control unit. Air circulation in the house works on the principle of forced ventilation. Air passes from the control unit into the interior of the house through ducts which have their openings in the ceiling.

These can be seen in Fig. 7 which shows the interior of the house. Pens are arranged on either side of a central race. At the back of each pen is a dunging area, each separated from the next by a movable gate. For cleaning out these gates swing back against the pens to form one long dung passage on either side of the house. Fig. 9 gives pen dimensions.

Chemical analyses of feed and faecal samples were carried out in the laboratories of the Massey Biochemistry Department. The dry matter oven of the Dairy Research Institute was used for drying faecal samples.

PART 1. PRELIMINARY TRIAL

1. ANIMALS USED

Four Large White x Berkshire barrows of 6 weeks of age and weighing 20-25 lb were used. Two animals were allotted at random to each of two pens.

2. EXPERIMENTAL CONDITIONS AND TREATMENT

Continuous thermograph recordings showed that the day temperatures inside the test house, fluctuated from 65°-70°F. External temperatures during the same period of time ranged from about 40°-58°F. On a number of occasions frosty nights were responsible for outside temperatures in the 30°F range. Under these conditions, temperatures within the house fell to about 60°F for a period of 2-3 hours, usually in the very early hours of the morning.

Each pen was equipped with a self-feeder, which enabled a dry meal mixture to be offered ad libitum. The animals were placed onto the experimental diet for a period of 10 days. The composition of this diet is shown in Table 8.

Because of the hygroscopic nature of whey powder, mixtures in which it is included are inclined to "cake". By using the mixture described (containing 45% of whey powder) it was possible to test its flow in the self-feeders and to make observations on its general use.

TABLE 8

Composition of experimental diet for preliminary trial.

Ingredient	
+ Whey powder	45%
x Buttermilk powder	30
* Meat meal	5
Barley meal	15
Sugar	5
"Apac" (Vit. A: 10,000 I.U.; Vit. D: 1,000 I.U.)	84 gms/100lb dry mix
"Vetspen" (1% procaine penicillin)	8 ozs/ " " "
Ferrous sulphate	75 gms/ " " "
Manganese sulphate	12 " " " "
Copper sulphate	5 " " " "
Zinc sulphate	2.5 " " " "
Cobalt sulphate	2.5 " " " "
Potassium iodate	3 " " " "

+ Unneutralised lactic casein whey powder
(analysis: Table 5)

* Guaranteed minimum crude protein content:- 57%

x Roller dried

This mixture was in fact, identical to experimental feed treatment IV, planned for the main trial. Of all the four experimental diets used in the main trial (see Part 2), No. IV contained the most whey powder.

A bulk quantity of the experimental mixture was prepared before commencement of the trial and chromium oxide was incorporated in it at a level of 1% (by weight).

Each pen was equipped with an ad lib supply of water and special sleeping quarters.

3. TECHNIQUES AND OBSERVATIONS

The main purpose of this preliminary trial, was to test equipment and standardise techniques to be used in the main trial.

(a) Construction of pen apparatus

(i) Self feeders

These were constructed of galvanised iron sheet screwed onto a wooden framework. The unit was wired onto the side of the pen (see Figs. 10 and 11).

(ii) Drinking troughs

No provision had been made in the test-house for individual pen drinking troughs. A set of troughs was constructed by cutting 4-gallon kerosene tins longitudinally and attaching them with straps of hoop iron, to a solid wooden base (see Fig. 11).

(iii) Sleeping quarters

It has been suggested by a number of authors that the body temperature regulating mechanism in the newborn pig is not fully developed. Subsequent development of this mechanism heat regulation is poor compared with many other species of

FIG. 9. PEN LAYOUT.
(not to scale.)

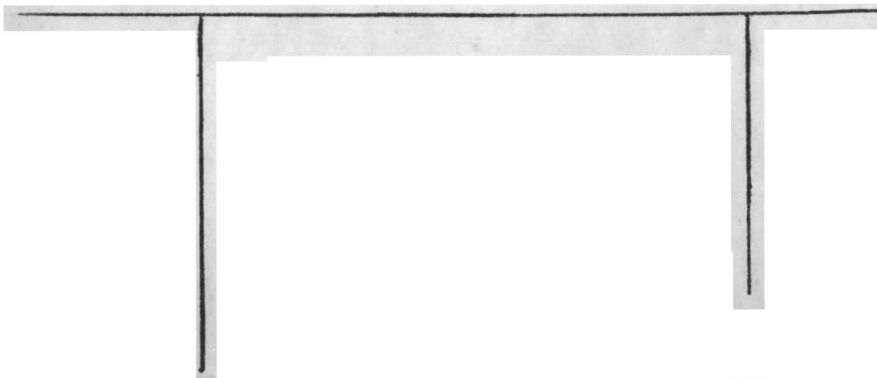
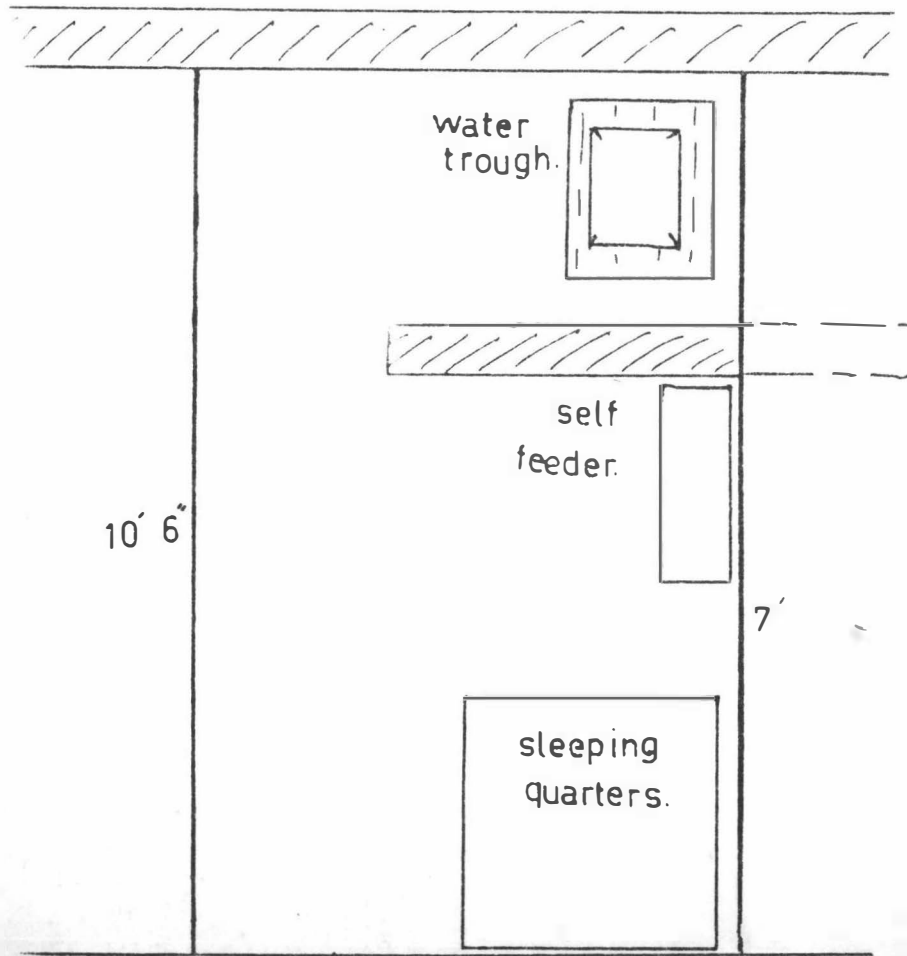




Fig. 10.

INDIVIDUAL PEN LAYOUT



Fig. 11.

domestic livestock (Heitman and Hughes 1949, 1951).

Temperature adaption in the baby pig was studied by Wallach et al. (1948); Newland et al. (1949) and Pomeroy (1953). These authors found that the rectal temperature of the newborn pig fell at least 3°F shortly after birth. The time taken for the piglet to reach the "normal" body temperature of 102.5°F depended on a number of factors. These included the ability of the piglet to find its way round to the sow's teats, (this depended on the vigour of the piglet itself), the supply of milk energy and the surrounding ambient air temperature. In environments of $70-75^{\circ}\text{F}$, baby pigs reached the normal body temperature in about 2 days. Even at one month of age piglets on low planes of nutrition, and in poor health were unable to tolerate low temperatures as well as more thrifty animals.

More critical work is needed to determine the ideal temperatures for optimum growth and thrift of pigs in the 3 week - 8 week age range. Temperatures between 60°F and 75°F are commonly quoted in practical recommendations.

It is a general observation that below certain temperatures, pigs at all ages, often huddle together in a heap, so reducing the surface area exposed to the atmosphere. This tends to reduce the rate of heat loss to the surroundings and has been described as the "community heating" effect.

As mentioned, the present trial was the first of its kind in the test house. This lack of previous experience

combined with so few critical observations reported in the literature, made it difficult to predict whether the 60-70°F temperature range within the test house, would be suitable for younger pigs.

To take advantage of "community heating", two pigs were placed in each pen. In addition, sleeping quarters were provided in the form of a tea chest laid on its side (see Fig. 10). It was hoped that the air temperature within this shelter, with the contributing warmth of the inmates, would be in a more suitable range for their well being. Theoretically, such a shelter would be less prone to experience the temperature fluctuations common to the rest of the house. Temperature readings were taken inside the shelter, periodically.

(b) Incorporation of Cr_2O_3 in the food

(i) Mixing in the food

With a system of ad lib feeding, capsule administration of Cr_2O_3 is not suitable, as daily food intake is not known. A bulk quantity of the experimental feed mixture was thus prepared before the start of the trial, in which Cr_2O_3 was incorporated at a level of 1%.

(ii) Problem of "settling out" of the indicator

Owing to the high specific gravity of Cr_2O_3 (5.21) and its very fine state of sub-division, it is liable to sink to the bottom of feeding troughs or containers. Although Barnicoat (1945), found no "settling out" of the compound in

his trials, several other workers have reported stratification of the substance in feed mixtures.

As mentioned the feed was mixed and stored in bulk. Samples were periodically taken for analysis from different levels of the storage bins and feeders. In addition several samples of each of the experimental mixtures to be used in the main trial were prepared and stored in glass jars. These were shaken from time to time, to simulate handling and examined for signs of Cr_2O_3 stratification.

It was felt that several advantages would accrue if feed pellets could be used. These included easier handling of the food, less wastage through spillage from the self-feeders, less tendency perhaps of "caking" in the feeders and above all a means of binding feed ingredients to prevent stratification of the index material. Consequently samples of the feed mixtures were sent to a local stock feed firm to see whether pelleting was possible.

(c) Sampling of feed and faeces

Periodic sampling of feed from the self-feeders and storage bins presented no real problems. Screw-topped glass jars were used for storing these samples.

With faecal samples however, a satisfactory technique of collecting, drying and subsequent storage for analysis, had to be investigated.

The literature, reviewed in Chapter II, indicated that while

a 10-20% "grab" sample of the total daily faecal output was fairly satisfactory, collection of larger daily samples was likely to give more accurate estimates of digestibility. This was particularly so as far as crude fibre digestibility was concerned.

The procedure adopted was to take collections at approximately 7 a.m. and 5 p.m. each day, after a 5-day preliminary feeding period, so as to cover both night and day voidings. Collection consisted of placing all the uncontaminated faecal material available (i.e. uncontaminated with urine, feed, etc.) into a 6" x 6" shallow cake tin. Each tin was numbered for reference, one tin being used per pen, per collection. Filled tins were then placed in a specially constructed wooden container and transported to the drying ovens.

Collection was made night and morning over three consecutive days. For the convenience of drying, material from each collection and pen was kept separate. Dried material was bulked together on a per pen basis for the three day period so that two bulk samples resulted (i.e. one for each pen). These were subsequently ground in a laboratory mill, quartered and stored for analysis.

Observations and adjustments were made on the drying oven to find the most suitable time and temperature combination.

(d) Chemical analysis of samples

(i) Cr₂O₃

Cr₂O₃ concentration in feed and faecal samples was deter-

mined by the method used by Barnicoat (1945). When this method proved unsatisfactory, that of Stevenson and de Langen (1960) was used.

(ii) Composition of feed and faeces

Henneberg analyses of both feed and faecal samples were carried out.

(iii) Other analyses

A trial run was made with a Mahler-Cook Bomb Calorimeter, for estimation of the gross energy content of feed and faeces. The method of Richards (1959) for the estimation of reducing sugar was also tried out on feed and faecal samples.

(e) Recording Data

An efficient system of data recording is essential to any experimental project. A series of data sheets were cyclostyled off for recording weight data, feed data and collection data. Over each pen was placed an observation card giving all the relevant information on the inmates (growth record, collection days, feed consumption checks, etc.).

(f) General

These preliminary studies gave an opportunity to observe whether or not such young animals could be handled under the experimental conditions. Adjustments to equipment were also made.

KEY TO FIGURE 12

EXPERIMENTAL PLAN

1. PIG NUMBER & SEX
2. WEANING DATE (3 WEEKS OF AGE)
3. WEIGHING DAYS
4. MEAL CONSUMPTION CHECK-DAY
5. FAECAL COLLECTION DATES
6. 58TH DAY OF AGE (CONCLUSION OF TRIAL PERIOD)
7. FEED TREATMENT

N.B. This plan is orientated in the same way as the photograph of the test house shown in Fig. 7. Pen numbers (1-24) are shown in the centre of the plan.

PART 2. MAIN TRIAL

1. ANIMALS USED AND EXPERIMENTAL DESIGN

A randomised block design was used, with a total of 6 blocks, each block containing four pens. Within each block of four pens the four experimental feed treatments were assigned at random, i.e. one treatment per pen. Thus a total of 24 pens was used and each of the four treatments was replicated six times.

48 Large white x Berkshire piglets were removed from their dams and brought into the test house at 21 days of age.

To each of the blocks described, eight littermates were allocated at random, i.e. two per pen. In selecting these littermates however, liveweight and sex were taken into account so that wherever possible each pen would contain littermates of approximately equal weight and a member of each sex. Invariably there was not always an equal number of boars and gilts in each litter. Consequently liveweight was regarded as the most important factor in cases where balancing for both weight and sex was not possible. It was considered that competition for feed and bullying by a heavy pig over its lighter mate, could appreciably upset the results of the trial.

The experimental plan is outlined diagrammatically in Fig. 12.

These animals remained on the trial for a period of 5 weeks, concluding at 58 days of age.

2. EXPERIMENTAL CONDITIONS

A suitable pen layout was developed in the preliminary trial (see Figs. 10 and 11).

A minimum temperature of about 60°F was recorded in the test house during the preliminary trial. As outlined this temperature was experienced on frosty nights. For the main trial therefore, two small space heaters operated in the house in addition to the main air temperature unit, when low exterior temperatures were likely.

The test house was cleaned out daily, immediately after the morning faecal sampling at 7 a.m.. This involved washing out the dung passages, sweeping up spilled food, re-filling water troughs and generally tidying up the pens.

3. EXPERIMENTAL FEED MIXTURES

(a) Up to 21 days of age

From 10 days of age and while still suckling their dam, piglets had been offered an ad libitum starter ration in the form of a "creep". The composition of this ration was identical to that fed from 21-28 days of age in the test house and is described in (b) following.

(b) 21-28 days of age

On entering the test house at 21 days of age, all animals were fed on a common starter ration up to 28 days of age. The composition of this ration is shown in Table 9.

TABLE 9

Composition of common starter ration (21-28 days)

Ingredient	%
Buttermilk powder	40
* Whey powder	20
* Meat meal	10
Sugar	15
Tallow	2
Barley meal	8
+ Premix : flour	5
Cr_2O_3	1
"Apac") as in preliminary trial "Vetspen") mixture (see Table 8) Minerals)	

* as used in preliminary trial.

+ see note further on: "Incorporation of Cr_2O_3 ".

This common starter mixture differed from that currently in use at the Massey Figgery, only in that one third of the dried buttermilk powder was replaced by whey powder. 20% of whey powder was included for the following reasons:-

- (i) To observe whether any adverse affects were noticeable when whey powder was included in the diet at this early age.
- (ii) To provide a medium level of whey powder, so that

the changeover onto the experimental mixtures, would not give too much of a nutritional or physiological shock to the animal. Some degree of check in growth, usually occurs in early weaned piglets during the first week after weaning. It was hoped that the use of the procedure described, i.e. an "acclimatization" period, would minimize this settling in process and possible growth check, to the first few days under the test conditions.

(c) After 28 days of age

Table 10 shows the four experimental feed mixtures fed from 28 to 57 days of age. Final faecal collection was carried out on the 55th, 56th and 57th days of age and consequently feed treatments were continued until the 57th day.

TABLE 10

Composition of experimental feed treatments (28-57 days)

Ingredient %	Treatments			
	I	II	III	IV
* Whey powder	0	15	30	45
* Buttermilk powder	30	30	30	30
* Meat meal	5	5	5	5
Barley meal	55	40	25	10
Sugar	5	5	5	5
+ Premix (Flour (Cr ₂ O ₃)	5 1	5 1	5 1	5 1
Minerals } "Apac" } "Vetspen" }	as for common starter mixture			

* as used in common starter mixture

+ see (4) following.

4. INCORPORATION OF Cr₂O₃

Cr₂O₃ was incorporated into all feed treatments and the common starter ration at a level of 1% by weight. The preliminary trial showed that stratification of Cr₂O₃ within the feed mixtures could occur. Full details of these findings and the subsequent procedures carried out, will be found in Chapter IV: Results.

At this stage, it will suffice to say that attempts to produce pellets of feed mixtures complete with marker failed. As an alternative, Cr₂O₃ was incorporated into a flour and water premix, which was dried and ground and then mixed with the other ingredients.

As a further precaution, final mixing of all feed mixtures was carried out at a local milling plant. 200 lb of the common starter ration, and 700 lbs of each of the four trial mixtures, were prepared in this way. Each was stored in plastic lined bags and prior to feeding each new bag was remixed as thoroughly as possible to minimise dangers of Cr₂O₃ "settling out".

5. FEEDING PROCEDURES

All feed mixtures were fed ad libitum in the self feeders described in Part I of this Chapter. In order to reduce the chances of "caking", particularly with those mixtures containing high levels of whey powder, feeders were not filled completely. A system of supplying fresh feed each morning was adopted.

Further daily checks were made to prevent clogging and any spillage was swept up and returned to the feeders.

Feed consumption checks were carried out on a weekly basis (see Fig. 12). Complete records were kept of the amounts eaten daily and at the end of each week all uneaten food was weighed back.

Random samples of feed were taken periodically from the bulk stores and self feeders for analysis.

6. SAMPLING OF FAECES

The procedure described for collecting samples of faeces in the preliminary studies, proved satisfactory and was adopted for the main trial. In planning the days on which to collect faecal samples, the following factors appeared important:-

- (a) The time lapse between initial feeding of the index substance and the time when it reaches a state of equilibrium in the faeces.
- (b) The possibility of digestibility changes in time, i.e. as the animal increases in age, its digestive powers for assimilating different nutrients may change.
- (c) Possible diurnal variations in faecal composition.

In the former case the recommended time lapse is a minimum of 3 days. Some workers however, (e.g. Moore 1957) have found that even on the fourth day complete recovery of ingested marker has not been possible.

The following plan was adopted involving four collection

periods for each pair of animals under test:

Collection 1: at the end of the first week under test
(4 weeks old - common starter mixture).

Collection 2: at the end of the third week under test
i.e. on the experimental mixtures - 6 weeks
old.

Collection 3: at the end of the 4th and 5th weeks of the
4: test period respectively (7 and 8 weeks old).

Thus a period of at least 7 days was taken between the start of the trial and the first collection and successive collections thereafter. It was thus possible to compare apparent digestibility coefficients from one period to the next.

Each collection extended over a period of three days - the middle day falling on the weekly "birthday" of the animals concerned. In view of the reports in the literature on diurnal variations in faecal composition, it was considered that a composite sample of faeces from three days of collection would be more representative of the faecal constituents, at that time.

Material from each pen (i.e. per two piglets) was collected separately at each collection time (7a.m. and 5p.m.), placed in a numbered tin and dried at approximately 70-80°C for 12 hours to a dry matter level of approximately 90%. The total dried material for the three day period was bulked together on a per pen basis, ground in a laboratory mill, quartered and stored

for analysis. In this way a total of 24 samples (one for each pen) were held for analysis from each of the four collection periods.

7. GROWTH DATA

Every animal was weighed twice a week:-

(a) on each weekly "birthday" i.e. 21st day, 28th, 35th etc.

(b) on the fourth day after this.

At the conclusion of the trial, each animal was weighed on the 56th day, then again on the 57th day and finally on the 58th day after 24 hours of starvation. In planning the trial, it was felt that a starved final weight would be useful. Whereas at 21 days of age, the weight of the stomach contents would be relatively small, (possibly less than $\frac{1}{2}$ lb) this might not be so with 8 week old animals. At 8 weeks of age the amount of food in the stomach (2-3 lbs), could affect the final weight recorded.

Because the 58th day coincided with the fourth and final faecal collection period (55th, 56th and 57th days), it was considered inadvisable to starve the animals during this period. For this reason, starved weight was taken on the 58th day.

8. CHEMICAL ANALYSES

(a) Proximate constituents

Analysis of feed and faecal samples for moisture, ash, crude protein and ether extract, crude fibre and nitrogen-free-

extract was by the Henneberg method. Comments on the use of this method appear in subsequent chapters. Collection of feed samples as described in Part I, consisted of random sampling at periodic intervals from storage bins and feeders.

(b) Cr₂O₃

Analysis of the Cr₂O₃ concentration of feed and faeces samples was carried out by the method of Stevenson and de Langen (1960). The preliminary trial showed that the method recommended by Barnicoat (1940¹⁹⁴⁵) was unsatisfactory.

(c) Gross Energy

Determinations of the gross energy content of feed and faecal samples were carried out in a Mahler-Cook Bomb Calorimeter. In preparing the calorimeter for use, two Beckman thermometers were forwarded to D.S.I.R. for checking and graduation.

9. REPLICATION OF CHEMICAL ANALYSES

At each of the four faecal collection periods, 24 composite samples (i.e. one from each pen) were collected. This gave a total of 96 faecal samples for analysis. In addition to this, five composite feed samples were obtained (one from each treatment and one from the common starter mixture), from the random samples collected during the trial.

Considerable time had already been spent in the preliminary trial standardizing analytical procedures. Unfortunately, it was necessary, due to limited time, to abandon the reducing sugar

test and concentrate on the Henneberg analysis, Cr_2O_3 concentration and gross energy determinations.

Duplication of these presented another time problem. It was considered doubtful whether the standard procedure of duplicating every analysis in strict order was sound. Ideally duplicates should be carried out on different days or at different times of the day, to reduce the possibility of bias, due to the technician, reagents used, environmental conditions, etc.

Because the Cr_2O_3 analysis was more delicate than the other analyses, complete duplication, but on different days, was carried out on all feed and faecal samples. Henneberg duplication of faecal samples consisted of 16 sets of analyses, representing four samples (one from each treatment) for each collection period. Selection of these duplicates was done with the aid of a set of random numbers using the pen number (1-24) and the treatment number (1-4), for each collection period (see Table 11).

TABLE 11

Faecal samples selected for duplicate Henneberg analysis.

Collection Period							
1		2		3		4	
Pen No.	Treatment	Pen No.	Treatment	Pen No.	Treatment	Pen No.	Treatment
2	Cs	4	I	3	IV	8	I
5	Cs	6	IV	7	III	12	II
10	Cs	22	III	13	II	15	IV
23	Cs	24	II	17	I	18	III

Cs Common Starter

In the event of a duplicate not agreeing with the previous determination, duplicates were carried out for all other samples from that block. Hence if the sample from pen 3, collection period 2, failed to agree with earlier results, analyses of samples 1/2, 2/2, 3/2 and 4/2 were repeated.

Duplicate Hennebergs were carried out on each of the five feed samples.

Considerable difficulty was experienced in determining the water equivalent of the bomb calorimeter. Adjustments were continually made until repeatable results could be obtained. The time factor again prevented a gross energy determination of all samples and as a compromise, the 16 sets of faecal samples outlined in Table 11 were used. Duplicate determinations were carried out on these and on each of the five feed samples.

10. CALCULATION OF APPARENT DIGESTIBILITY COEFFICIENTS

The formula used by Schurch et al. (1952) was used to calculate the apparent digestibility coefficients:-

Apparent digestibility %

$$= \frac{100 (a - b)}{a}$$

where a = parts of "nutrient" (i.e. ash, protein, ether extract, etc.) per unit index in feed

b = parts of "nutrient" (i.e. ash, protein, ether extract, etc.) per unit index in faeces.

11. OBSERVATIONS

The following observations were made during the trial:-

(a) Dung consistency and incidence of scouring (if any) on the experimental treatments. This followed from observations in every pen on each day, regardless of whether a daily faecal collection was carried out in that pen, or not.

(b) Feeding habits of animals on the different experimental treatments. Apart from daily observations on feeding habits throughout the trial, two 24-hour watches were kept on groups of animals.

The first observation was carried out from 8 a.m. on 21st August to 8 a.m. on the 22nd August. Times of feeding, drinking, urinating and defecating of each pig, were recorded throughout the 24-hour period.

Two blocks (eight piglets in each) were involved. Animals in Block "A" and in Block "B", were 7 and 5 weeks old respectively.

The second observation was carried out along the same lines as the first, 2 weeks later. Eight piglets were used, viz. those in Block "B" of the previous observation and now 7 weeks old. It was hoped to be able to compare habits between the two observation periods.

(c) Water consumption of animals on different feed treatments.

From the literature two factors appear to have a bearing on water consumption of animals fed concentrated or dried whey products:-

- (i) The high soluble salt content of these products (e.g. Webb and Whittier 1948). Apart from imparting a salty flavour to the feed, water is required in the process of elimination of these salts from the animal.
- (ii) The hydragogue action of lactose (Fischer and Sutton, 1949). Hydragogue action, according to these authors, is characterised by dehydration. Substances belonging to this group are only slowly absorbed from the intestine; many of their ions and molecules remain within the lumen of the gut and thus raise the osmotic pressure therein, above that of the blood. Water therefore diffuses into the lumen of the intestine from the blood, resulting in a dehydration of tissues and/or decreased urine volume. Lactose is believed to have these properties. Several authors have reported an increase in water consumption in animals fed rations high in lactose or with a dried whey product (e.g. Krider et al., 1949). Presumably this is an attempt to restore the water balance.

In view of these reports a water consumption study was planned as part of the trial.

For the purpose of describing the procedure used, blocks (i.e. 4 pens; 2 pigs per pen) in which consumption was measured, will be referred to as "A", "B", "C", etc.

Over a three day period, (21st - 23rd Aug.) water consumption in Block "A" (pens 1-4); "B" (pens 5-8); "C" (pens 9-12) and "D" (pens 21-24) was measured. This involved keeping a

record of water added to each pen trough (i.e. per 2 pigs) during the three day period. (It was normal practice to give fresh water to all pigs in the test house after cleaning out each morning.) No account could be made of spillage.

One week later this procedure was carried out on Block "E" (pens 17-20) and again on "D" (pens 21-24). Block "D" consumption was then repeated for another three days.

(d) General habits of the animals during the trial were observed. In particular the adaptability of the animals to the trial conditions and ease of handling were watched as guides to possible improvements for future work of this nature in the test house.

III STATISTICAL METHODS

The analysis of variance, as outlined by Snedecor (1959) was used to test for significant differences among the data on liveweight gain, relative growth rate, feed conversion efficiencies, apparent digestibility coefficients, gross digestible energy and water consumption.

In the case of rate of gain data, the covariance analysis (Snedecor, 1959) was applied to test the regression of weight gain during the trial, on initial liveweight, and to see whether, in fact, the covariance method could be used to increase the accuracy of statistical analysis of the data.

Relative growth rate was obtained by transforming the liveweight data to a logarithmic scale as follows:

Huxley (1924) introduced an equation relating to his allometric concept of growth, and this has been used extensively in the study of relative growth. Snedecor (1959) expressed the equation as

$$W = A e^{bt}$$

where A and b are constants to be evaluated and e is the base of the natural system of logarithms (value 2.718).

In logarithmic form this becomes

$$\log_e W \equiv \log_e A + bt$$

The regression coefficient, b, is the relative rate of increase of W i.e. the rate of increase per unit t per unit W.

Glenday (pers. comm. 1961) rearranged this relationship so that:

$$b \text{ (relative growth rate)} \\ = \frac{\log_e \left(\frac{W_2 \text{ (Final Wt.)}}{W_1 \text{ (Initial Wt.)}} \right)}{t_2 - t_1}$$

where $t_2 - t_1$ represent the time interval during the period of growth concerned.

$$\text{or using } K = \log_{10} \frac{W_2}{W_1}$$

$$\text{then R.G.R.} = K \times \frac{2.30258}{t_2 - t_1}$$

Where the F-test showed significant differences in the data, Duncan's (1955) multiple range test was used to try and gauge the pattern of these differences.

With respect to the data on food conversion efficiency, consideration was given to the use of a covariance analysis using the initial liveweight data and the corresponding total food intake. Similar consideration was given to the possibility of testing for the effect of feed intake on the apparent digestibility coefficients of the feed.

As a logical starting point to the statistical treatment of the growth data, an analysis to determine whether any differences in liveweight gains between pigs, were due to differences in sex, was carried out. The t-test method described by Snedecor (1959) for comparing data from two randomised groups of the same size, was used.

CHAPTER IV

RESULTS

- PART I EXPERIMENTAL CONDITIONS.
- II USE OF CHROMIUM OXIDE.
- III SAMPLING AND COLLECTING TECHNIQUE.
- IV OBSERVATIONS.
- V HENNEBERG ANALYSIS OF FEED AND FAECES.
- VI GROWTH DATA.
- VII FEED CONVERSION EFFICIENCIES.
- VIII COEFFICIENTS OF DIGESTIBILITY.
- IX GROSS DIGESTIBLE ENERGY.

RESULTS

PART I. EXPERIMENTAL CONDITIONS

1. ADAPTION TO EXPERIMENTAL CONDITIONS.

During the first two or three days in the test house, piglets were extremely noisy and very nervous. This was no doubt due to their sudden removal from the dam and litter-mates into strange surroundings. After this initial period, "settling in" was surprisingly rapid and the animals became quite used to the movements of the author in the house and in their pens. Although a period of scouring caused some fouling of the eating and sleeping area of each pen, most pen mates quickly learnt to use the dunging area.

2. SUITABILITY OF PEN APPARATUS.

In the preliminary trial, the use of heavier animals (20-25 lb) proved to be a fortuitous move. Water troughs, self feeders and sleeping quarters alike received quite a battering from the pen inmates, but without exception, this equipment stood the test admirably. Some difficulty was experienced in fastening the self feeders and the boxes used as sleeping quarters securely onto the side of the pens, as the animals habitually pushed their snouts under the apparatus. More secure fastenings were used in the main trial.

(a) Self-Feeders

Great difficulty was experienced in obtaining an adequate flow of feed from the self-feeders, without overflow or spillage. Frequent adjustments had to be made to the apparatus. Throughout the trial pigs nosed feed out of the feeder and onto the floor. Adjustments to the height of the feeder above the pen floor, were made according to the size of the pigs eating from it, to find the easiest position for them to eat from and to minimise spillage. Similarly, adjustments were made to the width of the actual feeding apertures.

Neither of these adjustments completely prevented feed spillage. Feed deposited on the floor became fouled and was rapidly spread around the pen and into the dung passage, unless swept up. This wastage amounted to 2 or 3 lbs of feed per day in some cases. Consequently it was necessary to sweep up and return spilt food to the feeders two or three times a day. Only in this way could wastage be reduced to a minimum.

Further trouble was experienced in the "caking" of feed mixtures in the feeders. This clogging in the feeders grew progressively worse as the amount of whey powder in the feed mixtures increased. Hence treatment I mix caused little trouble in this way, whereas treatment IV mix formed into hard lumps which frequently had to be broken up. Moisture absorbed by the feed either from the atmosphere or from the animals' saliva caused mixture IV in particular to form a

sticky mass of feed in the bottom of the feeders. Unless precautions were taken to remove this, a solid lump formed which restricted feed flow.

(b) Water troughs

Siting of the water troughs in the dung passage meant that on a number of occasions, fouling of the water occurred. Fresh water was thus provided in each pen, every day or replenished when necessary. Data on water consumption are presented in Part IV of this Chapter.

(c) Sleeping quarters

Piglets made constant use of the sleeping shelters provided. During the first two or three weeks of the test period, animals only left the shelter to feed and drink. As they grew older and larger, more time was spent during the day lying outside the shelter. At night, however, when temperatures in the test-house on a number of occasions dropped to about 60°F (see Chapter III, Part I), all animals slept inside the shelter.

Temperatures ranging from 65°-70°F were recorded in the interior of the shelters.

3. SUITABILITY OF AMBIENT AIR TEMPERATURES

On no occasion did piglets appear to be chilled or to be suffering from the cooler temperatures experienced at night. No critical tests were made however, to corroborate this

observation. The constant use of the sleeping quarters suggested a natural reaction of the animals to keep themselves warm.

PART II. USE OF CHROMIUM OXIDE

1. INCORPORATION INTO FEED MIXTURES

(a) Preliminary Trial

Results obtained in the preliminary trial, indicated that settling out of the Cr_2O_3 in the meal mixtures, was occurring. Visual inspection of the jars of samples showed definite layers of the index substance, much of which worked its way down to the bottom of the jars.

This settling out appeared to be less marked in the samples of treatments III and IV (containing 30 and 40% of whey powder respectively.)

Chemical analyses of samples from different levels of the bulk containers were carried out to determine the Cr_2O_3 concentration, using the Barnicoat method. These samples were the first to be analysed in the present trial by the Barnicoat method and due to the difficulties experienced in the use of the method (described in this Chapter), it was doubtful whether the results were reliable. It was not possible to delay the main trial until a satisfactory technique for the estimation of Cr_2O_3 had been found or until more definite chemical information was available on the

degree (if any) of stratification in the feed mixtures. The possibility of stratification occurring however, indicated the need to try other methods of overcoming the problem.

A local stockfeed firm was unable to make pellets out of samples of the experimental feed mixtures. The manufacturing process involves the forcing of the feed material through steel dies, under a pressure of steam. When subjected to this steam treatment, those feed samples containing whey powder became sticky and unworkable. This material set hard as soon as exposed to the air and blocked the machine.

In the light of these findings it was necessary to seek alternative means of minimising Cr_2O_3 stratification. A number of authors (e.g. Schurch et al, 1952), prepared a "premix" of Cr_2O_3 plus some binding substance and incorporated this into the experimental diet. Two such premixes were tried in the present trial.

- i) Cr_2O_3 + barley meal + water.
- ii) Cr_2O_3 + flour + water.

Five parts of barley meal or flour and one part Cr_2O_3 were mixed with water into a thick paste. The mixture was subsequently dried in an oven and ground to medium sized particles in an electric mincer. This premix was then incorporated into samples of the experimental feed mixtures and stored in glass jars. Visual examination of these samples followed frequent handling and shaking of the containers.

The barley meal and water formed a wet mash which had

little binding effect on the marker substance. On the other hand the flour and water mix gave a sticky paste with reasonable binding action, although some Cr_2O_3 was inevitably ground out during the drying and grinding of the mixture. Nevertheless, it was decided that the flour and water premix was the most satisfactory of the two and was therefore adapted for use in the main trial.

(b) Main Trial

In preparing bulk quantities of the experimental feed mixtures, the flour - Cr_2O_3 premix was incorporated so that the flour constituted some 5% of the experimental diet and the Cr_2O_3 an additional 1%. A bulk quantity of the premix was prepared, placed in shallow tins and dried in the oven.

Appreciating that even this premix might not completely prevent stratification of the index material in the feed, additional precautions were taken. All feed was mixed in bulk at a local milling plant, before the trial commenced and the contents of each feed container were subsequently remixed by hand immediately prior to feeding.

2. CHEMICAL ANALYSIS OF FEED AND FAECAL SAMPLES

(a) Preliminary Trial

The Barnicoat method proved most unsatisfactory, being both cumbersome and unreliable. The main reasons for this were as follows:-

(i) Fusion of the ashed sample with sodium peroxide was not only dangerous but no two samples fused alike. It was difficult to obtain any uniformity in fusing technique.

(ii) The wear and tear on the nickel crucibles was immense. After only 12-15 fusions, the bottoms of the crucibles were worn right through and had to be replaced. Nickel apparatus is expensive.

(iii) It was difficult to ascertain when all the excess peroxide had been removed by "boiling for about one hour". It is vital that no traces of this oxidising agent are left in solution if the subsequent titrations with iodide and thiosulphate are to give accurate results.

(iv) The method lacked precision - end points of the various stages being difficult to determine. Furthermore each batch of samples took 12 hours to complete and, with the apparatus available, only 12 samples could be completed in any one day. With several hundred samples involved the task appeared formidable.

Advice was sought therefore, from Ruakura Animal Research Station, where Christian, Coup, Lancaster, de Langen and others had been working for a number of years on the estimation of Cr_2O_3 concentration in faecal material from sheep and cattle, in a series of nutrition studies.

Stevenson and de Langen (1960) presented a "wet digestion" method for the estimation of Cr_2O_3 . The final step in their procedure was a colorimetric determination of Cr_2O_3 concentration,

after all the chromic compounds had been brought into solution by oxidation to dichromate.

A trial run on feed and faecal samples, using this method proved substantially more satisfactory than the previous method. While less critical conditions were required, end points were more definite, a higher reproducibility could be obtained and the daily output was in the vicinity of 20-30 samples.

Trouble was experienced at first with the accurate dilution rates required immediately before the colorimeter readings were taken. This was solved by using more accurately graduated equipment and keeping all the apparatus spotlessly clean.

Although colorimetry is a highly sensitive procedure it is speedy and fairly accurate. The portable Beckman photometer used had a limit of accuracy of readings of 3%. No intermediate graduations in the light value scale of the instrument existed and it was only possible to read values to one place of decimals. Thus any duplicate samples whose results differed by more than 3% of each other, were repeated. With the de Langen method this accuracy between duplicates was achieved with over 80% of the samples tested. On the other hand, with the Barnicoat method over half of the samples had to be repeated and it was seldom that, even then, the differences between duplicates could be reduced to 3%.

This is indicated in Table 12 which gives comparative

figures from duplicated analyses using the two methods.

TABLE 12

Concentration of Cr_2O_3 in feed samples: Comparison of results obtained by two analytical methods.

(Duplicate analyses)

Feed Sample	Method	Cr_2O_3 %	
		(1) De Langen and Stevenson (1960)	(2) Barnicoat (1945)
Common Starter		.860	.870
		.862	.923
Tt. I		1.055	1.143
		1.051	1.053
II		0.927	0.910
		0.924	1.112
III		1.049	0.918
		1.046	1.034
IV		0.966	0.869
		0.965	0.927

(1) Duplicate results from a total of 6 feed samples analysed, i.e. only one set of analyses had to be repeated.

(2) Duplicate results selected from a total of 30 feed samples analysed being those 6 duplicated samples with the closest results.

(b) Main Trial

The method of Stevenson and de Langen (1960) was used. Observations on the use of this method confirmed the findings of the preliminary trial. The results of the Cr_2O_3 analyses of feed samples are shown in Tables 12 and 16 and those of faecal samples appear in Appendix 2.

PART III. SAMPLING AND COLLECTING TECHNIQUES

The procedure developed and described in Chapter III for collection of faecal material proved satisfactory. The cake tins used were easy to handle and clean and even with older pigs were large enough to hold most of the dung voided.

Lloyd and Crampton (1958) recommended a temperature of 100°C for 24 hours as suitable for drying faecal samples. In the present trial a temperature of $70^\circ\text{--}80^\circ\text{C}$ for 12 hours was found to be more suitable. This reduced the material to a moisture content of about 10%. Samples with a higher moisture content were liable to clog up the laboratory mill on grinding.

Furthermore the 12 hour drying period was a handy time interval. Morning samples could be removed from the oven as the evening ones were put in and vice versa. Evening samples could be conveniently left in the oven overnight.

PART IV. OBSERVATIONS1. DUNG CONSISTENCY AND INCIDENCE OF SCOURING

Three arbitrary levels of consistency were used in observations on the dung, viz. scours (very soft-liquid faeces), soft (semi-formed) and well-formed. No scouring was observed in the preliminary trial.

A bad bout of scouring occurred with the first 3 litters (eight piglets in each) to go under test in the main trial. Scouring began on the 2nd and 3rd day after the animals had entered the test house and were being fed on the common starter ration. In many cases fouling of the pen area, sleeping quarters and the animals themselves, became a serious problem. In most cases this scouring continued until the 6th or 7th day under test and by the 10th day normal faecal consistency was regained. Scouring appeared to have little effect on growth in comparison with the non-scouring animals. All piglets had a small growth check during the first week under test.

At the first faecal collection period (on the 7th day) a considerable amount of liquid and very soft faecal material was collected. It was thus possible to compare digestibility data from both the scouring and non-scouring animals. These are presented later in this chapter.

In the remaining three blocks of litters under test, no scouring was observed, although a few animals passed soft faeces during the first 3 or 4 days of the trial. This was

surprising considering that some of these piglets were in the house at the same time as the scouring groups.

While it was considered that the scouring was due to a nutritional upset, the possibility of bacterial scours could not be ignored. Samples of faecal material were therefore sent for a microbiological examination. No evidence of an abnormal number of organisms likely to cause bacterial infection, could be found. However, as an additional precaution all animals in the house were given a single intramuscular injection of 1cc of sulphamethazine. At this stage the first litter of eight had been in the test house for 5 days. All successive litters to enter the house were automatically given this injection. This had little effect on those litters already scouring and did not prevent scouring from occurring in several other litters.

This bout of scouring disrupted the feeding plan. It was originally intended to place the animals on the experimental "carry-on" mixtures at 28 days of age, i.e. on the 7th day in the test house. In view of the prolonged scouring, this changeover was delayed until the 31st day of age and involved a gradual change, with increasing amounts of the experimental mixtures and lesser amounts of the starter ration. By the 35th day of age (14 days under test) all animals were feeding on the carry-on mixtures.

No scouring was observed at any stage of the "carry-on" feed period. Very characteristic faeces were passed however,

by animals on the different feed treatments. In the case of animals on treatment I fairly moist but well formed faecal material was passed. At the other extreme pigs on treatment IV voided extremely dry material in hard round pellets. Faeces of the animals on treatments II and III fell into an intermediate range of physical character, to those extremes described.

2. FEEDING HABITS - 24 HOUR OBSERVATIONS

General observations and those made during the two 24 hour "round the clock" studies on piglet habits, showed that distinctive habits developed according to the feed treatment.

During the day animals stood at the trough or nosed around the pen, more than they did at night. Because of the daily movements of Piggery staff, pen cleaning, weighing, etc. it was very difficult to determine whether the animals spent more time at the trough during the day because they had been disturbed or because they were genuinely hungry.

Animals on treatment IV ate "little and often" during the day, appearing at the feed trough every 20 minutes - $\frac{1}{2}$ hour. Eating was invariably accompanied by frequent visits to the water trough - usually every 4-5 minutes. Water consumption of pigs on this treatment was the heaviest of all treatments. More frequent drinking was accompanied by more frequent urinating.

On the other hand, pigs feeding on treatment I fed at

approximately hourly intervals during the day. They drank considerably less water, visiting the trough only once every one to two hours. Urine volume was correspondingly less. Pigs on treatment II reacted in a manner more similar to those described for I, while those feeding on treatment III had habits more like those on treatment IV.

Irrespective of feed treatment, all animals defecated every 5-6 hours.

The movement pattern, as might be expected, was more settled at night than it was during the day. With approaching dusk (5.30 - 6 p.m.), animals became restful and settled, and presumably because the temperature of the house fell slightly at night, spent more time huddled together inside the sleeping shelter. During the observation periods the test-house lights were not switched on during the hours of darkness and only a small red bulb of low wattage remained burning.

During the night, animals feeding on treatments I and II appeared at the feeder at hourly intervals with almost uncanny accuracy. Animals on treatments III and IV did not observe such regularity, particularly those on treatment IV, but as observed during the day spent less time eating but appeared more often.

A comparison of the results of the two observation periods showed that the older the animals, the less frequently did they appear at the feeder. In the 2nd observation period for example, pigs on treatments I and II fed only ~~once~~ every

$1\frac{1}{2}$ - 2 hours and pigs on treatments III and IV every 1 - $1\frac{1}{2}$ hours.

It was interesting to note that little bullying between pen mates occurred, at the feed trough, even in pens where one pig was heavier than the other. Each piglet rapidly developed feeding habits relatively independent of those of his mate.

3. WATER CONSUMPTION

Table 13 gives the average daily water consumption of each pair of piglets per pen over the observation period. These figures are taken from Appendix 5.

TABLE 13

Average daily water consumption (galls.) per pen (i.e. per two pigs) over 3 three-day observation periods.

Age (weeks) Treatment	6 - $6\frac{1}{2}$	7 - $7\frac{1}{2}$	$7\frac{1}{2}$ - $7\frac{3}{4}$	$7\frac{3}{4}$ - 8
I	1.3	1.3	1.6	1.9
II	1.3	2.0	2.2	2.3
III	2.3	2.9	3.0	3.0
IV	2.9	3.4	3.5	4.0

Over the range of ages involved, those pigs on treatment IV, consumed approximately twice as much as those on

treatment I. Pigs on treatments II and III consumed more than those on I but less than those on IV.

In Table 14 the results of an analysis of variance of the data presented in Appendix 5, are shown. There were highly significant age and treatment differences.

TABLE 14

Analysis of variance of data on daily water consumption.

Source	S.S.	d.f.	M.S.	F	Result
Age	1.691	3	0.5637	17.24	**
Treatment	8.858	3	2.9527	90.30	**
Error	0.294	9	.0327		
Total	10.843	15			

The multirange test showed that the increase in water consumption from animals on treatment I up to those on treatment IV, was highly significant between all treatments. The increase in water consumption with increasing age was also highly significant between all four age groups.

4. GENERAL

The first week of the trial, during which animals settled into their new environment, was the most difficult period from a management point of view. This initial phase

was aggravated by the incidence of scouring in some litters. Once routines had been developed, however, there was no question that young pigs could be handled satisfactorily under the experimental conditions.

PART V. HENNEBERG ANALYSIS OF FEED AND FAECES

Estimation of the ether extract and crude fibre fractions of feed and faeces by the Henneberg method, proved troublesome.

During ether extraction of samples, particles of finely ground Cr_2O_3 (particularly in faecal samples) worked their way through the extraction thimbles into the ether solution. Re-extracting with ether with brand new thimbles made little difference.

By a process of trial and error the following technique was developed. After the first extraction, ether was evaporated off in the normal way and the material left was re-dissolved in petroleum ether.

N.B.: Petroleum ether has a greater absorptive capacity for crude fat and is also less likely to absorb moisture either from the surrounding atmosphere or from the sample during extraction (extraction is carried out with oven dry samples but the possibility exists that moisture might be absorbed at some stage).

TABLE 15

Henneberg analysis of principal ingredients in experimental
feed mixtures (Massey Biochemistry Department 1960)

	Dry Matter %		Ash %		Crude Protein %		Fat %		Crude Fibre %		N.F.E. %	
	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)
Meat Meal	90.2	-	16.4	18.2	57.3	63.5	14.4	16.0	-	-	2.1	2.3
Whey Powder	89.7	-	10.9	12.2	12.9	14.4	1.2	1.3	-	-	64.7	72.1
Buttermilk Powder	95.4	-	7.0	7.2	33.5	34.7	9.6	10.0	-	-	45.3	48.1
Barley Meal	85.4	-	1.0	2.9	10.3	12.0	1.2	1.4	3.8	4.4	69.1	79.3

(a) Air dry

(b) Oven dry

TABLE 16

Henneberg and Cr₂O₃ analyses of experimental feed mixtures

	Dry Matter %		Ash %		Crude Protein %		Fat %		Crude Fibre %		N.F.E. %		Cr ₂ O ₃ %
	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	
Common Starter	91.7	-	8.4	9.3	22.0	24.2	7.8	8.6	-	-	53.5	58.0	0.86
I	89.5	-	9.5	10.9	18.9	21.3	4.3	5.0	Included		56.8	62.8	1.05
II	90.1	-	9.4	10.6	19.0	21.3	4.6	5.3	in		57.1	62.8	0.92
III	90.5	-	9.3	10.3	19.7	21.9	5.1	5.8	N.F.E.		56.4	62.0	1.04
IV	89.7	-	9.1	10.2	20.6	23.1	5.7	6.2			54.3	60.5	0.96

(a) Air dry

(b) Oven dry - Cr₂O₃ free

The re-dissolved fat extract was then filtered through a medium grade filter paper into evaporating flasks. Fat particles tended to adhere to the edges of the filter paper, where the ether was evaporating very quickly, and were removed by repeated washings with petroleum ether. This procedure, although tedious, gave reproducible results. About 12 samples per day could be completed in this way.

Estimation of crude fibre was even more difficult. The method itself is lengthy and the numerous steps involved lend themselves to errors of all kinds. In the filtering stages after acid and then alkali treatment, particles of Cr_2O_3 and other material clogged up the linen filter pads and could not be removed by washing. 40-50 attempts at crude fibre estimations produced not one reproducible result. On the advice of the Biochemistry Department, whose past experience had shown that crude fibre levels below about 2-3%, were difficult to determine accurately by the Henneberg method, the estimation of this fraction was abandoned. (It was calculated that the crude fibre level of feed samples was in the vicinity of 1-3%.)

Henneberg analysis of the principal ingredients in the experimental feed mixtures are shown in Table 15. It should be noted, however, that the figures shown were collected from analytical records made available by the College Biochemistry Department. No samples were taken for analysis from the ingredients actually used to prepare the experimental feed mixtures.

MEAN
FIG. 13. GROWTH CURVES.

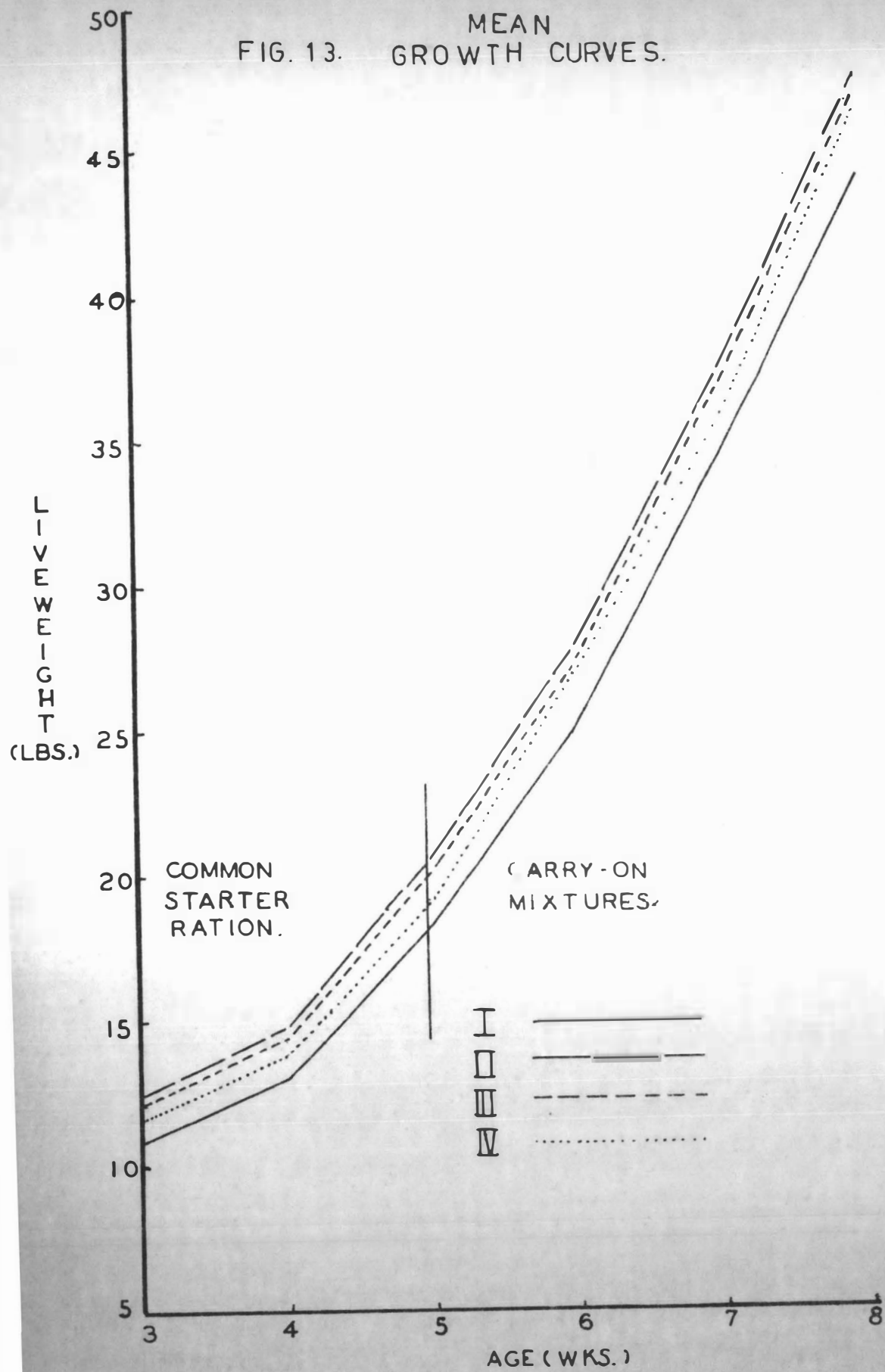


Table 16 shows results of the Henneberg and Cr_2O_3 analysis of the trial diets. Henneberg and Cr_2O_3 analysis of faecal samples are presented in Appendix 2.

Analysis of the remaining fractions in feed and faeces by the Henneberg method proceeded smoothly and it was found possible to obtain duplicate results which differed by 1.2%.

PART VI. GROWTH DATA

Liveweight data recorded during the trial are presented in Appendix 1. Average weekly weight reached by animals on each feed treatment are given in Table 17. This data is presented graphically in Figure 13.

TABLE 17

Average weekly weight (lbs) of pigs on the experimental feeds.

Age	Liveweight (lbs)			
	Common	Starter	Ration	
3 weeks	10.9	12.5	12.2	11.6
4 "	13.0	14.7	14.5	13.8
	I	II	III	IV
5 "	18.1	20.5	20.1	19.3
6 "	24.9	27.8	27.8	27.0
7 "	34.1	37.4	36.5	35.5
8 "	44.0	47.5	46.4	45.2

1. SEX

Fifteen pens contained a piglet of each sex. Analysis of the liveweight gains from the 21st - 58th day (data extracted from Appendix 1) showed no significant differences between each group. This is presented in Table 18.

TABLE 18

Statistical Analysis of Liveweight Data for Differences Due to Sex.

s^2	s^2/n	$S\bar{x} - \bar{y}$	$\bar{x} - \bar{y}$	t	Result
22.62	1.51	1.74	1.3	.75	N.S.

Where S^2 = pooled mean square

S^2/n = variance of means

$S\bar{x} - \bar{y} = \sqrt{2 \frac{S^2}{n}}$ = variance of difference between means

2. RATE OF GAIN

The mean growth curves for animals on the experimental diets are shown in Fig. 13. There would appear to be no obvious treatment differences. This observation was subsequently confirmed as a result of the statistical analyses.

In the statistical treatment of liveweight data, 35-58 day weights were used. This was in view of the fact that the four main experimental feed treatments were fed from the

35th day of age. Prior to this, all animals were feeding on a common ration and this was regarded as a common settling in period.

There were no statistically significant differences in growth rate from 35 to 58 days of age, between pigs on the four experimental feed treatments. This was shown by the analysis of variance of liveweight gains during this period (Table 19).

TABLE 19

Analysis of Variance of Liveweight Gains (per pig)
from 35 to 58 Days of Age.

Source	SS	df	MS	F	Result
Blocks	12.09	5	2.418	0.22	N.S.
Treatments	5.72	3	1.907	0.17	N.S.
(E ₁) Pens	161.43	15	10.762	1.77	N.S.
(E ₂) Within Pens	145.88	24	6.08		
Total	325.12	47			

An analysis of covariance to test the effect of 35 day liveweight on the liveweight gain from 35-58 days, also showed no significant block or treatment effects. The analysis did however, increase the accuracy of statistical analysis by reducing the standard error of the treatment means from ± 1.9

TABLE 20

Analysis of Covariance and Significance of Regression.

y = liveweight gains per pen from 35-58 days of age.

x = initial liveweight per pen.

COVARIANCE:

Source	df	x	xy	y	y ¹	df ¹	MS	F
Total	23	762.24	+ 325.95	358.49				
Blocks	5	330.93	+ 39.83	24.18				
Treatments	3	82.37	+ 21.87	11.45				
Error	15	348.94	+ 264.25	322.86	122.75	14	8.768	
r + E	18	431.31	+ 286.12	334.31	144.51	17		
Difference					21.76	3	7.253	0.83 N.S.

Unadjusted treatment means and S.E. of means:-

$$I \quad 51.2 \pm \sqrt{\frac{21.524}{6}} = \pm 1.9 \quad III \quad 51.5 \pm 1.9$$

$$II \quad 53.0 \pm 1.9 \quad IV \quad 51.9 \pm 1.9$$

SIGNIFICANCE OF REGRESSION:

Source	SS	df	MS	F	Result
Regression	200.11	1	200.11	22.82	**
Error	122.75	14	8.77		
Total	322.86	15			

$$\begin{aligned} \text{Regression coefficient } b &= \frac{+264.25}{348.94} \\ &= + 0.757 \end{aligned}$$

$$s^2_b = \frac{8.77}{348.94} = .025$$

$$b \pm S_b = + 0.757 \pm 0.159 \text{ lbs}$$

Adjusted treatment means:

$$I \quad 51.2 - 0.7573 \quad (36.2 - 39.0) = 53.3$$

$$II \quad 53.0 - 0.7573 \quad (40.9 - 39.0) = 51.6$$

$$III \quad 51.5 - 0.7573 \quad (40.3 - 39.0) = 50.5$$

$$IV \quad 51.9 - 0.7573 \quad (38.5 - 39.0) = 52.3$$

$$\text{Approx. S.E. of treatment means} = \sqrt{\frac{8.768}{6}} = \pm 1.2$$

Relative efficiency of covariance analysis

$$= \frac{21.524}{8.768} = 245\%$$

to ± 1.2 (Table 20).

A significant result was found on testing for the significance of regression. The regression coefficient (b) was found to be:

$$b = +0.757 \pm 0.159 \text{ lbs}$$

In the analysis of variance of 58 day liveweight, a significant difference was found between pens ($p < 5\% > 1\%$) (Table 21).

TABLE 21

Analysis of Variance of Liveweight (per pig) at
58 Days of Age.

Source	SS	df	MS	F	Result
Blocks	217.37	5	43.475	1.09	N.S.
Treatments	68.77	3	22.923	0.57	N.S.
(E ₁) Pens	600.17	15	40.011	2.26	*
(E ₂) Within Pens	424.00	24	17.667		
Total	1310.31	47			

The analysis of covariance using 35 day weight as the independent variable and 58 day (final) weight as the dependent variable, similarly improved the accuracy of statistical analysis of the data (Table 22). Although no significant treatment or block differences were found, the standard error of the treatment means was reduced from ± 3.7 to ± 1.2 .

TABLE 22

Analysis of Covariance and Significance of Regression

y = Final weight per pen at 58 days.

x = 35 day weight per pen.

VARIANCE:

Source	df	x	xy	y	y ¹	df	MS	F
Total	23	762.24	+ 1088.19	1772.62				
Blocks	5	330.93	+ 370.75	434.74				
Treatments	3	82.37	+ 104.23	137.54				
Error	15	348.94	+ 613.21	1200.34	122.71	14	8.77	
r + E	18	431.31	+ 714.44	1337.88	144.49	17		
Difference					21.78	3	7.26	0.83 N.S.

Unadjusted treatment means and S.E. of means

$$\begin{array}{llll}
 \text{I} & 87.3 \pm \sqrt{\frac{80.022}{6}} & = \pm 3.7 & \text{III} & 91.8 \pm 3.7 \\
 \text{II} & 93.9 \pm 3.7 & & \text{IV} & 90.4 \pm 3.7
 \end{array}$$

SIGNIFICANCE OF REGRESSION:

Source	SS	df	MS	F	Result
Regression	1077.63	1	1077.63	122.9	**
Error	122.71	14	8.77		
Total	1200.34	15			

Regression coefficient b = + $\frac{613.21}{348.94}$

$$\begin{aligned}
 &= + 1.757 \\
 S_b^2 &= \frac{8.77}{348.94} = 0.025
 \end{aligned}$$

$$b \pm S_b = + 1.757 \pm 0.159 \text{ lbs}$$

Adjusted treatment means

$$\begin{array}{llll}
 \text{I} & 87.3 - 1.7573 & (36.2 - 39.0) & = 92.2 \\
 \text{II} & 93.9 - 1.7573 & (40.9 - 39.0) & = 90.6 \\
 \text{III} & 91.8 - 1.7573 & (40.3 - 39.0) & = 89.5 \\
 \text{IV} & 90.4 - 1.7573 & (38.5 - 39.0) & = 91.3
 \end{array}$$

$$\text{Approx. S.E. of mean} = \sqrt{\frac{8.77}{6}} = \pm 1.2$$

The relative efficiency of the covariance analysis in this case was 912%.

A very highly significant regression was found and on calculation of the regression coefficient:

$$b = + 1.757 \pm 0.159 \text{ lbs}$$

3. RELATIVE GROWTH RATE

Table 23 summarises the analysis of variance on relative growth rate data between 35 and 58 days of age. No significant treatment differences were found, nor was there a significant block-treatment interaction. A highly significant difference was found between block means ($p < 1\%$). The multi-range test showed that animals in block 5 (pens 17-20) had the highest relative growth rate and those in block 2 (pens 5-8) the lowest.

TABLE 23

Analysis of Variance of Relative Growth Rate
(35-58 Days of Age).

Source	SS	df	MS	F	Result
Blocks	.000318	5	.0000636	6.49	**
Treatments	.000045	3	.0000150	1.53	N.S.
(E ₁) Pens	.000147	15	.0000098	1.36	N.S.
(E ₂) Within Pens	.000128	24	.0000072		
Total	.000683	47			

PART VII. FEED CONVERSION EFFICIENCY

Meal consumption records over the trial period are presented in Appendix 6 and feed conversion efficiencies in Appendix 7. Average meal consumption per pen (i.e. per pair of piglets), increased from about 1 lb per day in the first week of the trial, to between 5 and 6 lbs per day in the last week. Details are summarised in Table 24.

TABLE 24

Average Weekly Meal Consumption (lbs) Per Pen (i.e. Per Two Pigs) from 21-56 Days of Age; Average Meal Consumption 35-57 Days and FCE, 35-57 Days.

Age (Days)	Average Meal Consumption (lbs)			
	Common	Starter	Ration	
21-28	7.0	6.6	7.0	6.9
28-35	12.5	11.7	11.8	11.9
	I	II	III	IV
35-42	19.7	20.9	18.3	18.3
42-49	30.0	31.8	29.1	28.0
49-56	38.4	37.5	37.5	37.0
Feed Conversion Efficiency				
Average Liveweight Gain per Pen (lb) 35-57 Days	54.7	57.8	56.8	56.3
Average Total Meal Consumed (lb) 35-57 Days	93.3	97.1	92.5	88.7
lbs Meal/lb Gain	1.71	1.68	1.63	1.56

Table 24 shows that feed conversion efficiency in terms of the number of pounds of meal eaten for each pound increase in liveweight between 35 and 57 days of age, improved as the amount of whey powder in the diet increased.

An analysis of variance of the feed conversion efficiency data (Table 25) showed no significant differences between treatments, but a highly significant difference between blocks ($p < 1\%$).

TABLE 25

Analysis of Variance of Feed Conversion Efficiencies,
35-57 Days of Age.

Source	SS	df	MS	F	Result
Blocks	0.41	5	0.082	5.46	**
Treatments	0.08	3	0.027	1.80	N.S.
Error	0.22	15	0.015		
Total	0.71	23			
Linear Trend	0.0785	1	0.0785	5.34	*

The improvement in FCE from treatment I to treatment IV, as shown in Table 24 was of the order of 9%. Furthermore the fact that the whey powder levels had been increased by 15% of the ration in each treatment from treatment I up to treatment IV, i.e. a graded series, suggested that there might be a significant linear trend as far as the improvement in FCE was concerned. Calculation of the linear component (Table 25) showed that this was the case, and that there was

a significant linear trend in the improvement of the FCE as the amount of whey powder in the ration increased, at the 5% level of probability.

In the original experimental plan, it was intended to test for the regression of total liveweight gain, on total feed intake. In deciding that such an analysis was not likely to improve statistical interpretation of the data, two main factors were taken into account. These were; firstly the fact that examination of the raw data revealed no obvious treatment effects on liveweight gains, (see also analyses of variance on growth data); and the x variable (intake) could be affected by treatment. Data on weight gains and feed intake provided a conversion factor for each treatment. Fully realizing the risk of non-normality of these ratios, it was decided that an analysis of variance of the FCE would be easier to interpret.

When the significance of the difference found for the block means (Table 25) was analysed; blocks 4, 5 and 6 (with mean FCE's of 1.50, 1.49 and 1.60 lbs. feed/lb gain respectively) had significantly better FCE's than block 3 ($P < 1\%$); blocks 4 and 5 were better than block 1 ($P < 5\%$) and block 5 was significantly better than block 2 ($P < 5\%$). Blocks 1, 2 and 3 had mean FCE's of 1.71, 1.69 and 1.87 lbs meal/lb gain respectively.

Figures 14 and 15 show food intake plotted against age and liveweight of the pigs, respectively. These graphs also show that in general meal consumption on treatment IV was

FIG. 14. FOOD INTAKE - AGE.

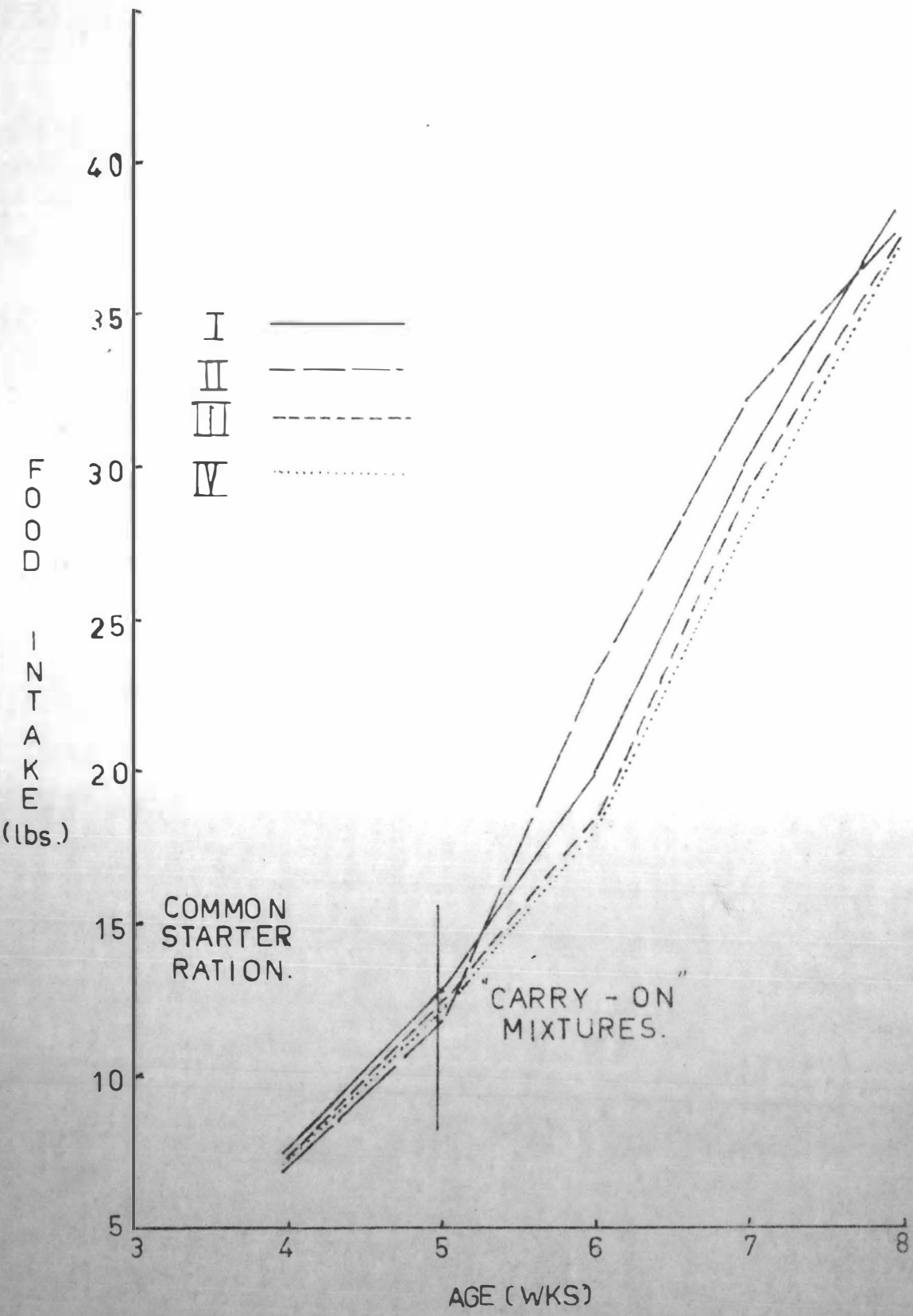


FIG. 15. FOOD INTAKE - LIVELWEIGHT.

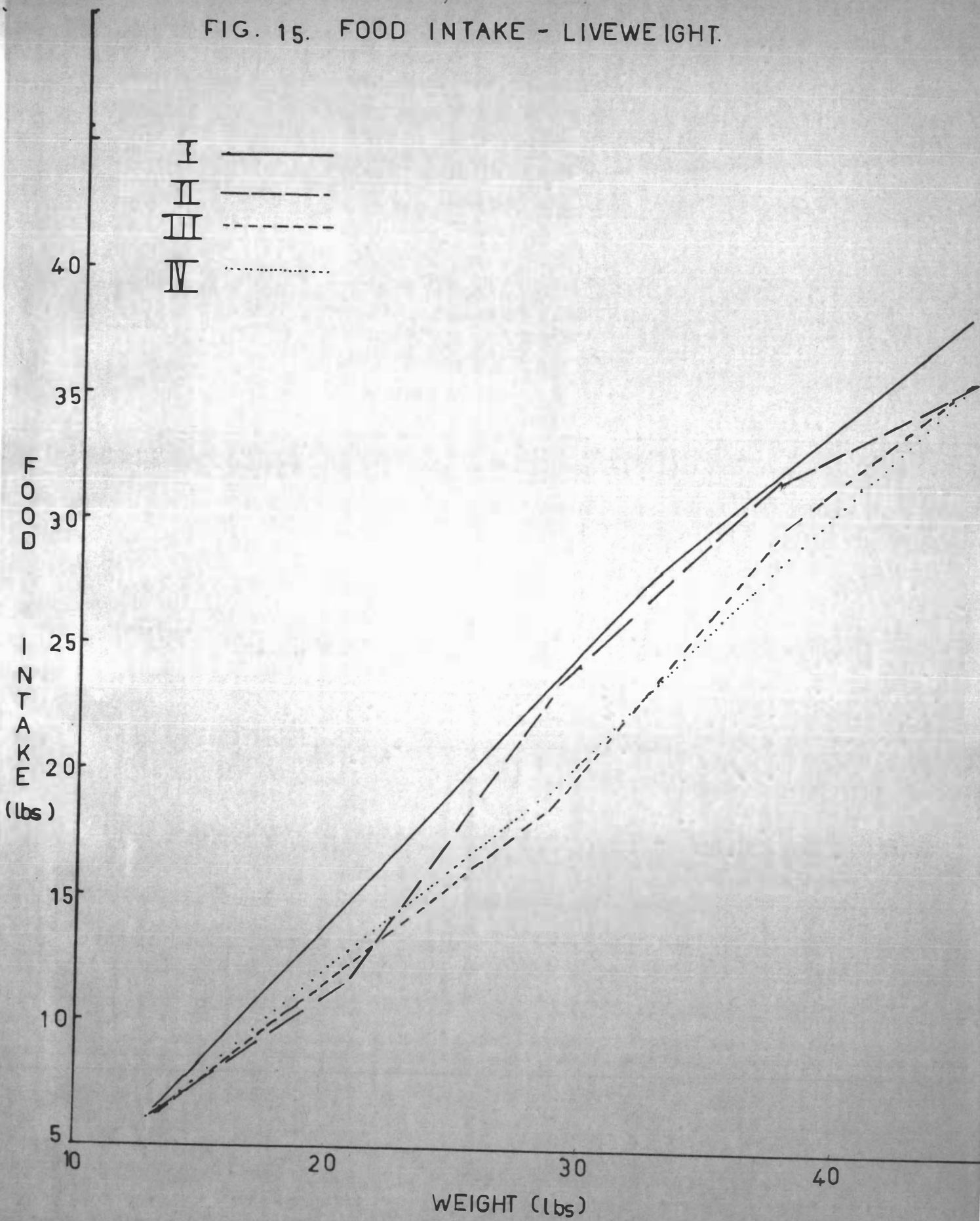


TABLE 26

Block Means for the Apparent Digestibility Coefficients at 28 Days
of Age (Collection Period 1)

Block Fraction	1	2	3	4	5	6	Standard Error of Mean	Significance of Difference
	Mean Apparent Digestibility %							
Dry Matter	80.27	79.19	79.19	84.70	83.87	83.08	0.523	4, 5, 6 > 1, 2, 3 **
Crude Protein	67.79	67.91	67.73	79.64	77.84	75.44	1.015	4, 5, 6 > 1, 2, 3 ** 4 > 6 *
Ether Extract	82.33	77.65	75.20	86.13	85.53	85.40	1.507	4, 5, 6 > 3, 2 ** 1 > 3 ** 1 > 2 *
Nitrogen Free Extract	88.37	86.77	87.04	89.82	89.33	89.32	0.412	4, 5, 6 > 2, 3 ** 4 > 1 * 1 > 2, 3 *
Ash	54.82	54.37	58.30	65.31	61.97	60.32	1.797	4 > 2, 1 ** 4 > 3 * 5, 6 > 1, 2 *

* P < .05

** P < .01

slightly lower than consumption on treatment I. Consumption on treatment II increased rather sharply up to the 7th week of age (see also Table 26) but then dropped back to a level near that of II, III and IV.

PART VIII. APPARENT COEFFICIENTS OF DIGESTIBILITY

Apparent coefficients of digestibility for the five Henneberg fractions - dry matter, crude protein, ether extract, nitrogen-free extract and ash - are tabulated in Appendices 3, A, B, C and D.

Consideration was given to the possibility of feed intake affecting digestibility, particularly as far as the greedier animals were concerned. Again the difficulties of interpreting any figures obtained from such an analysis, and the lack of any noticeable pattern in the raw data suggested that an analysis of variance would be adequate. These analyses are presented in Appendix 8.

Tables 26-29 give the mean apparent digestibility coefficients, for blocks in the case of the first collection period, and treatments for the remaining periods, plus the result of the multiple range test on these means.

(a) Collection period 1. (28 days of age) (see Table 26)

At this stage all animals were being fed the common starter ration. As previously described in this Chapter, a fairly severe bout of scouring developed in the first 24 piglets to enter the test-house. No scouring was observed

TABLE 27

Treatment Means for the Apparent Digestibility Coefficients at 42
Days of Age (Collection Period 2)

Treatment Fraction	I	II	III	IV	Standard Error of Mean	Significance of Difference
	Mean Apparent Digestibility %					
Dry Matter	82.82	86.73	86.11	86.38	0.552	II, III, IV > I **
Crude Protein	77.80	82.44	80.98	82.06	0.666	II, III, IV > I **
Ether Extract	70.21	80.73	82.79	86.40	1.145	II, III, IV > I ** IV > II **
Nitrogen Free Extract	86.38	89.71	90.52	92.07	0.423	II, III, IV > I ** IV > II ** IV > III *
Ash	77.84	79.94	71.27	62.92	1.43	I, II, III > IV ** I, II > III **

* P < .05

** P < .01

from the remaining animals to enter under test.

Highly significant differences were found between the block means of all five fractions. The multiple range test showed the mean apparent digestibility coefficients for those animals which did not scour (blocks 4, 5 and 6), to be significantly higher than for those of the scouring groups (blocks 1, 2 and 3).

(b) Collection period 2. (42 days of age) (see Table 27)

At this stage, all animals had been fed on one of the four experimental diets for one week. An analysis of variance on digestibility coefficients showed highly significant differences between treatments for all five fractions. The multiple range test, showed that the mean digestibility coefficients of dry matter, crude protein, ether extract and nitrogen free extract for treatments II, III and IV were significantly higher than the mean digestibility coefficients of these fractions in treatment I ($P < 1\%$). In addition the digestibility coefficients of ether extract and nitrogen free extract for treatment IV were significantly higher than for treatment II ($P < 1\%$).

On the other hand the digestibility of the ash fraction for treatments I, II and III, was significantly higher than for treatment IV, ($P < 1\%$).

(c) Collection period 3. (49 days of age) (See Table 28)

In period 3, the mean apparent digestibility coefficients of the dry matter and crude protein did not have such signif-

TABLE 28.

Treatment Means for the Apparent Digestibility Coefficients
at 49 Days of Age (Collection Period 3)

Treatment Fraction	I	II	III	IV	Standard Error of Mean	Significance of Difference
	Mean Apparent Digestibility %					
Dry Matter	82.66	86.55	84.37	84.92	0.635	II > I ** II > III * IV > I *
Crude Protein	78.70	81.99	79.98	81.13	0.783	II > I *
Ether Extract	72.43	80.01	82.43	85.28	0.996	II, III, IV > I ** IV > II **
Nitrogen Free Extract	86.23	86.43	89.53	91.87	-	N. S.
Ash	76.57	75.60	64.02	53.72	1.523	I, II, III > IV ** I, II > III **

* P < .05

** P < .01

N.S. Not Significant

icantly higher values in the whey powder containing rations as in period 2. Compared with the previous period, dry matter digestibility was greatest in treatment II only, the difference from that of I being significant at the 1% level of probability and from that of III, at the 5% level. The only significant difference in crude protein digestibility between treatments, was also in treatment II, which was significantly higher than I ($P < .05$). (A similar trend was noted in period 2, where the highest digestibility coefficient for dry matter and crude protein was for treatment II. This was not however, significantly greater than the mean digestibilities of these fractions for treatments III or IV, but was significantly greater than for treatment I.)

The Mean digestibility coefficients for the ether extract and ash fractions had significant treatment differences of the same order as those observed in the previous period.

An analysis of variance showed that there were no significant differences between treatments for the digestibility of the nitrogen-free extract. As observed in period 2, however, the digestibility of this fraction increased as the amount of whey powder in the ration increased (Table 28). Calculation of the linear component, on the basis of the whey powder increase being a graded series (Appendix 8), proved this trend to be a significant one.

(d) Collection period 4. (56 days of age) (See Table 29)

The pattern of the treatment differences for the mean digestibility coefficients in this period, was similar to that

TABLE 29

Treatment Means for the Apparent Digestibility Coefficients
at 56 Days of Age (Collection Period 4)

Treatment Fraction	I	II	III	IV	Standard Error of Mean	Significance of Difference
Mean Apparent Digestibility %						
Dry Matter	81.71	84.56	82.43	83.99	0.536	II > I ** II > III * IV > I *
Crude Protein	77.15	80.74	76.30	79.61	1.118	II > III, I *
Ether Extract	67.73	73.12	75.24	80.97	1.020	II, III, IV > I ** IV > II, III **
Nitrogen Free Extract	85.85	88.84	89.97	91.83	0.351	II, III, IV > I ** IV > II, III ** III > II *
Ash	76.02	72.81	57.35	50.16	1.57	I, II, III > IV ** I, II > III **

* P < .05

** P < .01

observed in period 3. Compared with the previous period the major difference occurred in the digestibility of the nitrogen-free extract, which was more similar to that observed in period 2. NFE digestibility for treatments II, III and IV was significantly greater than for treatment I. In addition the NFE coefficient of digestibility for treatments III and IV were significantly greater than those for treatments II; and II and III respectively.

Furthermore the mean coefficient of digestibility for crude protein in treatment II was significantly greater than in treatments III and I, and the digestibility of ether extract in treatment IV was significantly greater than in treatments III and II.

GENERAL

The average digestibility coefficients for the five fractions for each treatment comparison and at each faecal collection period, are listed in Table 30.

In general digestibilities of the fractions, increased over the first 3 weeks of the trial but dropped slightly in most cases, over the last 2 weeks of the trial.

TABLE 30

Average apparent digestibility coefficients for the five fractions at each faecal collection period.

Trt.	Collection Period	Dry Matter %	Crude Protein %	Ether Extract %	Nitrogen Free Extract %	Ash %
I	1 *	81.37	71.80	81.21	88.43	58.47
	2	82.82	77.80	70.21	86.38	77.84
	3	82.66	78.70	72.43	86.23	76.57
	4	81.71	77.15	63.73	85.85	76.02
II	1 *	81.75	73.11	83.34	87.94	57.92
	2	86.73	82.44	80.73	86.38	77.84
	3	86.55	81.99	80.01	86.23	76.57
	4	84.56	80.74	73.12	85.85	76.02
III	1 *	81.65	72.13	82.61	88.54	57.92
	2	86.11	80.98	82.79	90.52	71.27
	3	84.37	81.99	82.43	89.53	64.02
	4	82.43	76.30	75.24	89.97	57.35
IV	1 *	82.09	73.01	80.09	88.94	60.01
	2	86.38	82.06	86.40	92.07	62.92
	3	84.92	81.13	85.28	91.87	53.72
	4	83.99	79.61	80.97	91.83	50.16

* Common Starter Ration (N.B. For comparison with the other collection periods the means for the six blocks have been re-calculated on the basis of the four treatments which were subsequently allotted in those blocks.)

PART IX. GROSS DIGESTIBLE ENERGY

Table 31 gives the gross energy content of faecal samples, as determined in the Bomb Calorimeter. Gross energy content of the five experimental feed mixtures, determined in the same way, are shown in Table 32. By using the chromium oxide ratio between feed and faeces, as used in the determination of the apparent digestibility coefficients, it was possible to calculate the gross digestible energy of each feed treatment. This value expressed as a percentage is listed in Table 31. In Table 32 this percentage has been applied to the gross energy content of the corresponding feed treatment to give an estimate of the gross digestible energy in calories per gram, of each feed mixture.

TABLE 31

Gross energy of faecal samples and gross digestible energy percentages of treatment comparisons at collection periods.

Collection Period	Pen No.	Treatment	Gross Energy Faecal Sample (Cals/G.M. of D.M.)	Gross Digestible Energy %	Mean G.D.E. %
1	2	Common Starter	6990	72.59	73.71
	5		7207	71.25	
	10		7204	72.03	
	23		6722	78.97	
2	4	I	5965	81.89	83.37
	6	IV	6630	83.10	
	22	III	6363	84.26	
	24	II	6297	84.23	
3	3	IV	6231	83.56	82.17
	7	III	6150	80.00	
	13	II	6127	82.95	
	17	I	5978	82.15	
4	8	I	6217	78.20	80.00
	12	II	6045	80.53	
	15	IV	6295	80.64	
	18	III	6164	80.67	

TABLE 32

Gross energy; Mean G.D.E. % and G.D.E. of the
Experimental Feed Mixtures

Treatment	Common Starter	I	II	III	IV
Gross Energy (Cals/G.M.)	5349	5281	5250	5216	5160
Mean G.D.E. % of Feed over Trial Period	73.71	80.75	82.57	81.64	82.43
G.D.E. in Feed (Cals/ G.M.)	3943	4264	4335	4258	4253

Although slightly higher for treatment II, the estimated gross digestible energy contents of the four main treatment comparisons, were very similar, being in the order of 4,250 calories per gram.

As only a small number of results were available the only statistical treatment of the energy calculations was an analysis of variance on the gross digestible energy percentages presented in Table 31. This was to compare differences between feed treatments and between collection periods in the range of energy values measured (Table 33).

TABLE 33

Analysis of variance of gross digestible energy
% of feed treatments.

Source	SS	df	MS	F	Result
Collection Periods	221.88	3	73.96	12.93	**
Treatments	1.73	3	0.58	0.101	N.S.
Error	51.49	9	5.72		
Total	275.10	15			

There were no significant differences between treatments. A highly significant difference was found between collection periods. The multirange test showed that the mean G.D.E. % for collection periods 2, 3 and 4 (42, 49 and 56 days of age respectively) were significantly greater than the mean G.D.E. % for period 1 (28 days of age) - $P < 1\%$. There were no other significant differences.

CHAPTER V

DISCUSSION AND CONCLUSIONS

- I. ADAPTABILITY OF ANIMALS TO EXPERIMENTAL CONDITIONS.
- II. USE OF CHROMIUM OXIDE
- III. OBSERVATIONS.
- IV. HENNEBERG ANALYSIS.
- V. GROWTH.
- VI. FEED CONVERSION EFFICIENCY.
- VII. APPARENT COEFFICIENTS OF DIGESTIBILITY.
- VIII. GROSS DIGESTIBLE ENERGY.
- IX. GENERAL.
- X. FUTURE RESEARCH FIELDS.

DISCUSSION AND CONCLUSIONS

I. ADAPTABILITY OF ANIMALS TO EXPERIMENTAL CONDITIONS

This trial proved beyond a doubt that young pigs could be handled very easily under the experimental conditions. Young pigs are inclined to be boisterous and pen apparatus must be able to withstand a fair battering. Pen cleanliness is important, not only in the event of a bout of scouring such as in the present trial, but in order to prevent excessive waste of spilled food where a food consumption check is kept. The growth rate of the pig makes it an ideal experimental animal, with relatively short experimental periods in which a large amount of data can be collected. Furthermore the housing arrangement in the present trial was admirable for the purpose of constant observation on all the animals, with a minimum of trouble.

II. USE OF CHROMIUM OXIDE

While no comparison was made of the Cr_2O_3 - reference method with any other method of measuring digestibility, the method proved satisfactory in the present trial, easy to manage once techniques had been developed, and the results would appear to give a fair indication of the digestibility of feed fractions through the trial. These will be discussed in more detail elsewhere in this Chapter.

1. Incorporation into the Diet

Just how real the problem of stratification of the index substance in the feed would have been, if the premix method of incorporation had not been used, is difficult to ascertain. This problem could only be answered, if a trial comparing the results of the use of the index with and without a premix or "binder", was conducted.

It would appear however, that the use of the flour - Cr_2O_3 - water premix did help to prevent excessive stratification of the index substance through the feed.

Visual inspection of the jars of stored feed samples showed that less stratification of Cr_2O_3 was occurring in treatments III and IV. This could possibly have been due to the whey powder exerting a binding action on the fine Cr_2O_3 particles.

It was unfortunate that attempts to produce the trial feeds in pellet form failed. Apart from the fact that pelletting would have obviated the necessity to prepare a premix of the index substance, the problem of "caking" of the feed mixtures and feed overflow may have been easier to cope with.

A number of authors have satisfactorily used pelleted feeds for young pigs and have reported that there is less waste than with the same ration fed in a non-pelleted form (Carroll and Krider, 1956; Terrill et al, 1956; Dyrendahl et al, 1958). Acker and Catron (1953) claimed that in a comparative trial young pigs offered the same good starter ration in three forms - pellets,

crumbles (granulated) and meal - showed a preference to eating them in that order.

The manufacturer concerned in the present instance reported that he had always experienced trouble, trying to manufacture pellet feeds containing more than about 20% of milk products. This difficulty is probably due to the hygroscopic nature of some of these products.

2. Cr₂O₃ Analysis

The poor results obtained from the Barnicoat alkaline oxidation fusion method would concur with the findings of Stevenson and de Langen (1960). These workers examined the fusion methods of Barnicoat (1945), Kane et al (1950), Schurch et al (1950), Raymond and Misson (1955), and Kamsola et al (1957).

In fusing with sodium peroxide, Stevenson and de Langen found that the loss in weight of the nickel crucible was 2-5 mg per assay. The crucibles (as in the present trial) became pitted and eventually holed. Retention of chromate in the nickel oxide precipitate was considerable and at no times was this loss of chromate a standard one of 2%, as suggested by Barnicoat (1945). Fusing with potassium and sodium hydroxides showed less loss in weight of the nickel crucibles, but low recoveries of chromate and poor reproducibility.

More satisfactory results were obtained with the method of Maunsell (1944). This method consisted of a sodium carbonate fusion, oxidation being completed by addition of

hydrogen peroxide. The solution was then boiled to ensure that all the chromate was completely dissolved and to remove excess peroxide before colorimetry. It was found that the large expenditure of nickel crucibles and the retention of chromate in the nickel oxide precipitate, could be avoided if the oxidising substance was added to the crucible after fusing. However, reproducibility of results, depended on critical heating conditions during fusing, and adequate mixing and grinding of the Cr_2O_3 - carbonate ash. These conditions made the method a difficult one for large scale routine work.

For this reason a "wet digestion" method was developed by Coup and Lancaster (1952) and modified by Christian and Coup in 1954. This method consisted essentially in the use of potassium bromate as the oxidising substance. In the presence of a sulphuric acid/phosphoric acid mixture and a manganese compound a complete oxidation of the Cr_2O_3 to the dichromate state could be achieved. Previous attempts to establish such a wet digestion procedure had failed with a number of oxidising agents, catalysts and controlled heating, mainly due to the incomplete formation of dichromate or, conversely, complete conversion into insoluble chromic compounds. Estimation of dichromate was achieved by volumetric methods. The authors presented this procedure as an improvement over Coup and Lancaster's (1952) method where a low daily output was common. Furthermore a long-boiling period was required because the Cr_2O_3 was not readily attacked by the oxidising agents at the temperature of the dilute acid mixtures used and also to ensure

at a later stage that all excess bromate was removed before the back titration.

Stevenson and de Langen (1960) however, describe a further modification to this method which avoids the critical heating conditions of Christian's modification and the long boiling time of Coup and Lancaster's method is reduced to 10-15 minutes. Furthermore these authors consider a colorimetric method of determining the concentration of dichromate more accurate than the volumetric one (it does away, of course, with the necessity of preparing standard solutions which could introduce further error). Chromate solutions conform to Beer's Law and a wide range of concentrations can be measured at a wavelength of 400 m μ with sufficient accuracy.

For this reason the method was adopted in the present trial and proved satisfactory.

Since this trial was completed de Langen (pers. comm. 1960) has indicated that further modifications to this method have been made. Again these consist in the main of reducing the critical conditions required at certain stages of the procedure, in this case in the final removal of the Mn O₂ precipitate, (in the previous method, shaking of the solution tended to break this precipitate down into the colloidal state again) and the preparation of the dichromate solution for a photometric reading.

In the present trial, the "wet digestion" method used proved satisfactory once familiarization with the procedures had been achieved. It was vitally important however, to keep equipment spotlessly clean. The modifications to the method, which have

been developed since the present trial was carried out, would be well worth consideration for future Cr_2O_3 analytical work.

III. OBSERVATIONS

1. Dung Consistency and Incidence of Scouring

The bout of scouring recorded in the first 24 animals to go under test, serves to emphasise the importance of avoiding sudden changes in diet. In this case removal from the sow into an environment in which ad libitum food was provided and virtually no competition for food with littermates existed. All animals had however, been given a "creep" feed while on the sow, identical in composition to that of the common starter test ration.

Whether or not, this scouring was whey induced is open to conjecture. In the starter ration whey powder constituted only 20% of the ration. Becker et al (1957) found no incidence of scouring at any stage of their trial, in spite of the fact that dried whey powder was included in a semi-purified diet fed to young pigs (14-42 days of age) up to a level of 60%. Krider et al (1949) on the other hand reported the occurrence of diarrhoea in weanling swine fed from 56 days of age, on a corn-soya bean type of ration containing 4% and 8% of a dried whey product. In the preliminary trial of the present study, no scouring was observed in the 6-week old pigs used, although whey powder was fed at a level of 45% of the diet.

It would thus appear that tolerance to whey powder feeding in young pigs is governed by a delicate balance between the age of the animal and the remaining ingredients in the diet.

It is unlikely that physical conditions within the test-house contributed. Although all the scouring occurred in animals on one side of the house, a complete litter of eight in which no scouring was observed, were housed on the same side.

It is possible that appetite was a contributing factor. Generally the scouring animals were slightly heavier when they entered under test than the non-scouring animals. The last two litters to enter the test-house (Pens 17-24) in particular were generally lighter in weight than most of the other litters, (Appendix 1) and did not suffer from scours. The heavier animals were inclined to have heavier appetites (Appendix 6) and over-eating on their part could have induced scouring. In particular pig 49/69 B in pen 3 ate extremely greedily and heavily throughout the trial, had the heaviest consumption of any of his mates and topped the scales at each weighing. During the first fortnight this animal suffered heavily from scouring and was the last member of the scouring groups to recover from the bout. It is suggested that this was an exaggerated case of a general pattern in the scouring groups.

The characteristic form of faecal material voided by animals on each of the experimental treatments would concur with the generally accepted physiological role of the large intestine in water conservation in the body (Dukes 1955). Fischer and Sutton (1949) referred to the dehydrating effect of lactose in the small intestine. Krider et al (1949) reported an increase in water consumption by animals fed rations high in lactose or in dried whey products. Removal of water from the final undigested

products of alimentation, by the large intestine would help to counteract this dehydration.

The hard dry faecal matter voided by animals on treatment IV in the present trial, corroborates this.

2. Feeding Habits

The sow has very close control over the let down of her milk. Smith (1952) found that the interval between sucklings in sows varied from a mean of 60 minutes in the first week of lactation to 70 minutes in the eighth week. The pattern of feeding in the present trial, particularly when the animals were settled at night, suggested that this hourly feed to which they had become accustomed prior to weaning, was carried through to the post weaning stage. This was particularly so with animals feeding on treatments I and II. More frequent visits to the feeders by animals on treatments III and IV might be explained in terms of these mixtures being less palatable. The observations indicated that animals on these treatments ate little but often. These treatments were high in their whey powder content, rapidly became sticky on exposure to the air and from animal saliva and caused animals to make frequent visits to the water trough. To the human palate, these mixtures were extremely salty.

As the animals became older, the interval between feedings increased. This was no doubt a natural adaption developed as the animals lost their pre-weaning suckling habits and fed according to their new needs.

3. Water Consumption

The importance of providing fresh clean water when dry meals are fed to pigs was shown in this trial. On all treatments animals made constant use of the water provided and in most cases refused to drink contaminated water.

The fact that more water was drunk by those animals on the high whey powder feeds would follow from the reports cited earlier, on the dehydrating effect of feeds rich in lactose or concentrated whey products, and which also have a high soluble salt content.

There is little data in the literature on the water consumption of young pigs. Most of the available information relates to older pigs. The amount needed undoubtedly varies according to the age of the animal, the type of food and the environmental temperatures. Linton and Williamson (1943) put forward the general rule that the daily supply of water should be 3 lbs of water for each 1 lb of meal up to 100 lb liveweight. On the other hand Evvard, Wallace and Culbertson (1927) calculated that a 25 lb pig would require 4.25 and 5.45 lbs of water per day, in the autumn and spring respectively. A 50 lb animal would require 4.80 and 5.80 lbs per day. Leroy (1937) suggests 3.5 lbs of water per day for a 44 lb pig. The water consumption of animals on treatment I at approximately $\frac{5}{4}$ gals. - 1 gal. (7-10 lbs) per day, at liveweights ranging from 30-45 lbs, would be slightly higher than the above recommendations. With the treatments containing whey powder (II, III and IV), these recommendations are definitely too low. Daily consumption by animals on

treatment IV was in the vicinity of 2 gals. (20 lb). This would further indicate the importance of providing adequate quantities of water when feeding whey powder.

IV. HENNEBERG ANALYSIS

The remarks of Crampton (1956) concerning the limitations of the Henneberg analysis, and quoted in Chapter II, were well borne out in the present trial. Namely, that this method was never intended to give results which our modern knowledge of nutrition deems desirable. The problem still remains to find suitable methods of analysis which give more precise information on the individual chemical compounds in feedstuffs, but are easy to carry out on a large number of samples.

In the present trial the major faults with the Henneberg method lay in the estimation of:-

- (1.) Crude fibre
- (2.) Nitrogen-free extract

1. Crude Fibre

Wallace (pers. comm. 1960) and other workers have reported on the difficulties of accurately estimating the crude fibre content of materials by the Henneberg method, at levels lower than 2-3%. In Table 15 (Chapter IV) barley meal is given an oven-dry crude fibre percentage of 4.4 and is the only ingredient in which crude fibre is found. Calculation of the crude fibre content of the main treatment comparisons in the present trial would thus give the following:

Treatment	I	II	III	IV
Barley Meal %	55	40	25	10
Crude Fibre %	2.4	1.8	1.1	.4

The accuracy of a crude fibre estimate at these levels is questionable. This is unfortunate, particularly as the main trial was primarily to observe the effect of replacing the barley meal with whey powder.

The extent of crude fibre digestion in the monogastric animal is of great interest and importance. Hallsworth (1949), Mitchell (1942) and Walker and Hepburn (1955) are but a few of the workers who have found that the crude fibre content of animal diets, even at low levels, often have a direct bearing on the digestibility of the other nutrients. Many have found a negative correlation between the crude fibre content of the organic matter and the digestibility of the organic matter. For this reason several current investigations include a study of the more complete analyses of plant constituents in animal diets. To date most of these methods are difficult to operate and lengthy.

Hallsworth (1950) suggests modifications to the Henneberg crude fibre analysis by using an acid digestion alone, to eliminate variations which may occur due to the alkali method more commonly used.

Crude fibre is a misleading term, the fraction which it represents is not a single chemical entity and varies widely in constitution between materials and between feed and faeces.

2. Nitrogen Free Extract

Like the crude fibre fraction the "nitrogen free extract" portion, obtained by difference in the Henneberg analysis, is not a single chemical compound. It is usually regarded as that portion of the material containing the soluble carbohydrates. In the present trial the specific constituents of the NFE portion were of particular interest as these would have changed as whey powder replaced barley meal in the treatment comparisons. This was particularly the case with respect to lactose which constituted some 60% of lactic casein whey powder. Reference to the sensitivity of the young pig to lactose was made in Chapter II.

The ash content of the experimental feed treatments (Table 16) was slightly higher than that calculated by using the data in Table 15. This was probably due to the mineral mixture added to the trial diets. Furthermore, this calculation shows an increase in ash content of the trial feeds as the amount of whey powder increases; not a decrease as found on analysis. This would emphasize the danger of placing too much weight on the nutrient fractions of feedstuffs as calculated from data on the individual ingredients.

V. GROWTH

Overall liveweight gains of the animals during the trial were very satisfactory. The period of slower growth recorded during the first week of the trial, was as expected, while the animals settled into their new conditions. This was also the first week after weaning. The absence of any significant

treatment effect on liveweight gains would emphasize that whey powder was a successful replacement for barley meal under the conditions of the present experiment, so far as growth performance was concerned.

The highly significant block differences found in the relative growth rate data were attributed by the multirange test to block 5. This could possibly be explained in terms of the litter in that block having a slightly superior inherent relative growth rate, compared with the other litters under test.

At the end of the trial (8 weeks of age) the average liveweight of animals on the main treatment comparisons, I to IV was 44.0, 47.5, 46.5 and 45.2 lbs respectively. Among the individual weights recorded several animals weighed between 55 and 65 lbs at the 8 week stage, having reached this from a 3 week weight in the vicinity of 10-12 lbs. These were some of the highest liveweights recorded at the Massey Piggery for pigs of this age.

VI. FEED CONVERSION EFFICIENCY

It is of interest to note that the feed conversion efficiency increased as the amount of whey powder in the ration increased, (although not statistically significant on a treatment basis). This was due to a slight decrease in the amount of feed eaten as the whey powder content of the feed increased and not because of an increase in liveweight gain as the whey powder content increased. Mention has been made of the feeding habits and increased water consumption of animals on the higher levels of whey powder suggesting that these mixtures were less palatable. The increased FCE's

might have been due to a restriction in intake of the high whey powder containing rations, imposed by their less palatable nature.

On the other hand, rather than a restriction imposed simply by palatability or taste, the dehydrating effect of whey powder which was presumably counteracted (or partly so) by frequent water drinking could have had some physiological effect on the mechanism of appetite.

In the trial of Becker et al (1954), in which lactose was fed to baby pigs at a level of 56.6% of the diet, a superior efficiency of gain was reported, compared with diets in which glucose or starch was the carbohydrate source. The subsequent trial, however, (Becker et al, 1957) in which dried whey powder was fed to young pigs up to a level of 60% of the diet, produced no significant improvements in FCE. Danielson et al (1960) reported a decrease in feed efficiency when dried whey levels were increased above a level of 10% of the ration. In this trial, reported in Chapter II, whey powder was being used as a replacement for protein as well as carbohydrate concentrates, at different levels.

These results would still further emphasize the fact that the overall value of whey powder in young pig rations will depend largely on the nutrients it replaces (i.e. where comparisons are being made) and the remaining ingredients in the ration.

Comparison of the mean FCE on a block basis brings out two interesting facts:

(a) The fact that block 5, had the best FCE value of all the blocks,

although this was significantly superior only to blocks 1, 2, and 3. Animals in block 5 also showed a significantly higher relative growth rate. It might be argued that a superior FCE and relative growth rate was an inherent characteristic of this litter.

(b) The fact that blocks 4, 5 and 6 had superior FCE's to blocks 1, 2 and 3 (although only measured from the 35th-57th day) would lend weight to the remarks made earlier on the reasons for scouring in the latter blocks. It would appear that animals on blocks 1, 2 and 3 not only overate during the first week but continued doing so through the trial with correspondingly poorer food conversion efficiencies.

VII. APPARENT COEFFICIENTS OF DIGESTIBILITY

In the trial of Lloyd and Crampton (1958) estimates of the apparent digestibility coefficients, threw some light on the reasons for the failure of their whey powder rations to support satisfactory growth. This poor growth was due primarily to the failure of the whey powder and meat meal to adequately replace the protein of skim milk powder. The present trial differed because the whey powder was primarily a substitute for barley meal, or a carbohydrate concentrate. With no significant treatment effects on growth however, the digestibility percentages can be discussed only from the point of view of the biochemistry of digestion of the rations, or in terms of the slight improvements observed in feed conversion efficiency.

Lowest mean digestibilities were observed at the end of the

first week of the trial. This indicates that the settling in period during the first week, and in which slower growth rates were recorded, is accompanied by lower digestibilities of the feed fractions. In addition as this was the first week after weaning, slower growth rates and lower digestive efficiencies are to be expected. Scouring was associated with significantly lower digestibilities of the feeds.

Mention was made in the previous section to the slightly better FCE's of animals in blocks 4, 5 and 6 (pens 13-24) from the 35th-57th day, than animals in blocks 1, 2 and 3. There appeared to be no similar improvement in digestibilities in blocks 4, 5 and 6; the only significant block difference was found for the digestibility of the crude protein in collection period 3.

The general significant increase in the apparent digestibility of the dry matter, crude protein, ether extract and nitrogen free extract fractions, as the amount of whey powder in the ration increased could explain the improvement in FCE also observed as the whey powder level increased. It is suggested that the feed conversion efficiency is associated with the digestibility of the feed fractions.

Catron (1957) found that intestinal lactase activity decreased rapidly after the 2nd or 3rd week of age (see Fig. 4). The results of the present trial would indicate that in spite of this possible decrease in lactase activity, the carbohydrate fraction of the high whey powder diets was still highly digestible at 8 weeks of age.

It was interesting to note that the apparent digestibility coefficient of the ether extract remained consistently and significantly higher in all the whey powder treatments and particularly in treatment IV, throughout the 35-56 day period. This was the same with the nitrogen-free extract fraction except at the third collection period.

Lloyd and Crampton (1958) found with the particular rations used in their trial, that the average apparent digestibility of the dry matter, crude protein and nitrogen free extract portions, were significantly higher for 7- than for 3-week old pigs. While the apparent digestibility coefficients found in the present trial are of a similar order to those determined by Lloyd and Crampton, in contrast to their results, the apparent digestibility coefficients of dry matter, crude protein and ash on treatments I and II increased from 4 weeks of age up to the 6th week and then decreased over the last 2 weeks of the trial. On treatments III and IV a similar trend was observed for the ether extract and nitrogen-free extract portions, as well as the other fractions.

Without further data being available it would be difficult to attribute these small decreases in digestibility to decreases as far as carbohydrate digestion was concerned, in lactase activity. Treatment I, which contained no whey powder and therefore little lactose, except in the buttermilk powder, also exhibited a similar decrease in the digestibility of its feed fractions including carbohydrate. It is possible that in all treatments any enzymological effects which might have appeared towards the end of the trial period, were confused with a general

lowering in digestibilities in the final 2 weeks of the experiment, due to the increasing amount of feed being eaten. It is likely that this resulted in decreased feed conversion efficiency, at least as far as digestibility was concerned.

VIII. GROSS DIGESTIBLE ENERGY

The mean G.D.E. % was higher in the rations containing whey powder, although this was not statistically significant. As a similar trend was observed in the digestibilities of four of the feed fractions, it would appear as though the G.D.E. % follows the pattern of these digestibility coefficients.

The significantly higher G.D.E. % in the 6th, 7th and 8th weeks compared with the 4th week was similar to that observed by Lloyd and Crampton (1958). In their trial the gross digestible energy percentage was significantly higher at the 7- than at the 3-week stage.

The G.D.E. % of their whey powder rations were lower however, than the G.D.E. % of the other rations, presumably for the same reasons outlined in other sections of this Chapter.

IX. GENERAL

1. Nutrition Aspects

The good health and growth rates maintained by all animals throughout the trial indicate that the diets were nutritionally balanced. No signs of deficiency were observed. The improved apparent digestibilities on the rations containing whey powder support the conclusion that whey powder can replace barley meal

in early weaning meal diets at the levels used in this trial.

It is difficult to compare levels of nutrient fractions with the results obtained by other workers because of the different nature of the diets used. As far as the fat percentage of the trial diets are concerned (5-6%), they would be slightly lower than the levels used by Speer et al (1954) - 7%; and Crampton and Ness (1954) - 8%. With protein the 21-23% levels used in the present trial would agree fairly closely with the levels successfully used in other trials where milk products have constituted the basic source of protein, e.g. McRea and Tribe (1956); Reber (1953); Becker et al (1954) and others cited in Chapter II.

The results of Lloyd and Crampton's (1958) trial in particular would emphasize the importance of the other ingredients in the rations as far as the value of including whey powder is concerned. In their case and in that of Danielson et al (1960), the available protein in the feed mixtures containing whey powder, was the limiting factor in the overall performance of these rations. While whey powder is a good carbohydrate replacement it would appear to fail as a complete protein replacement.

2. Managemental Factors

The hygroscopic nature of the whey powder used in the present trial, made it extremely difficult to handle. Treatments III and IV in particular were inclined to "cake" to the extent that self-feeders became blocked unless precautions were taken. Furthermore stocks of feed mixtures had to be kept in air-tight containers.

Under commercial feeding conditions, where attention to the animals might not be as rigorous as under experimental conditions, the hygroscopic nature of whey powder would be a serious disadvantage.

Spellacy (1953) discussing the manufacture and use of whey products referred to the desirability of producing whey powder of a non-hygroscopic nature. He listed several methods which could be used to "stabilise" dried whey powder. These included the addition of moisture to the product during the de-hydrating process or after dehydration had been completed.

Latimer (pers. comm. 1961) informed the author that the Dairy Research Institute (N.Z.) was investigating methods for reducing the hygroscopic nature of whey powder.

3. Economic Considerations

The results of the present trial indicate that whey powder can successfully replace barley meal in early weaning mixtures for young pigs - although the maximum level at which successful substitution can be achieved was not determined.

The N.Z. Co-operative Dairy Company Ltd. (pers. comm. 1961) claimed that, in the current season, lactic casein whey powder would have to sell at between £35 and £40 per ton if the direct costs of production were to be re-couped. On this basis whey powder competes with barley meal, which is selling at approximately £32-35 per ton at present. From an economic point of view therefore the decision on which of the two products to use will depend on the prices ruling at that time. The handling and packaging of a hygroscopic material would also tend to put the cost of

production up.

X. FUTURE RESEARCH FIELDS

The results of the present trial show that the use of whey powder in rations for young pigs could be a potential source of disposal of some of the enormous surplus of liquid whey in New Zealand. It is considered that the following fields of research would add immensely to any final conclusion on the value of whey powder feeding in young pigs.

1. Levels of whey powder

(a) As a substitute for barley meal.

A trial is needed to determine the maximum successful substitution rate of whey powder for barley meal in an early weaning mixture. For example, could all the barley meal at the levels used in the present trial be replaced by whey powder?

(b) As a substitute for other ingredients.

Clearly trials are needed to determine not only the maximum amount of whey powder which can be fed in the diets of young pigs without deleterious effects to efficient growth and good health; but also to determine which ingredients or nutritive fractions can successfully be replaced.

Further trials, similar to those conducted by Lloyd and Crampton (1958) and Danielson et al (1960), for example, where whey powder was used both as a carbohydrate and protein replacement, are needed.

In terms of the present trial, to what extent could the buttermilk levels in the rations used, be replaced by whey powder?

2. More detailed studies on the physiology of digestion of whey powder in the young pig.
3. Research into the more economic production of whey powder or whey products of a non-hygroscopic form, as a source of animal or human feeds.
4. Apart from the point of view of the use of whey powder as a means of disposal of liquid whey surplus, the present trial indicates how useful digestibility data could be in a nutrition trial. Because no significant treatment effects on growth were found, the digestibility results were of no particular use as far as growth was concerned. They did however, give a clearer picture of the reaction of the digestive system to the different rations. It was also suggested that they were useful in explaining the differences observed in F.C.E.

It is possible that in future trials digestibility data might usefully explain variations in growth between treatments as well as contribute to knowledge on the biochemistry of digestion. For this reason it is suggested that a large field of research exists in developing techniques of measuring digestibility in the pig. For example, a more detailed study of the use of the Cr_2O_3 - reference method would be useful, to determine more accurately the uniformity of distribution of the marker in the feed; to investigate methods of incorporating the marker in the feed or in the

animal; to develop satisfactory chemical analytical techniques and to assess the accuracy of the method.

CHAPTER VI

SUMMARY

SUMMARY

1. An experiment is described in which a study was made of the effect of different levels of substitution of lactic casein whey powder for barley meal, in early weaning meal mixtures for young pigs.
2. Forty-eight Large White x Berkshire pigs, weaned at 3 weeks of age, were allotted in pairs to a randomised block layout in the experimental fattening house of the Massey College Piggery.
3. During the first 14 days of the trial all animals were fed on a common starter ration. This was followed by four main treatment comparisons in which whey powder constituted 0, 15, 30 and 45% of a dry meal diet respectively. These rations were fed until the animals had reached 8 weeks of age.
4. There were no significant treatment effects on growth. Growth in all animals was satisfactory and at 8 weeks of age the mean liveweights for treatments I to IV were 44.0, 47.5, 46.4 and 45.2 lbs respectively. A period of slow growth was recorded during the first week of the trial as animals "settled in" to their new conditions. This was accompanied by scouring in some animals, believed to be due to a nutritional upset, over the first few days. No subsequent scouring occurred.
5. The feed conversion efficiency was slightly improved as the amount of whey powder in the ration increased, viz. 1.71, 1.68,

1.63 and 1.56 lbs of meal eaten per pound liveweight gain for treatments I, II, III, IV respectively. This represented an improvement of 9% from treatment I to IV which was not a statistically significant treatment effect, but was a significant linear trend.

6. In order to study more closely the physiology of digestion of the experimental diets, the apparent digestibility coefficients of the dry matter, crude protein, ether extract, nitrogen-free extract and ash fractions were measured, using the chromium oxide-reference marker method. The method of Stevenson and de Langen (1960) was found to be the most suitable for measuring the concentration of Cr_2O_3 in feed and faecal samples. The Henneberg method was used with moderate success to estimate the five nutrient fractions. Data is presented on the use of these methods in digestibility determinations.

7. The apparent digestibility coefficients were measured at 4, 6, 7 and 8 weeks of age. The coefficients of all five fractions were significantly lower in those animals which suffered from scouring in the first week of the trial, than in those which did not. Significant treatment differences were found with the digestibility of the dry matter, ether extract, crude protein and nitrogen-free extract portions. Digestibility of these fractions increased in most cases as the amount of whey powder in the ration increased. The reverse was true for the ash fraction. These effects were most noticeable up to the 6th week, but became less pronounced in the 7th and 8th weeks with the exception of the

nitrogen free extract.

8. The apparent digestibility coefficients of all five fractions increased up to the 6th week but decreased in the 7th and 8th weeks. These differences were however, of a fairly low order and no statistical test was applied.

9. Gross digestible energy determinations on a limited number of samples showed that the G.D.E. % followed a similar pattern to the digestibilities of the dry matter, ether extract, crude protein and N.FE. fractions both on a treatment and time basis. The treatment effects were not statistically significant but the increase in G.D.E. % from the 4th to the 7th week was statistically significant. All four main feed rations were found to have a gross digestible energy value of the same order, viz. approximately 4,250 cal/gm.

10. There was a statistically significant increase in daily water consumption as the amount of whey powder in the ration increased. Whereas the average consumption per pair of piglets was the order of 1-2 gallons per day on treatment I, consumption on treatment IV was approximately 4 gallons per pair of pigs per day. There was also a significant increase in water consumption with age.

Observations on feeding habits of animals on the four main treatments are also presented.

11. The hygroscopic nature of the whey powder used would be a serious disadvantage from a commercial management point of view. "Caking" of the high whey powder feeds was a constant problem.

12. The results indicate that lactic casein whey powder can successfully replace barley meal at least up to a level of 45% of the diet, in an early weaning mixture for young pigs. The use of whey powder in this way could be a potential means of disposal of some of New Zealand's liquid whey surplus, particularly if present costs of production of the product could be reduced, and its poor physical properties improved.

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APPENDICES

1. Liveweight record : 21-58 days of age
2. Henneberg and Cr_2O_3 analysis of faecal samples.
3. A,B,C,D. Apparent digestibility coefficients.
4. Feed : index ratio.
5. Water consumption
6. Weekly meal consumption
7. Feed conversion efficiencies
8. Analyses of variance on digestibility data.

APPENDIX 1

Liveweight Record (lbs)

Common Starter

Pen No.	Pig No.	3 wks Wt.		4 wks Wt.		Tt.	5 wks Wt.		6 wks Wt.		7 wks Wt.		8 wks Wt.	57th Day	58th Day
1	49/59B	11.5	10.0	10.0	11.0	II	13.5	17.5	20.5	25.0	29.0	34.0	39.0	39.5	38.0
	49/6 G	12.0	12.5	14.0	17.0		21.0	25.5	29.0	35.0	37.5	44.0	50.0	51.5	47.5
2	49/8 G	12.0	12.0	13.5	16.5	III	20.0	24.5	27.5	32.5	39.5	41.5	46.5	49.0	45.5
	49/78B	12.0	12.0	13.0	15.0		18.5	21.5	25.5	30.0	34.0	39.0	44.5	46.5	43.0
3	49/69B	16.0	16.0	18.0	23.0	IV	26.5	31.0	36.5	41.5	47.0	50.0	57.5	63.0	57.0
	49/7 G	13.0	12.5	13.0	16.5		20.0	23.5	29.0	33.5	39.0	41.5	48.0	51.0	47.5
4	49/58B	9.5	9.5	10.0	12.5	I	14.5	18.0	21.0	25.0	30.0	34.5	38.5	39.0	38.5
	49/5 G	12.0	13.0	15.5	19.0		21.5	27.0	31.0	36.0	41.5	47.5	51.5	51.5	51.0
5	50/57B	16.0	16.5	18.5	21.5	II	24.5	31.0	32.5	38.5	41.5	47.0	51.5	53.0	50.0
	50/56B	14.5	15.0	17.0	19.5		22.5	27.2	29.0	36.5	39.5	46.0	52.0	53.0	49.5
6	50/68B	13.5	15.5	17.5	21.0	IV	23.5	30.0	33.0	38.5	40.0	47.5	54.5	55.5	54.5
	50/5 G	14.0	15.5	16.5	20.0		22.0	27.5	31.0	37.0	39.0	45.5	50.5	52.0	50.5
7	50/58B	14.0	16.0	18.0	21.0	III	24.5	27.5	28.5	33.0	36.0	41.5	47.5	49.5	46.5
	50/6 G	14.0	14.5	17.5	21.5		23.5	30.5	34.0	40.0	41.5	49.0	55.5	57.0	53.5
8	50/8 G	10.0	11.0	11.0	13.5	I	15.5	18.5	20.5	23.0	26.0	30.5	35.0	35.5	34.5
	50/7 G	12.5	14.5	15.5	19.0		20.5	25.5	28.0	32.5	37.0	42.5	48.5	50.0	48.0
9	51/9 G	12.0	13.5	14.5	19.0	III	20.5	24.5	28.5	34.5	38.0	43.0	47.5	49.0	47.0
	51/79B	14.0	15.5	16.5	20.5		24.5	28.5	33.5	39.0	42.5	49.0	53.5	56.0	53.5
10	51/68B	12.5	14.0	15.5	19.5	IV	21.5	26.0	29.5	34.5	37.5	44.5	47.0	48.0	47.0
	57/5 G	11.5	13.0	14.0	17.5		21.0	25.0	28.5	33.5	36.5	42.0	45.5	46.5	45.0
11	51/59B	11.5	12.0	14.5	17.5	I	20.0	23.0	27.0	33.0	36.0	42.0	46.0	48.0	46.5
	51/7 G	11.0	13.0	13.5	16.5		18.5	21.5	24.5	30.0	33.5	39.0	43.0	45.0	43.0
12	51/6 G	10.5	11.5	13.0	15.0	II	19.0	21.5	24.5	30.0	34.5	40.5	44.5	45.5	44.5
	51/78B	11.5	14.0	16.0	19.5		22.0	26.5	30.6	36.0	40.5	47.0	51.0	52.5	50.0

B Boar

G Gilt

(Contd.)

APPENDIX 1 (Contd.)

Pen No.	Pig No.	3 Wks Wt.		4 Wks Wt.		Tt.	5 Wks Wt.		6 Wks Wt.		7 Wks Wt.		8 Wks Wt.	57th Day	58th Day
13	53/58B	13.5	15.0	18.0	21.5	II	25.5	29.5	33.5	39.0	46.5	53.0	57.5	61.5	57.5
	53/8 G	13.0	15.0	17.0	20.0		22.5	27.5	30.5	36.0	40.5	45.5	50.0	53.5	50.0
14	53/57G	11.5	13.5	15.5	18.5	III	20.5	22.5	26.0	30.0	34.5	39.5	43.5	46.5	43.0
	53/56G	11.0	12.0	14.5	17.5		19.0	22.5	25.5	30.0	34.5	39.5	43.0	46.5	43.0
15	53/7 G	9.0	10.5	12.5	14.0	IV	15.5	18.0	22.0	27.5	30.0	35.0	38.0	40.0	37.0
	53/68B	8.5	9.5	10.5	13.0		14.5	17.5	20.5	25.0	29.5	33.0	38.0	41.5	38.5
16	53/67B	9.0	10.0	12.5	12.5	I	16.0	19.0	22.0	27.5	31.5	37.5	43.0	44.0	41.0
	53/6 G	10.0	10.5	12.5	13.5		17.5	20.0	24.0	28.5	32.5	37.5	42.0	43.5	41.0
17	56/78B	12.0	12.0	13.5	15.5	I	17.0	20.0	24.0	29.0	33.0	40.0	44.5	46.0	44.0
	56/67B	11.5	11.0	12.5	15.0		17.0	20.0	24.0	29.0	34.5	40.5	44.0	45.0	43.0
18	56/58G	9.5	9.5	10.5	12.5	III	14.0	16.5	21.0	25.0	28.5	33.0	37.0	38.0	37.5
	56/56G	9.5	10.0	11.0	14.0		15.0	19.5	23.5	27.5	31.5	37.0	41.5	42.5	41.0
19	56/79B	10.5	10.5	12.5	15.0	IV	16.5	21.0	24.5	29.5	34.0	39.5	45.5	46.5	45.5
	56/7 G	10.5	10.0	11.5	13.5		15.0	19.0	21.5	26.0	30.0	34.0	37.5	39.0	39.0
20	56/9 G	11.0	11.0	12.5	16.0	II	18.0	22.0	26.5	31.5	34.5	40.0	44.5	46.0	45.0
	56/6 G	10.5	11.0	12.0	14.5		16.0	19.5	23.0	27.5	30.5	35.5	39.5	40.5	39.5
21	57/58B	10.0	10.0	11.5	14.0	IV	16.5	20.0	23.5	27.5	30.5	33.5	38.5	41.5	39.0
	57/8 G	10.5	11.5	13.0	15.5		18.5	22.5	25.0	29.5	32.5	38.0	42.0	44.5	42.0
22	57/56B	13.0	12.5	13.5	17.0	III	21.0	26.0	29.5	35.0	38.5	44.0	49.0	52.0	49.0
	57/78B	14.0	14.0	15.5	18.5		21.0	26.5	30.0	34.0	38.5	43.5	47.5	50.5	48.5
23	57/5 G	11.0	11.0	12.5	15.5	I	19.5	23.0	26.5	31.5	36.0	40.5	44.0	47.0	45.5
	57/7 G	11.0	11.0	12.0	15.5		19.5	24.0	26.5	31.5	37.5	42.0	47.5	50.5	48.0
24	57/68B	12.0	12.5	13.5	17.0	II	19.5	23.5	26.0	31.5	35.5	39.5	43.5	46.5	44.5
	57/67B	13.5	14.0	15.0	18.0		21.5	24.0	28.5	34.5	38.5	43.0	47.0	49.5	47.5

APPENDIX 2

Analysis of Faecal Samples (Duplicate Average) for
each Collection Period

N.B. Crude Protein, Ether Extract, Ash and N.F.E. %, on an Oven Dry - Cr₂O₃ - Free Basis

Collection Period		Dry Matter				Crude Protein				Ether Extract			
		1*	2	3	4	1*	2	3	4	1*	2	3	4
Pen No.	Tt.												
1	II	90.83	88.54	89.29	89.22	38.01	29.36	29.41	26.18	7.45	6.32	7.18	8.73
2	III	89.55	89.79	90.22	90.29	38.40	29.74	26.23	28.29	7.62	6.08	5.42	8.15
3	IV	88.46	89.90	91.48	90.33	38.13	29.53	28.45	29.51	7.72	4.60	5.53	7.43
4	I	87.55	89.76	90.40	90.09	40.38	28.55	26.48	26.33	7.01	9.17	7.41	10.19
5	II	87.33	90.26	89.88	90.03	37.01	27.09	30.54	26.98	9.12	9.72	8.46	11.12
6	IV	88.24	89.28	89.69	90.22	34.32	31.72	32.76	31.34	8.49	7.75	6.55	8.26
7	III	87.55	89.66	91.03	90.09	35.39	29.46	29.19	31.20	9.59	8.86	6.57	8.58
8	I	88.59	89.44	90.21	90.93	36.47	27.18	29.20	26.58	9.88	9.87	7.98	10.95
9	III	87.52	89.21	89.89	89.30	38.88	32.65	29.95	30.30	8.68	8.59	6.96	8.64
10	IV	88.32	90.27	90.70	89.91	37.57	32.25	29.91	29.48	11.66	7.43	6.60	8.32
11	I	90.62	88.03	90.93	89.89	36.38	30.65	29.64	28.29	11.48	8.07	7.97	10.40
12	II	87.18	89.24	90.04	90.13	36.69	30.21	28.32	28.15	8.00	8.47	7.11	9.93
13	II	92.35	89.04	89.65	90.00	31.03	28.13	25.49	26.73	7.62	7.35	7.23	8.88
14	III	91.99	89.35	90.71	90.25	34.03	30.57	27.83	26.93	8.11	6.80	6.27	8.23
15	IV	92.04	89.82	90.37	90.33	31.97	31.10	27.48	27.33	9.17	6.07	4.96	6.21
16	I	91.85	88.98	91.53	89.91	32.44	27.95	24.90	25.61	6.48	7.13	8.84	10.60
17	I	91.03	91.48	91.16	89.66	34.28	26.03	24.86	24.98	8.21	8.45	7.44	8.68
18	III	91.91	91.13	91.42	90.36	33.37	27.05	26.32	28.34	6.54	5.55	7.02	7.35
19	IV	90.19	90.14	91.70	89.78	34.92	27.49	27.20	29.52	9.39	5.84	6.42	7.12
20	II	92.20	90.33	91.12	90.44	29.55	24.49	22.61	23.20	6.29	5.94	7.11	8.37
21	IV	90.61	90.74	90.61	90.73	35.29	31.35	29.51	30.51	9.26	5.60	6.45	6.62
22	III	91.27	89.81	90.44	89.87	34.57	29.07	28.98	32.51	6.50	6.37	6.73	7.38
23	I	90.53	89.43	90.18	90.35	34.49	25.06	26.75	29.19	6.55	9.02	8.12	8.47
24	II	91.28	89.53	91.01	90.75	35.11	28.48	27.37	25.84	7.05	7.46	7.59	7.75

* On common starter ration

APPENDIX 2 (Contd.)

Collection Period		Ash				N.F.E.				Cr ₂ O ₃			
		1*	2	3	4	1*	2	3	4	1*	2	3	4
Pen No.	Tt.												
1	II	19.41	16.04	16.87	16.35	35.13	48.28	46.54	46.74	4.48	6.97	6.47	6.28
2	III	21.35	24.45	24.76	23.92	32.63	39.73	43.59	39.34	4.10	7.12	6.66	6.23
3	IV	21.21	30.25	32.67	32.91	32.94	35.62	33.35	30.15	4.01	5.77	7.05	6.16
4	I	20.38	12.78	15.06	14.19	32.23	49.50	51.05	49.29	4.38	6.55	6.97	6.26
5	II	18.57	16.38	17.40	17.51	35.30	46.81	43.69	44.39	4.03	6.85	6.52	6.08
6	IV	18.09	28.91	28.70	31.47	39.10	31.62	31.99	28.93	4.41	7.30	5.96	5.65
7	III	21.37	18.73	19.98	25.11	33.65	42.95	44.26	35.11	3.81	6.95	6.10	6.03
8	I	19.72	14.16	16.48	14.89	33.93	48.79	46.34	47.58	3.68	6.91	6.67	5.67
9	III	17.99	18.75	23.31	23.43	34.45	40.01	39.78	37.63	4.21	7.17	6.88	6.02
10	IV	17.84	22.00	32.08	32.85	32.93	38.32	31.41	29.35	4.14	6.97	6.10	5.72
11	I	18.12	13.40	13.52	14.00	34.02	47.88	51.57	47.31	3.95	5.94	5.52	6.03
12	II	17.73	15.07	18.86	19.00	37.58	46.25	45.71	42.92	3.68	7.05	6.46	5.44
13	II	19.54	15.00	18.05	20.25	41.81	49.52	49.23	44.14	5.52	6.14	6.30	5.40
14	III	22.08	20.95	24.07	26.42	35.78	41.68	41.83	38.42	5.62	7.59	6.95	4.79
15	IV	20.98	27.27	33.62	32.45	37.88	35.56	33.94	34.01	6.04	7.10	6.21	6.05
16	I	21.84	13.84	13.24	14.01	39.24	51.08	53.02	49.78	5.43	6.03	6.63	5.71
17	I	20.39	14.90	14.12	14.95	37.12	50.62	53.58	51.39	5.16	5.48	6.66	5.17
18	III	21.09	21.61	25.80	27.37	39.00	45.79	40.86	36.94	5.33	7.81	7.57	6.36
19	IV	21.86	30.06	31.85	30.35	33.83	36.61	34.53	33.01	5.02	7.94	6.48	6.00
20	II	22.77	17.49	20.94	22.27	41.39	52.08	49.34	46.16	5.78	7.42	6.73	6.68
21	IV	21.71	28.61	31.07	31.68	33.74	34.44	32.97	31.19	5.04	7.82	6.99	6.71
22	III	20.26	22.50	25.47	23.21	38.67	42.06	38.82	37.20	5.02	8.06	6.06	6.23
23	I	22.04	15.04	16.76	14.94	36.92	50.58	48.37	47.40	5.14	5.97	4.95	5.91
24	II	21.96	15.92	18.69	17.30	35.88	48.14	46.35	49.11	4.96	7.00	6.83	6.10

* Common starter ration

APPENDIX 3

Apparent Digestibility Coefficients of Dry Matter,
Crude Protein, Ether Extract, Ash, Nitrogen-Free
Extract.

A. Collection Period 1. (28 days of age)

Pen No.	Tt.*	D.M.		Cr. Prot.		Eth. Ex.		Ash		N.F.E.	
		(b) +	%	(b) +	%	(b) +	%	(b) +	%	(b) +	%
1		20.28	80.99	8.48	69.90	1.66	83.40	4.33	59.83	7.84	88.37
2		21.84	79.52	9.37	66.73	1.86	81.34	5.21	51.67	7.96	88.20
3		22.06	79.31	9.51	66.24	1.93	80.64	5.29	50.93	8.21	87.82
4		19.99	81.25	9.22	67.27	1.60	83.95	4.65	56.86	7.36	89.08
5		21.69	79.66	9.18	67.41	2.26	77.33	4.61	57.24	8.76	87.00
6		20.01	81.23	7.78	72.38	1.93	80.64	4.10	61.97	8.87	86.84
7		22.98	78.45	9.29	67.02	2.52	74.72	5.61	47.96	8.83	86.90
8		24.07	77.43	9.91	64.82	2.68	73.12	5.36	50.29	9.22	86.32
9		20.79	80.50	9.24	67.20	2.06	79.34	4.27	60.39	8.18	87.87
10		21.33	80.00	9.07	67.80	2.82	71.72	4.31	60.02	7.95	88.21
11		22.94	78.49	9.21	67.31	2.91	70.81	4.59	57.42	8.61	87.23
12		23.69	77.78	9.97	64.61	2.17	78.23	4.81	55.38	10.21	84.85
13		16.73	84.31	5.62	80.05	1.38	86.16	3.54	67.16	7.57	88.77
14		16.37	84.65	6.06	78.49	1.44	85.56	3.93	63.54	6.37	90.55
15		15.24	85.71	5.29	81.22	1.52	84.75	3.47	67.81	6.27	90.70
16		16.92	84.13	5.97	78.81	1.19	88.06	4.02	62.71	7.23	89.27
17		17.64	83.46	6.64	76.43	1.59	84.05	3.95	63.36	7.19	89.33
18		17.24	83.83	6.26	77.77	1.23	87.66	3.96	61.41	7.32	89.14
19		17.97	83.15	6.96	75.29	1.87	81.24	4.35	59.65	6.74	90.00
20		15.95	85.04	5.11	81.86	1.08	89.17	3.94	63.45	7.16	89.38
21		17.98	83.14	7.00	75.15	1.84	81.54	4.31	60.19	6.69	90.08
22		18.18	82.95	6.89	75.54	1.29	87.06	4.04	62.52	7.70	88.58
23		17.61	83.48	6.71	76.18	1.27	87.26	4.29	60.20	7.18	89.35
24		18.40	82.74	7.08	74.87	1.42	85.76	4.49	58.35	7.23	89.27

* All on common starter ration

+ Faecal : index ratio

APPENDIX 3 (Contd.)

B. Collection Period 2. (42 days of age)

No.	Tt.	D.M.		Cr. Prot.		Eth. Ex.		Ash		N.F.E.	
		(b)+	%	(b)+	%	(b)+	%	(b)+	%	(b)+	%
1	II	12.70	87.03	4.21	81.82	0.91	84.06	2.30	80.09	6.93	89.99
2	III	12.61	85.51	4.18	80.18	0.85	84.66	3.43	65.49	5.58	90.64
3	IV	15.58	83.33	5.12	78.76	0.80	87.54	5.24	50.71	6.17	90.22
4	I	13.70	83.93	4.36	78.52	1.40	70.28	1.95	81.21	7.56	87.37
5	II	13.18	86.54	3.95	82.94	1.42	75.13	2.39	79.31	6.83	90.00
6	IV	12.23	86.91	4.35	81.95	1.06	83.49	3.96	62.75	4.33	93.13
7	III	12.90	85.18	4.24	79.90	1.27	77.08	2.69	72.94	6.18	89.63
8	I	12.94	84.82	3.93	80.64	1.43	69.64	2.05	80.25	7.06	88.20
9	III	12.44	85.70	4.55	78.43	1.20	78.34	2.62	73.64	5.58	90.64
10	IV	12.95	86.14	4.63	80.79	1.07	83.33	3.16	70.27	5.50	91.28
11	I	14.82	82.61	5.16	74.58	1.36	71.13	2.26	78.23	8.06	86.53
12	II	12.66	87.07	4.29	81.48	1.20	78.98	2.14	81.47	6.56	90.40
13	II	14.50	85.20	4.58	80.22	1.20	78.98	2.44	78.87	8.07	88.19
14	III	11.77	86.47	4.03	80.89	0.90	83.75	2.76	72.23	5.49	90.79
15	IV	12.65	86.46	4.38	81.83	0.85	86.76	3.84	63.88	5.01	92.06
16	I	14.76	82.68	4.64	77.14	1.18	74.95	2.30	77.84	8.47	85.85
17	I	16.69	80.42	4.75	76.60	1.54	67.30	2.72	73.80	9.24	84.56
18	III	11.67	86.59	3.46	83.59	0.71	87.18	2.77	72.13	5.86	90.16
19	IV	11.35	87.85	3.46	85.64	0.74	88.47	3.79	64.35	4.61	92.69
20	II	12.17	87.57	3.30	85.75	0.80	85.99	2.36	79.57	7.02	89.72
21	IV	11.60	87.59	4.01	83.36	0.72	88.79	3.66	65.57	4.40	93.02
22	III	11.14	87.20	3.61	82.88	0.79	85.74	2.79	71.19	5.22	91.24
23	I	14.98	82.43	4.20	79.31	1.51	67.94	2.52	75.72	8.52	85.76
24	II	12.79	86.94	4.07	82.43	1.07	81.26	2.27	80.35	6.88	89.93

+ Faecal : index ratio

APPENDIX 3 (Contd.)

C. Collection Period 3 (49 days of age)

No.	Tt.	D.M.		Cr. Prot.		Eth. Ex.		Ash		N.F.E.	
		(b)	%	(b)	%	(b)	%	(b)	%	(b)	%
1	II	13.80	85.91	4.55	80.35	1.11	80.56	2.60	77.49	7.19	89.47
2	III	13.55	84.43	3.94	81.32	0.81	85.38	3.72	62.58	6.55	89.00
3	IV	12.98	86.11	4.04	83.24	0.78	87.85	4.63	56.44	4.73	92.50
4	I	12.97	84.78	3.80	81.28	1.06	77.49	2.16	79.19	7.32	87.77
5	II	13.79	85.92	4.68	79.79	1.30	77.23	2.67	76.88	6.70	90.19
6	IV	15.05	83.89	5.50	77.18	1.10	82.87	4.82	54.66	5.37	91.48
7	III	14.92	82.85	4.79	77.29	1.08	80.51	3.28	67.00	7.26	87.82
8	I	13.52	84.14	4.38	78.42	1.20	74.52	2.47	76.20	6.95	88.39
9	III	13.06	84.99	4.35	79.37	1.01	81.77	3.39	65.90	5.78	90.30
10	IV	14.87	84.09	4.90	79.67	1.08	83.18	5.26	50.17	5.15	91.83
11	I	16.47	80.68	4.88	75.96	1.44	69.43	2.45	76.40	9.34	84.39
12	II	13.94	85.77	4.38	81.09	1.10	80.74	2.92	74.72	7.08	89.64
13	II	14.23	89.15	4.05	82.51	1.15	79.86	2.87	75.15	7.81	88.67
14	III	13.05	85.00	4.00	81.03	0.90	83.75	3.46	65.19	6.02	89.90
15	IV	14.55	84.43	4.43	81.62	0.80	87.54	5.41	49.11	5.47	91.33
16	I	13.81	83.80	3.76	81.48	1.33	71.76	2.00	80.73	8.00	86.63
17	I	13.69	83.94	3.73	81.63	1.12	76.22	2.12	79.58	8.05	86.55
18	III	12.08	86.12	3.48	83.50	0.93	83.21	3.41	65.69	5.40	90.94
19	IV	14.15	84.86	4.20	82.57	0.99	84.58	4.92	53.72	5.33	91.55
20	II	13.54	86.18	3.36	85.49	1.06	81.44	3.11	73.07	7.33	70.65
21	IV	12.96	86.13	4.22	82.49	0.92	85.67	4.44	58.23	4.72	92.52
22	III	14.92	82.85	4.78	77.34	1.11	79.96	4.20	57.75	6.41	89.24
23	I	18.22	78.63	5.40	73.40	1.64	65.18	3.39	67.34	9.77	83.67
24	II	13.33	86.39	4.01	82.69	1.11	80.56	2.74	76.28	6.79	90.06

APPENDIX 3 (Contd.)

D. Collection Period 4 (56 days of age)

No.	Tt.	D.M.		Cr. Prot.		Mth. Ex.		Ash		N.F.E	
		(b)	%	(b)	%	(b)	%	(b)	%	(b)	%
1	II	14.21	85.49	4.49	80.61	1.39	75.66	2.60	77.49	7.44	89.11
2	III	14.49	83.35	4.54	78.47	1.31	76.35	3.84	61.37	6.31	89.41
3	IV	14.66	84.31	4.79	80.12	1.21	81.15	5.34	49.76	4.89	92.25
4	I	14.39	83.32	4.21	79.26	1.63	65.39	2.27	78.13	7.87	86.85
5	II	14.89	84.80	4.44	80.83	1.83	67.95	2.88	75.06	7.30	89.31
6	IV	15.97	82.91	5.55	76.97	1.46	77.26	5.57	47.60	5.12	91.88
7	III	14.94	82.83	5.17	75.49	1.42	74.37	4.16	58.15	5.82	90.23
8	I	16.04	81.18	4.68	76.95	1.93	59.02	2.63	74.66	8.39	85.97
9	III	14.83	82.96	5.03	76.15	1.44	74.01	3.89	60.87	6.25	89.95
10	IV	15.72	83.18	5.15	78.63	1.45	77.41	5.74	46.00	5.13	91.86
11	I	14.91	82.51	4.69	76.90	1.72	63.48	2.32	77.65	7.85	86.88
12	II	16.57	83.08	5.17	77.68	1.83	67.95	3.50	69.70	7.89	88.45
13	II	16.66	82.99	4.95	78.63	1.64	71.28	3.75	67.53	8.17	88.04
14	III	18.84	78.35	5.62	73.35	1.72	68.95	5.52	44.47	6.64	88.86
15	IV	14.93	84.02	4.52	81.24	1.03	83.96	5.36	49.58	5.62	91.09
16	I	15.75	81.52	4.49	77.88	1.86	60.51	2.45	76.97	8.72	85.43
17	I	17.34	79.66	4.83	76.21	1.68	64.33	2.89	72.16	9.94	83.39
18	III	14.21	83.67	4.46	78.85	1.16	79.06	4.30	56.74	5.81	90.25
19	IV	14.96	83.99	4.92	79.59	1.19	81.46	5.06	52.40	5.50	91.28
20	II	13.54	86.18	3.47	85.02	1.25	78.11	3.33	71.69	6.91	89.88
21	IV	13.52	85.53	4.55	81.12	0.99	84.58	4.72	55.60	4.65	92.63
22	III	14.43	83.42	5.17	75.49	1.18	78.70	3.73	62.47	5.97	89.98
23	I	15.29	82.06	4.94	75.67	1.43	69.64	2.53	75.63	8.02	86.60
24	II	14.88	84.81	4.24	81.69	1.27	77.76	2.84	75.41	8.05	88.22

APPENDIX 4

Feed : index ratio (a) - calculated from
Table 17

Trt.	D.M.	Cr. Prot.	Ether Extract	Ash	N.F.E.
CS	106.63	28.17	9.97	10.78	67.41
I	85.24	20.30	4.71	10.38	59.84
II	97.94	23.16	5.71	11.55	68.31
III	87.02	21.09	5.54	9.94	59.59
IV	93.44	24.10	6.42	10.63	63.06

APPENDIX 5

Average Daily Water Consumption (galls.) per Two Piglets, over 3 Day Trial Periods

21/8/59 - 23/8/59				28/8/59 - 31/8/59			
Pen No.	Treatment	Age of Piglets	Average Water Consumption (Gallons)	Pen No.	Treatment	Age of Piglets	Average Water Consumption (Gallons)
A	1	II	} 7 $\frac{3}{4}$ - 8 weeks	17	I	} 7 $\frac{3}{4}$ - 8 weeks	1 $\frac{1}{2}$
	2	III		18	III		3
	3	IV		19	IV		3 $\frac{5}{8}$
	4	I		20	II		2
B	5	II	} 7 $\frac{1}{2}$ - 7 $\frac{3}{4}$ weeks				
	6	IV		2 $\frac{1}{8}$			
	7	III		3 $\frac{7}{8}$			
	8	I		3 $\frac{1}{4}$			
C	9	III	} 7 - 7 $\frac{1}{2}$ weeks				
	10	IV		2 $\frac{7}{8}$			
	11	I		3 $\frac{3}{8}$			
	12	II		1 $\frac{1}{4}$			
D	21	IV	} 6 - 6 $\frac{1}{2}$ weeks	28/8/59 - 31/8/59		30/8/59 - 1/9/59	
	22	III		} 7 $\frac{1}{2}$ - 7 $\frac{3}{4}$ weeks	3	} 7 $\frac{3}{4}$ - 8 weeks	4
	23	I			2 $\frac{3}{4}$		3 $\frac{1}{4}$
	24	II			1 $\frac{1}{2}$		2
		1 $\frac{1}{4}$	2 $\frac{1}{4}$				

E

APPENDIX 6

Weekly Meal Consumption (lbs) per Pair of Piglets -
21-57 days of age.

Pen No.	1st Week (Common Starter)	2nd Week	Tt.	3rd week	4th week	5th week	56th-57th Day	Total Consumption 21-57 Days	Total Consumption 35-57 Days
1	4.5	12.75	II	22.0	32.75	42.25	5.0	119.25	102.0
2	6.5	13.0	III	19.0	25.75	36.25	5.0	105.50	86.0
3	7.5	18.25	IV	29.0	34.5	46.0	6.5	141.75	115.0
4	7.5	16.50	I	23.5	28.5	41.5	6.0	123.5	99.5
5	8.0	15.0	II	25.0	27.5	38.5	5.5	119.5	96.5
6	9.0	17.25	IV	24.0	29.0	43.0	6.0	128.25	102.0
7	9.0	17.75	III	13.25	30.0	42.25	6.5	121.75	95.0
8	8.0	16.50	I	16.50	30.5	39.0	5.0	115.5	91.0
9	9.0	15.0	III	24.0	36.0	47.75	7.0	138.75	114.75
10	8.75	14.75	IV	20.0	28.5	46.5	6.5	125.0	101.5
11	9.5	14.0	I	18.0	34.0	39.5	4.5	119.5	96.0
12	9.5	15.0	II	25.0	35.75	38.50	5.5	134.5	104.75
13	6.0	11.0	II	25.0	34.5	44.5	6.0	127.0	110.0
14	7.25	8.5	III	16.0	25.5	35.25	4.0	96.5	81.75
15	5.0	7.25	IV	5.0	23.75	33.0	5.0	79.0	66.75
16	5.75	8.0	I	17.5	22.5	37.25	5.25	96.25	82.5
17	5.75	7.75	I	19.5	32.0	34.75	5.0	104.75	91.25
18	5.25	5.75	III	16.25	26.25	30.75	4.5	88.75	77.75
19	5.75	7.0	IV	16.25	25.0	25.0	3.5	82.50	69.75
20	5.75	7.25	II	20.25	30.25	30.25	4.5	98.25	85.25
21	5.25	7.0	IV	15.75	27.75	28.75	4.0	88.5	76.25
22	4.75	11.0	III	21.25	31.25	41.5	6.0	115.75	100.0
23	5.25	12.0	I	23.0	32.5	38.5	5.5	116.75	99.5
24	5.75	9.0	II	18.25	30.25	31.0	4.5	98.75	84.0

APPENDIX 7

Feed Conversion Efficiency per Pair of
Pigs - 35th-57th Day.

Pen No.	Treatment	lbs Meal 35th-57th Day	Combined Weight Gain 35th-57th Day (lbs)	lbs Meal per lbs Gain
1	II	102.0	56.5	1.80
2	III	86.0	57.0	1.51
3	IV	116.0	67.5	1.72
4	I	99.5	54.5	1.83
5	II	96.5	59.0	1.64
6	IV	102.0	62.0	1.65
7	III	95.0	58.5	1.62
8	I	91.0	49.5	1.84
9	III	114.75	60.0	1.91
10	IV	101.5	52.0	1.95
11	I	96.0	54.5	1.76
12	II	104.75	57.0	1.84
13	II	110.0	67.0	1.64
14	III	81.75	53.5	1.53
15	IV	66.75	51.5	1.3
16	I	82.50	54.0	1.53
17	I	91.25	57.0	1.6
18	III	77.75	51.5	1.51
19	IV	69.75	54.0	1.22
20	II	85.25	52.5	1.62
21	IV	76.25	51.0	1.5
22	III	100.0	60.5	1.65
23	I	99.5	58.5	1.7
24	II	84.0	55.0	1.53

APPENDIX 8

Analyses of Variance of Coefficients of Digestibility for each Faecal Collection Period. (See Chapter IV.)

a) Period 1: (28 days of age)

i. Dry matter

Source	SS	df	MS	F	Result
Between Blocks	120.93	5	24.19	22.19	**
Within Blocks	19.70	18	1.09		
Total	140.63	23			

ii. Crude protein

Source	SS	df	MS	F	Result
Between Blocks	658.86	5	131.77	31.98	**
Within Blocks	74.20	18	4.12		
Total	733.06	23			

iii. Ether extract

Source	SS	df	MS	F	Result
Between Blocks	481.83	5	96.37	10.63	**
Within Blocks	163.18	18	9.07		
Total	645.01	23			

iv. Nitrogen-free extract

Source	SS	df	MS	F	Result
Between Blocks	34.0	5	6.80	10.00	**
Within Blocks	12.26	18	0.68		
Total	46.26	23			

Period 1 (Contd.)

v. Ash

Source	SS	df	MS	F	Result
Between Blocks	358.06	5	71.61	5.54	**
Within Blocks	232.82	18	12.93		
Total	590.88	23			

b) Period 2 (42 days of age)

i. Dry matter

Source	SS	df	MS	F	Result
Blocks	3.36	5	0.672	0.367	N.S.
Treatments	59.03	3	19.67	10.74	**
Error	27.49	15	1.83		
Total	89.88	23			

ii. Crude protein

Source	SS	df	MS	F	Result
Blocks	46.46	5	9.29	3.49	*
Treatments	79.83	3	26.61	10.00	**
Error	39.91	15	2.66		
Total	166.20	23			

iii. Ether extract

Source	SS	df	MS	F	Result
Blocks	109.68	5	21.94	2.78	N.S.
Treatments	870.92	3	290.31	36.84	**
Error	118.24	15	7.88		
Total	1098.84	23			

Period 2 (Contd.)

iv. Nitrogen-free extract

Source	SS	df	MS	F	Result
Blocks	3.17	5	0.634	.587	N.S.
Treatments	103.74	3	34.58	32.02	**
Error	16.17	15	1.08		
Total	123.08	23			

v. Ash

Source	SS	df	MS	F	Result
Blocks	90.39	5	18.08	1.30	N.S.
Treatments	1057.3	3	352.43	25.35	**
Error	208.56	15	13.9		
Total	1356.25	23			

c) Period 3 (49 days of age)

i. Dry matter

Source	SS	df	MS	F	Result
Blocks	15.31	5	3.06	1.26	N.S.
Treatments	46.26	3	15.42	6.37	**
Error	26.23	15	2.42		
Total	97.80	23			

ii. Crude protein

Source	SS	df	MS	F	Result
Blocks	80.70	5	16.14	4.39	*
Treatments	36.77	3	12.26	3.33	*
Error	55.18	15	3.68		
Total	172.65	23			

Period 3 (Contd.)

iii. Ether extract

Source	SS	df	MS	F	Result
Blocks	71.79	5	14.36	2.41	N.S.
Treatments	546.29	3	182.10	30.55	**
Error	89.33	15	5.96		
Total	707.41	23			

iv. Nitrogen-free extract

Source	SS	df	MS	F	Result
Blocks	63.77	5	12.75	0.732	N.S.
Treatments	130.97	3	43.66	2.51	N.S.
Error	261.34	15	17.42		
Total	456.08	23			
Linear Trend	120.10	1	120.10	6.89	*

v. Ash

Source	SS	df	MS	F	Result
Blocks	43.78	5	8.76	0.631	N.S.
Treatments	2099.19	3	699.73	50.38	**
Error	208.33	15	13.89		
Total	2351.30	23			

d) Period 4 (56 days of age)

i. Dry matter

Source	SS	df	MS	F	Result
Blocks	15.09	5	3.02	1.76	N.S.
Treatments	31.71	3	10.57	6.15	**
Error	25.80	15	1.72		
Total	72.60	23			

ii. Crude protein

Source	SS	df	MS	F	Result
Blocks	23.97	5	4.79	1.39	N.S.
Treatments	77.60	3	25.87	7.52	**
Error	51.64	15	3.44		
Total	153.21	23			

iii. Ether extract

Source	SS	df	MS	F	Result
Blocks	205.46	5	41.09	6.61	**
Treatments	925.42	3	308.47	49.59	**
Error	93.24	15	6.22		
Total	1224.12	23			

iv. Nitrogen-free extract

Source	SS	df	MS	F	Result
Blocks	3.56	5	0.712	0.967	N.S.
Treatments	111.17	3	37.06	50.35	**
Error	11.04	15	0.736		
Total	125.77	23			

v. Ash

Source	SS	df	MS	F	Result
Blocks	157.05	5	31.41	2.13	N.S.
Treatments	2747.85	3	915.95	62.14	**
Error	221.14	15	14.74		
Total	3126.04	23			