PIG NUTRITION WITH SPECIAL REFERENCE TO EARLY WEANING

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INTRODUCTION.

The thesis consists of two parts: The first part is a review of the literature concerning certain aspects of the nutrition of the pig between birth and eight weeks of age, with special reference to early weaning diets and techniques and the purposes for which they may be used. The second part is a report on investigations carried out by the author on a system of rearing to which the name "Partial Early Weaning" has been given.

References are arranged in alphabetical order of authors' surnames at the end of each chapter. Titles of periodicals are abbreviated, wherever possible, in accordance with the "World List of Scientific Periodicals".

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SYSTEMS OF REARING.

For an unknown length of time pigs have been reared under a system which has come to be known as natural rearing and which is based on an eight-week lactation of the sow. At eight weeks of age the sow and litter are separated suddenly and finally and the sow returns, after a few days, to the boar. This system provides, in theory at least, for the production of two litters each year. It is seen, in fact, that the term "natural" used to describe this system is a misnomer, since the sow in the wild state produces only one litter per annum. The choice of eight weeks as a weaning age is quite arbitrary and was probably decided upon because it was the minimum age, before the adoption of creep feeding and other improvements to management and breeding, at which the average piglet was sufficiently well developed physiologically to be weaned on to a conventional pig meal. The object of shortening the lactation period was presumably to raise the output of the wild sow, this being roughly doubled.

Largely due to the adoption of creep feeding over the last twenty to thirty years, the average weaning weight of naturally reared pigs has risen considerably and pigs may now be weaned at ages earlier than that of eight weeks, commonly six weeks. This may be done without the use of special diets or techniques and does not constitute a departure from natural rearing. Those systems in which piglets are reared away from the sow from an early age and are fed diets specially designed for the purpose are the ones which qualify for description as "early weaning" systems. There is no lower limit to the age from which piglets may be reared away from the sow by early weaning techniques and the rearing of baby pigs obtained/

obtained by hysterectomy about two days pre-partum is described briefly in a later section. The term "artificial rearing" is very often used to describe systems in which piglets are weaned at ages of less than about one week as a deliberate policy and in cases where their rearing from a very early age is dictated by some circumstance such as the death of the sow. The upper age limit to early weaning occurs at about five to six weeks at which age early weaning merges into natural rearing.

Of all domestic animals the new-born pig is probably the quickest to commence suckling. Almost as soon as it is born, in some cases even before the severance of the umbilical cord, the baby pig finds a place on the udder and obtains the first milk, or colostrum, which is immediately available to it. The composition of colostrum in terms of total solids, fat, protein, lactose, minerals and vitamins is different from that of the later milk but its main value may be said to lie in the fact that it provides antibodies against various infections to which the piglet is exposed. In the pig the maternal and foetal circulations are separated by several tissue layers which block the transfer of antibodies from the dam to the foetus, and it has been established that at birth the baby pig is devoid of antibodies. It thus depends entirely on the colostral transfer of immunity.

Within a few days of parturition the secretion from the udder has altered and may be said to have become that of "normal milk", although the composition of milk is by no means constant throughout lactation. Yield also alters as lactation proceeds.

The average birth weight of the piglet is about 2.5 to 3.0 lb. and for the first three weeks of life the naturally reared piglet is almost entirely dependent on its dam's milk for nutrients (Table 1). The/

The amount of milk which the sow can produce is usually sufficient to provide for optimum growth during this period but thereafter the quantity of milk available becomes the limiting factor controlling the growth of the litter. These facts have led to two routine practices in the management of the naturally reared litter:

(a) The weighing of the litter at three weeks of age, the result being taken to indicate the capacity for milk production of the sow.

(b) The provision of a creep feed for the piglets, in the form of a meal or pellets, designed to supplement the nutrients obtained from the sow's milk from about three weeks of age.

The average weights, at eight weeks, of naturally reared piglets provided with a creep feed might be about 35 to 45 lb. as compared with averages of about 25 to 30 lb. for piglets reared solely on the milk of their dams.

TABLE 1. FOOD INTAKE OF NATURALLY REARED PIGLETS BETWEEN BIRTH AND EIGHT WEEKS OF AGE (Schneider, 1934).

Week	Sow's Milk (Percentage of Total Intake).	Supplementary Feed. (Percentage of Total Intake).
1	100.0	-
2	100.0	-
3	97.4	2.6
4	83.9	16.1
5	66.2	33.8
6	49.9	50.1
7	37.0	63.0
8	28.5	71.5

Even/

Even when a supplementary feed is provided, the main source of nutrients to naturally reared piglets for almost three-quarters of the period from birth to eight weeks of age is sow's milk (Table 1). In the rearing of piglets away from the sow, sow's colostrum and milk are again of considerable importance: Under practical conditions it is essential that early weaned piglets, as well as naturally reared ones, be allowed access to colostrum, and sow's milk constitutes an important source of nutrients to piglets weaned at ages of more than a few days. Sow's milk has, naturally, served as the pattern for most diets prepared for early weaning, particularly those designed for artificial rearing. The early sow's milk substitutes, based on the scant information on the composition of sow's milk, contained many nutrients, the amounts of which were quite empirical. The lack of knowledge of the composition of sow's milk and of the requirements of baby pigs resulted in the over-fortification of many of these diets, a wasteful and expensive procedure. In consequence of this, numerous investigations into the composition of sow's milk were initiated and the results provided information used in the preparation of better substitutes.

Sow's colostrum and milk are thus of great importance, and yield and composition will be considered in some detail.

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THE YIELD OF SOW'S MILK.

Unlike other large animals the sow will not voluntarily eject her milk except when her litter is suckling. This is because only the suckling pig provides the stimulus which results in the release of oxytocin from the pituitary, causing the let-down of the milk. Early in parturition, however, colostrum can be obtained readily by hand milking. The reason for this is that during parturition the pituitary releases oxytocin to assist the contraction of the uterus, and the hormone is present in the bloodstream for a short period at this time.

As a result of the sow's failure to eject her milk voluntarily, except when nursing her pigs, the method which has been used by almost all workers for estimating milk yield involves the weighing of the suckling pigs. This is done, either individually or as a litter, immediately before and immediately after suckling. The gain in weight recorded in this way is taken to be the weight of milk obtained by the pigs. This procedure is continued for a period of several hours, and is repeated at intervals throughout lactation. The piglets are allowed access to their dam only at pre-determined intervals during the controlled periods. The weight of milk obtained by the litter during these controlled periods is then multiplied by the interval between each of the periods to give an estimate of the total milk production during lactation.

In considering the results obtained from measurements of the milk yield of the sow some understanding of the suckling habits of litters is important:

It has been firmly established that the normal interval between sucklings is in the region of one hour. Wells et al. (1940) found the average interval in early lactation to be 60 minutes although late/

late in lactation intervals were more variable. Niwa et al. (1951) observed that the average interval between sucklings was 60 minutes up to the end of the second week, thereafter it lengthened gradually to 86.4 minutes just before weaning at 60 days. Smith (1952a) found the average interval between sucklings to be 60 minutes in the first week of lactation rising gradually to 72 minutes in the eighth week. Smith (1952b), reporting on the results of earlier workers, stated that there was substantial agreement that the frequency of suckling is at intervals of about 60 minutes early in lactation, the period being more variable in later lactation, 60 to 90 minutes. Barber et al. (1955) obtained data which showed that the average interval between sucklings ranged from 51 minutes for six-day-old piglets to 63 minutes for piglets aged fifty-one days. On occasions intervals between consecutive sucklings of as low as 25 minutes and as high as 96 minutes were recorded but the majority of the recordings were closely grouped around 60 minutes. The average interval between sucklings under natural conditions was observed by Salmon-Legagneur (1956) to be 65.5 ± 20.6 minutes. There was only a slight increase in intervals as lactation advanced. Berek and Csoka (1959) found the average interval between sucklings to be about 57 minutes at the beginning of lactation and 76 minutes towards the end. In addition, Smith (1952a) found little difference between day and night intervals, the latter being slightly but not significantly longer. The observations of Barber et al. (1955) and Salmon-Legagneur (1956) corroborate this.

These findings are of importance in view of the suckling intervals of from two to six hours imposed in a large number of the early studies on sow's milk yield. It has now been conclusively demonstrated that in this type of work the length of the suckling interval/

interval used is of fundamental importance and that the unnatural intervals imposed by a number of workers resulted in gross underestimations of yield.

Wells et al. (1940) stated in a brief report of their work that sows on an hourly suckling frequency gave approximately one-third more milk daily than those on a two-hourly frequency. Barber et al. (1955) obtained conclusive evidence that when suckling was permitted every hour, the quantity of milk obtained by the litters was much greater than when suckling was permitted only every two-and-a-half or three hours. Other evidence obtained in studies of the function of the mammary gland points to similar conclusions, as do the results of the small number of workers who used approximately hourly suckling frequencies. These results are much higher than those of workers who imposed longer intervals between sucklings.

Measurements of Sow's Milk Yield.

In considering the estimates of yield obtained by various workers, those from studies where normal suckling behaviour, as described above, was not simulated and which would seem, therefore, not to indicate the true milking capacity of the sows concerned, are summarised briefly in Table 2. Studies in which one to one-and-a-half hour intervals between sucklings were used are dealt with more fully, as representing milk yield more accurately.

Niwa et al (1951) investigated the milk yields of nine Middle White sows over a lactation period of sixty days. Intervals of approximately one hour were allowed between sucklings and observations were continued over twenty-four hours once weekly. The average daily milk yield per sow was 9.31 lb. and the daily average per piglet was 1.36 lb. Average total sixty-day lactation yield was 559 lb.

Smith/

TABLE 2. SOME EARLY ESTIMATES OF THE MILK YIELD OF SOWS AND THE METHODS USED TO OBTAIN THEM.

Breed	Interval Between Sucklings	Controlled Periods	Lactation Period Covered.	Average Daily Milk Yield(lb.) Total	Per Piglet	Lactation Yield(lb.)	Authority
York-shire	3 hr.	24hr. during 4th week.	4th week	2.75	0.31	-	Gohren (1865)
Poland China & Chester White	2 hr. by day. 4-5 hr. by night.	3-day periods every 17 days.	8-12 weeks	5.20	0.76	-	Henry & Woll (1897)
Berk-shire	2 hr. by day. 4 hr. by night.	2-day periods during 4th and 8th weeks.	12 weeks	6.31	0.82	354.4	Carlyle (1903)
Poland China				4.86	0.65	372.2	
Razor-back				5.17	0.82	289.5	
Land-schwein	3 hr.	24 hr. once weekly.	8 weeks	6.90	0.83	388.2	Schmidt & Lauprecht (1926)
-	2-6 hr.	24 hr. every 10 days.	10 weeks	7.70	1.03	413.2	Hughes & Hart (1935)
Large Black	2-3 hr.	24 hr. once weekly.	8 weeks				Bonsma & Oosthuizen (1935)
(a) Gilts & Sows				6.55	0.98	366.7	
(b) Gilts				6.04	0.88		
Poland China & Duroc Jersey	Some 1 hr. Some 2 hr.	-	8 weeks	11.70	-	655.0	Wells et al. (1940)

Smith (1952a) measured the milk production of five purebred Berkshire sows over their first, second and third lactations. Intervals of one hour, extended to one-and-a-quarter hours as lactation advanced, were allowed between sucklings, the actual interval in each case being determined by previous observation of the normal behaviour of the sow and litter concerned. Observations were continued over a period of twenty-four hours once weekly throughout a lactation of eight weeks. The average milk yield results obtained are shown in Table 3.

TABLE 3. AVERAGE MILK YIELD RESULTS OVER THREE LACTATIONS (Smith, 1952a).

Lactation Number.	Daily Yield Per Sow. (lb.)	Daily Yield Per Piglet. (lb.)	Total Lactation Yield Per Sow. (lb.)
1	10.73	1.53	601
2	15.46	2.21	866
3	17.09	2.08	957

These results were much higher than any others previously recorded and it was suggested that the feeding of skimmed milk to the sows might be the reason for this. Results obtained by later workers have, however, shown that while this factor may have played some part in producing the very high yields recorded, the main reason for them was the use of natural suckling frequencies in their measurement.

Smith (1952b) in a further report on his work, in which the suckling frequencies, controlled periods and lactation length were as in his previous paper (Smith, 1952a), reported average results obtained from Berkshire sows of 12.07 lb. milk per sow per day, 1.70 lb. per piglet per day and total lactation production of 674 lb.

Barber/

Barber et al. (1955) measured, under natural conditions, the lactation yield of three Large White gilts. Intervals of one hour were allowed between sucklings and the controlled periods were of forty-eight hours duration, with the exception of the last one (at fifty-one days) of gilt 3, which was of twenty-four hours duration owing to practical difficulties encountered. The controlled periods were carried out at eight weekly intervals, except in the case of gilt 3 where only seven were imposed.

The object of continuing each controlled period for forty-eight hours was to obtain data on the day to day, as opposed to week to week, variation in milk yield. A consistent fall in yield in the second part of each controlled period was found, however, and this was considered to be due to the disturbance caused to the pigs by the process of recording. After estimating the average total lactation yield on the bases of both the forty-eight hour totals and the totals obtained during the first twenty-four hours only of each controlled period, it was decided that the latter gave the better indication of the true milking capacity. It is on this basis that the results below were calculated. The actual difference between the two figures obtained for average total lactation yield was 28 lb., the estimate based on twenty-four hour totals being the higher. The yield results are shown in Table 4.

TABLE 4. MILK YIELD RESULTS FOR THREE GILTS (Barber et al., 1955).

Gilt No.	Daily Yield Per Gilt. (lb.)	Daily Yield Per Piglet. (lb.)	Total Lactation Yield. (lb.)
1	15.75	1.43	882
2	13.68	1.24	766
3	11.69	1.17	655

Gilt/

Gilt 3, the yield of which was considerably lower than the yields of the other two, had a very irregular lactation curve with two marked troughs during the third and sixth weeks respectively, indicating the occurrence of some upset in either milk secretion or ejection, or both, at these times.

Lodge (1959) studied the milk yield of eight Wessex Saddleback sows (four pairs of litter sisters) over their first three lactations. Feeding during pregnancy was the same for all sows but during lactation one sow of each pair was given a high plane of feeding and the other a low plane. Milk yields were measured and the effect of feeding during lactation on milk yield was studied. The intervals allowed between controlled sucklings were one-and-a-quarter hours for the first six weeks and one-and-a-half hours for the last two weeks of lactation. Each sow was recorded over a seven-and-a-half hour period once per week. The yield results obtained are shown in Table 5.

TABLE 5. AVERAGE MILK YIELD RESULTS OVER THREE LACTATIONS (Lodge, 1959).

Lactation Number.	Daily Yield Per Sow. (lb.)	Daily Yield Per Piglet. (lb.)	Total Lactation Yield Per Sow. (lb.)
High Plane.			
1	15.96	No data	894
2	21.79	No data	1120
3	20.07	No data	1124
Low Plane.			
1	13.64	No data	764
2	16.82	No data	942
3	18.07	No data	1012

The yields obtained in this work are extremely high. The mean lactation yield of all sows (993 lb.) is 185 lb. higher than that of the sows used by/

by Smith (1952a) which was previously the highest published mean value. Even the mean yield of the low plane sows is some 100 lb. higher than Smith's mean value. Lodge considered it improbable that his recording technique could have overestimated milk yield unless the sows used, unlike those of previous workers, produced considerably more milk during the day (over which period they were recorded) than at night.

The Effect of Litter Size on Milk Yield.

(a) The Effect on Total Milk Yield.

It has been established that total milk yield is positively correlated with the number of pigs in the litter. This was observed by a number of the early workers and, more recently, by Smith (1952b), Lalevic (1953), Kovacs (1954) and Allen and Lasley (1960). Barber et al. (1955) also found some confirmation of this correlation in a comparison of their results with those of Niwa et al. (1951).

(b) The Effect on Milk Yield per Piglet.

A number of the early workers noted that as the number of piglets in the litter increased, the total quantity of milk obtained by each piglet in the litter decreased. Barber et al. (1955) found confirmation of this in comparisons of their results with those of Niwa et al. (1951) and Smith (1952a).

The Effect of Sow's Age (Lactation Number) on Milk Yield.

Milk yield increases with advancing lactation number for at least the first three lactations. This has been mentioned by a large number of workers, including Wells et al. (1940), Smith (1952b), Berge and Indrebø (1953), Lalevic (1953) and Fey (1958). A study of the results of other workers who observed milk yield over successive lactations/

lactations shows the same trend: The average total lactation yields obtained from five sows by Smith (1952a) show yield increases of 44.1% in the second lactation over the first and of 10.5% in the third lactation over the second. Lodge (1959) found that four sows fed to a low plane during lactation yielded 23.3% more milk in their second lactation than in their first and there was a further increase of 7.4% over the second lactation yield in the third. However, four sows fed to a very high plane during lactation, although they yielded 36.5% more milk in their second lactation than in their first, produced 7.9% less in their third lactation than in their second.

That there is a turning point after which milk yield declines with advancing lactation number is well known and is evidenced by the poorer performance up to three weeks of age of the litters of old sows. No measurements of yield over successive lactations after the third have, however, been found and it is impossible to state at what age the decline sets in or to what levels the yield falls as age increases.

The Shape of the Lactation Curve.

The shape of the lactation curve has been described by many of the workers who have studied sow's milk yield. There is general agreement that production rises for some time after the start of lactation, reaches a definite peak and then falls again until lactation is ended by the separation of the sow from her litter. There is, however, considerable variation in reports concerning the stage of lactation at which peak yield occurs.

Kovacs (1954) reported peak yield in the second week of lactation; Barber et al. (1955) observed/

observed maximum yield in one of their gilts in the second week and of another in the third week (the lactation curve of a third gilt was atypical); Niwa et al. (1951) found that yield reached a peak two to three weeks post-partum; Hughes and Hart (1935) reported maximum production between the second and fourth weeks; Kertesz et al. (1959) reported a maximum about three weeks post-partum; Schmidt and Lauprecht (1926) found that peak yield was reached at three or four weeks; Henry and Woll (1897) reported maximum yield about the middle of lactation (which is taken as being the fourth week); Smith (1952a,b) obtained data which showed maximum production to be in the fourth to fifth weeks; Hartman and Pond (1960), who measured the lactation trends of sows by machine milking after injection of constant amounts of oxytocin, found that the maximum volume of milk was produced at the beginning of the fifth week; Lalevic (1953) found maximum yield to occur in the sixth to seventh weeks.

Smith (1952a,b) speculated upon the possibility of altering the shape of the lactation curve by feeding or management practices and the effects which this might have. Lodge (1959) observed marked differences in the shapes of the lactation curves of sows fed to a low plane of nutrition during lactation and those fed to a high plane. Marked differences between lactations also occurred. In the first lactation, the lactation curves of both treatment groups ran roughly parallel, with no marked peak but rather a plateau between the third and sixth weeks. In the second and third lactations the low plane sows followed the type of lactation curve described by most other workers, the peak being reached in this case in the second week with/

with a steady decline thereafter. The high plane sows, however, maintained a high although fluctuating level of production up to the sixth week before the yield started to fall. The difference in the level of production between the two treatments was evident only from the third week onwards.

The Relationship Between Milk Consumption and Growth of the Baby Pig.

That there is a close positive relationship between the milk consumption and growth of the baby pig while it is receiving its dam's milk only has been observed by a number of workers, including Bonsma and Oosthuizen (1935), Donald (1937), Smith (1952a) and Barber et al. (1955). After supplementary creep feeding begins, this close relationship is not seen (Smith, 1952a; Barber et al., 1955; Lodge, 1959).

The Relationship Between Milk Consumption and Creep Feed Consumption of the Baby Pig.

The majority of workers have found that, considering the litter as a whole, the shape of the lactation curve and creep feed intake are closely correlated and as milk yield decreases, creep feed consumption increases. Two explanations could be put forward to account for this relationship: Either the reduced milk consumption is a result of the increased creep feed intake or the drop in milk production causes increased intake of supplementary food. A number of findings point to the latter conclusion:

(a) The weight of evidence pointing to the conclusion that the supply of sow's milk is frequently insufficient to meet the requirements of the piglets for optimum growth (e.g. Barber et al., 1955).

(b)/

(b) The data obtained by Smith (1952a) which suggest that if milk yield is too high, the appetite of the piglets for supplementary food may well be reduced.

(c) Behaviour studies carried out by Smith (1952b) showed that litters almost invariably suckled the sow first and then went to the creep to feed. They then slept until the next suckling was due. It was concluded that the piglets ate the supplementary food because they were not receiving sufficient from the sow.

(d) The finding of Lodge (1959) that the considerable difference between the levels of production of sows on a high plane of nutrition during lactation and those on a low plane did not affect litter growth rates significantly. One of the reasons for this was that the difference in yield between the two treatment groups was evident only from the third week onwards, by which time the piglets had access to a creep feed. The tendency of piglets of the low-plane, low-yielding sows to consume more of this supplementary feed than those of the high-plane, high-yielding sows, resulted in the mean total dry matter consumption (milk dry matter plus creep feed dry matter) per piglet in the two treatment groups being virtually the same. However, Allen and Lasley (1960) found a positive correlation between the amount/

amount of milk produced by the sow and the amount of creep feed consumed by her litter, piglets of sows producing the most milk consuming the most creep feed.

(e) The suggestion of Barber et al. (1955) that, on the basis of their findings, a piglet receiving only limited supplies of sow's milk may be encouraged to start eating creep feed at an earlier age, and eat more during the last five weeks of lactation than a littermate suckling one of the more productive teats, the excess meal consumed by the former more than compensating for the lower milk intake.

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THE COMPOSITION OF SOW'S COLOSTRUM AND MILK

The fact that milk is the principal source of nutrients to the young during a considerable period of the lactation has resulted in the determination of at least the major constituents of the milk of many species of animals. Investigations into the constituents of the colostrum and milk of the sow began in the latter part of the nineteenth century and the work has continued up to the present day. The amount of information obtained in the early work was small, owing chiefly to the difficulty of obtaining satisfactory samples of milk from the sow. Samples of colostrum can be obtained readily during parturition by hand milking, but about two to three hours after the onset of parturition the sow beings to control the let-down of her milk and will normally give it up only when her piglets are suckling. This means that milk cannot be obtained from the sow by milking in the manner normally effective with other large animals.

In the early work on the subject, small samples of milk were obtained by quietly removing a piglet while the sow was nursing and milking the vacated teat by hand. The samples of milk obtained in this way were neither large enough nor representative enough to provide a satisfactory sample for analysis.

The difficulty of the sow having seemingly complete control over the let-down of her milk was overcome when Braude et al. (1947) applied a different technique to the problem. This was the technique which Ely and Petersen (1941) had devised for inducing the let-down of milk in the cow, by injection into the bloodstream of the oxytocic principle of the pituitary. Braude and his colleagues were able to obtain with ease from a number of sows large samples of milk at intervals/

intervals throughout lactation. To obtain a sample of milk by this method the sow was secured and 5 units of the oxytocic principle of the pituitary (0.5 ml. Pitocin diluted with about ten times its volume of normal saline) were injected into an ear vein. After a few seconds, two milkers, one on each side of the sow, expressed as much milk as was possible from a number of teats into glass containers. As a rule 200 to 300 ml. of milk were collected with ease. This stimulatory effect of injections of the oxytocic principle of the pituitary thus provided a means whereby representative samples of the whole milk could be obtained readily, and the investigations carried out by Braude and his colleagues provided the first really reliable information on the composition of the milk of the sow following complete milking.

Bowland et al. (1949 a,b,c) modified the above technique, using 1 ml. of Pitocin containing 10 units of the oxytocic principle of the pituitary and obtaining a rather larger sample. There were practical difficulties attached to the practice of hand milking done by two workers, one on each side of the sow, and, together with the limited time available in which to empty several pairs of teats, this may have resulted in the sample of milk withdrawn differing in volume and composition from the milk withdrawn by a litter during the natural suckling process. Bowland and his colleagues therefore attempted machine milking but this proved unsatisfactory.

The development of a milking machine for sows at the Ruakura Animal Research Station in New Zealand (Smith et al., 1951) made it comparatively easy for workers there to withdraw milk from a number of teats at the same time. The results obtained earlier indicated that the milk of different teats may vary in composition,/

composition, especially in fat content (Perrin, 1954a) and to obtain milk as close as possible in composition to that taken by the litter it is necessary to withdraw from all the functional glands at the same time. Perrin also regulated the size of the samples taken for analysis to that taken by the litter at an average suckling, in order not to upset the suckling habit and growth of the litter. Perrin considered that samples taken in this manner are more representative of the milk drawn by the litter than were those available to earlier investigators.

Lodge (1957a) introduced certain modifications in his design of a milking machine for sows and in the technique of milking, although basing both largely on the descriptions of the New Zealand workers. Both intramuscular and subcutaneous injections of up to 2.5 ml. of Pitocin were tried as alternatives to injection into an ear vein, but response to these injections was slow and the actual let-down effect was weak.

Hartman and Pond (1960) also developed a milking machine for sows which was broadly similar to those of previous workers. The machine was used for securing samples for composition studies and also for measuring yield. In this work, approximately 1.5 ml. of oxytocin (purified oxytocic principle) were injected into an ear vein to induce the let-down of the milk.

In dealing here with the composition of sow's colostrum and milk, some early results obtained for major constituents are tabulated under the appropriate headings. A more detailed consideration is given to estimates obtained in the modern work, carried out since the application of oxytocin-induced let-down and, more recently, machine milking to the problem of obtaining suitable samples for analysis.

Estimates of the Composition of Sow's Colostrum and Milk.

(1) Colostrum.

(a) Antibodies.

That antibodies are present in high titre in the colostrum of the sow and that the pig is dependent on the colostral transfer of immunity from one generation to the next has been demonstrated conclusively as a result of a number of studies:

Jakobsen and Moustgaard (1950) studied the γ-globulin content of the serum of piglets. No γ-globulin was found in the serum of new-born piglets, but a few hours after the first ingestion of colostrum γ-globulin made up a high proportion of the total serum protein. Similar results were obtained by Bauriedel et al. (1954). These workers found no measurable γ-globulin in the serum of new-born piglets or in the serum of colostrum-deprived pigs up to six weeks old. Piglets receiving colostrum, however, possessed appreciable serum γ-globulin a few hours after the first suckling.

In amino acid studies, Beacom and Bowland (1951) found colostral protein to be rich in leucine, valine and threonine which are known to constitute large proportions of immune proteins. These workers deduced from this that sow's colostrum is rich in antibodies.

Young and Underdahl (1950) studied the colostrum of three sows and the serum of their piglets (twenty-eight in all). The sows were immunised against swine influenza before breeding by intranasal inoculation with swine influenza virus. Samples of the colostrum of the sows (obtained at farrowing and also thirty hours post-partum) and the serum of the young (obtained at the same times) were tested for antibodies capable of neutralising or causing haemagglutination/

haemagglutination inhibition of swine influenza virus. Both antibodies were present in high titre in the colostrum of the sows. Neither antibody was found in the serum of the new-born piglets prior to the suckling but both were present in high titre in the serum obtained thirty hours post-partum.

Hoerlein (1957) compared the responses of colostrum-deprived piglets and piglets receiving colostrum, to antigens given by inoculation. Colostrum-deprived piglets failed to produce a measurable response up to eight weeks of age, whereas piglets receiving colostrum responded at the first inoculation, when they were three weeks old, and the response increased markedly up to six weeks of age.

(b) Total Solids.

TABLE 6. SOME EARLY ESTIMATES OF THE TOTAL SOLIDS CONTENT OF SOW'S COLOSTRUM.

Number of Sows	Total Solids Content (%)	Authority
1	29.87	Gohren (1865)
2	24.66	Ostertag & Zuntz (1908)
13	31.86	Hughes & Hart (1935)

The first of the modern work on the subject was that reported by Braude et al. (1946). These workers obtained fourteen samples of colostrum from Large White sows during parturition and found the mean content of total solids to be 23.9% with a range of 20.6% to 27.2%. In a second paper, Braude et al. (1947) described work in which colostrum samples were obtained during parturition from nine Large White sows in twelve lactations, six in summer and six in winter. The mean value obtained for total solids in the twelve samples/

samples of colostrum was 25.16 $\pm$ 0.96%. The range of values was 17.7 to 29.4%. The difference between summer and winter values was not statistically significant.

Bowland et al. (1949b) presented data from studies with two lots of sows, one lot carried through gestation on pasture and the second carried through gestation in drylot. The sows on pasture were Poland Chinas and Chester Whites, while those in drylot were all Poland Chinas. The mean value for total solids in the colostrum of pasture sows on the first day of lactation was 22.81%, this being also the value for total solids in the first-day colostrum of drylot sows.

Perrin (1955) reported analyses of the colostrum obtained from four sows. The total solids contents of the colostrum obtained from the sows at parturition were:

Sow A - 29.41%
Sow B - 33.10%
Sow C - 30.73%
Sow D - 27.60%

The average of these four values is 30.21%. Values are also given for the total solids content of colostrum at three-hour intervals from parturition up to thirty hours post-partum and at less frequent intervals thereafter up to five days post-partum.

(c) Fat.

TABLE 7. SOME EARLY ESTIMATES OF THE FAT CONTENT OF SOW'S COLOSTRUM.

Number of Sows	Fat Content (%)	Authority
1	9.53	Gohren (1865)
2	4.04	Ostertag & Zuntz (1908)
7	5.10	Hughes & Hart (1935)

Braude et al. (1946) found that the mean value for fat in eighteen samples of colostrum from Large White sows was 3.4% with a range of 1.7 to 5.8%. In a second paper, Braude et al. (1947) reported analyses of the colostrum of nine Large White sows in the course of twelve lactations, six in summer and six in winter. The mean value for fat in the twelve samples was 4.05 $\pm$ 0.43%, the range of values observed being 2.0 to 5.4%. There was no significant difference between summer and winter values.

Bowland et al. (1949c) measured the fat content of the colostrum of ten sows carried through gestation on pasture and ten carried through gestation in drylot. It was found that colostrum obtained on the first day of lactation from pasture sows had an average fat content of 6.73%, while that from drylot sows averaged 6.45%. No breed differences between the Chester White and Poland China sows used were apparent.

Perrin (1955) found the following values for fat content in the colostrum of four sows, samples being taken at parturition:

Sow A - 7.0%
Sow B - 7.62%
Sow C - 7.70%
Sow D - 6.51%

The average of these four values is 7.2%. Values are also given for the fat content of colostrum at three-hour intervals from parturition to thirty hours post-partum and at less frequent intervals thereafter up to five days post-partum.

(d) Solids-Not-Fat.

TABLE 8. SOME EARLY ESTIMATES OF THE SOLIDS-NOT-FAT CONTENT OF SOW'S COLOSTRUM.

Number of Sows	Solids-Not-Fat Content (%)	Authority
1	20.34	Gohren (1865)
1	19.66	Ostertag & Zuntz (1908)

Braude et al. (1946) found the average solids-not-fat content of fourteen samples of colostrum obtained from Large White sows during parturition to be 20.5%. In a second paper, Braude et al. (1947) reported studies of the colostrum of nine Large White sows in the course of twelve lactations, six in summer and six in winter. The mean value for solids-not-fat in the twelve samples was 21.11 $\pm$ 0.87%, the range of values observed being 14.2% to 25.0%.

Perrin (1955) recorded a detailed investigation of the colostrum obtained from four Berkshire sows. The values for solids-not-fat in the colostrum at parturition were:

Sow A - 22.41%
Sow B - 25.48%
Sow C - 23.03%
Sow D - 21.09%

The average of these four values is 23.0%.

(e) Protein

TABLE 9. SOME EARLY ESTIMATES OF THE PROTEIN CONTENT OF SOW'S COLOSTRUM.

Number of Sows	Protein Content (%)	Authority
1	15.56	Gohren (1865)
2	15.86	Ostertag & Zuntz (1908)
7	16.64	Hughes & Hart (1935)

Braude et al. (1947) obtained colostrum from six Large White sows at parturition. Protein was found to have a mean value in the six samples taken of 17.77 $\pm$ 0.93%, with a range of 14.64% to 21.30%.

Bowland et al. (1949b) conducted studies with two groups of sows, one group carried through gestation on/

on pasture and the other carried through gestation in drylot. Colostrum obtained from pasture sows on the first day of lactation had a mean protein content of 11.25% and that obtained similarly from drylot sows had a mean protein content of 14.29%.

Perrin (1955) obtained the following values for protein content from the colostrum of four Berkshire sows milked during parturition:

Sow A - 17.18%
Sow B - 22.55%
Sow C - 18.84%
Sow D - 16.96%

The average of these four values is 18.8%. Values are also given in this report for the protein content of colostrum at three-hour intervals up to thirty hours post-partum and at less frequent intervals thereafter up to five days post-partum.

(f) Essential Amino Acids.

The only investigation which has been conducted on this subject is that of Beacom and Bowland (1951). These workers studied the essential amino acid (except tryptophan) content of the colostrum of two Yorkshire sows. The results shown in Table 10 are those obtained from analyses of the colostrum of one of the sows. The samples were obtained three hours post-partum (the samples obtained from the other sow were taken ten hours post-partum). Samples were also obtained on the third day of lactation.

TABLE 10. THE ESSENTIAL AMINO ACID CONTENT OF SOW'S COLOSTRUM (Beacom & Bowland, 1951)

Amino Acid	Content (Percentage of protein)
Leucine	9.01
Isoleucine	3.33
Valine	6.46
Threonine	5.48
Lysine	6.30
Histidine	1.83
Arginine	5.58
Tryptophan	No data
Phenylalanine	4.01
Methionine	1.18

(g) Lactose.

TABLE 11. SOME EARLY ESTIMATES OF THE LACTOSE CONTENT OF SOW'S COLOSTRUM.

Number of Sows	Lactose Content (%)	Authority
1	3.84	Gohren (1865)
2	1.78	Ostertag & Zuntz (1908)

Braude et al. (1947) carried out analyses of samples of colostrum obtained at parturition from six Large White sows. The mean value for lactose in the samples was found to be 3.46 $\pm$ 0.09%, the range of values being 3.22% to 3.79%.

Bowland et al. (1949b) reported results from studies conducted with two groups of sows, one group carried through gestation on pasture and the second carried through gestation in drylot. The sows on pasture were Poland Chinas and Chester Whites, while all those in drylot were Poland Chinas. The values obtained for lactose in first-day colostrum from the two groups were:

Pasture sows - 2.89%
Drylot sows - 3.42%

Perrin (1955) recorded detailed analyses of the colostrum of four Berkshire sows. The values for lactose in the colostrum at parturition were:

Sow A - 2.48%
Sow B - 1.97%
Sow C - 2.45%
Sow D - 3.09%

The average of these four values is 2.5%. Values are also given for the lactose content of colostrum at three-hour intervals from parturition to thirty hours post-partum and at less frequent intervals thereafter up/

up to five days post-partum.

(h) Ash.

TABLE 12. SOME EARLY ESTIMATES OF THE ASH CONTENT OF SOW'S COLOSTRUM.

Number of Sows	Ash Content (%)	Authority
1	0.85	Gohren (1865)
2	0.71	Ostertag & Zuntz (1908)
13	0.61	Hughes & Hart (1935)

Braude et al. (1947) analysed samples of colostrum obtained during parturition from six Large White sows. The mean ash content of the samples was 0.63 $\pm$ 0.20%, the range of values being 0.54% to 0.67%.

In a study of the composition of sow's colostrum Bowland et al. (1949b) obtained samples from two groups of sows. One group was carried through gestation on pasture and the other was carried through gestation in drylot. The sows on pasture were Poland Chinas and Chester Whites, while all those in drylot were Poland Chinas. The mean values obtained for ash in the first-day colostrum of the two groups were:

Pasture sows - 0.72%
Drylot sows - 0.73%

Perrin (1955) recorded a detailed investigation of the colostrum of four Berkshire sows. The values for ash in the colostrum at parturition were:

Sow A - 0.66%
Sow B - 0.63%
Sow C - 0.62%
Sow D - 0.62%

The average of these four values is 0.63%. Values are also given for the ash content of colostrum at three-hour intervals from parturition to thirty hours post-partum/

partum and at less frequent intervals thereafter up to five days post-partum.

(i) Ash Constituents.

Calcium.

Hughes and Hart (1935) measured the calcium content of single samples of colostrum obtained during parturition from each of thirteen sows, the breed of which is not stated. The average value for calcium in the samples was 0.055%. Braude et al. (1947) obtained colostrum during parturition from six Large White sows, one sample being taken from each sow. The mean calcium content of the samples was 0.053 ± 0.005%. Perrin (1955) obtained colostrum from one Berkshire sow at parturition and found that this sample contained 0.055% calcium. Three hours post-partum the values for calcium in the colostrum of two sows were 0.049% and 0.041% respectively. Sampling was continued at frequent intervals up to eighty hours post-partum and values are given for the calcium contents at these times.

Phosphorus.

Hughes and Hart (1935) measured the phosphorus content of single samples of colostrum obtained during parturition from each of thirteen sows, the breed of which is not stated. The average value for phosphorus in the samples was 0.078%. Braude et al. (1947) obtained colostrum at parturition from six Large White sows, one sample being taken from each sow. The mean phosphorus content of the samples was found to be 0.082 ± 0.008%. Perrin (1955) obtained colostrum from one Berkshire sow at parturition. This sample contained 0.111% phosphorus. Three hours post-partum the values obtained for phosphorus in the colostrum of two sows were 0.111% and 0.108% respectively. Sampling was continued at frequent intervals up to eighty hours post-partum and values are given for the phosphorus contents at these times.

Magnesium./

Magnesium.

Perrin (1955) obtained colostrum from one Berkshire sow at parturition. This sample contained 0.018% magnesium. Three hours post-partum the values obtained for magnesium in the colostrum of two sows were the same at 0.013%.

Chlorine.

Perrin (1955) obtained colostrum from two Berkshire sows at parturition. These samples contained 0.097% and 0.091% chlorine respectively. Three hours post-partum the values obtained from the same two sows were 0.103% and 0.091% chlorine respectively. Sampling was continued at frequent intervals up to eighty hours post-partum and values are given for the chlorine contents at these times.

Iron.

Venn et al. (1947) collected samples of colostrum from a number of Large White and first-cross Wessex/Large White sows at parturition. Four sows received a basal ration, others were given a supplement of 12 g. of crude ferric oxide daily from the fourth week of pregnancy until farrowing and others received the same supplement during pregnancy and 16 g. daily during lactation. The iron content of the colostrum of sows receiving the basal ration averaged 265 µg. per 100 g., that of sows receiving supplementary iron during pregnancy only averaged 235 µg. per 100 g., and that of sows receiving supplementary iron during both pregnancy and lactation averaged 282 µg. per 100 g.

Manganese.

As far as is known, the manganese content of sow's colostrum has not been determined separately from that of later milk. Plumlee et al. (1956) found that five colostrum and milk samples obtained from a gilt fed from weaning a diet containing 40 p.p.m. of manganese/

manganese averaged 0.38 p.p.m. manganese. This compared with an average of 0.27 p.p.m. for a total of three samples obtained from two gilts fed from weaning a diet containing only 0.5 p.p.m. of manganese. The latter two animals were milking so poorly that no more samples could be obtained.

(j) Vitamins.

Vitamin A.

The first published work on the vitamin A content of the colostrum of the sow seems to have been that of Schofield et al. (1942). These workers found that the administration of large doses of vitamin A to sows during pregnancy increased the concentration of the vitamin in their colostrum. Values for the vitamin A content of the colostrum are given but the volume of colostrum to which they refer is not stated. The values range from 42.8 to 97.5 I.U. for samples from three sows receiving ordinary rations, and for samples from two sows which were given daily during pregnancy 30,000 I.U. of vitamin A the values given are 571 I.U. and 850 I.U., respectively.

Benham (1943) found that the vitamin A content of colostrum ranged from 131 I.U. per 100 ml. to 254 I.U. per 100 ml. on the first day of lactation. These figures are from five sows which were "at least partly deficient in vitamin A at parturition." Benham found that the administration of 400,000 I.U. of vitamin A during the ten days prior to farrowing caused the vitamin A level in the colostrum of one sow on the first day of lactation to rise to 1,165 I.U. per 100 ml.

Braude et al. (1946) found that the mean vitamin A content of eighteen samples of colostrum obtained from Large White sows during parturition was 247 I.U. per 100 ml. (89 I.U. per g. of fat). The range/

range of values was 103 to 462 I.U. per 100 ml.(42 to 137 I.U. per g. of fat). No carotene was detected in any of the samples. In a further study, Braude et al. (1947) found the mean vitamin A content of single samples of colostrum from nine Large White sows to be 71.1 ± 9.1 I.U. per g. of fat.

Luecke et al. (1947) obtained single samples of colostrum between parturition and three hours post-partum from six sows (two sows from each of the Chester White, Hampshire and Berkshire breeds). The vitamin A and carotene contents of these samples were determined. The mean values obtained were:

Vitamin A - 60 µg. per 100 ml.
(Range - 13 to 122 µg. per 100 ml.)

Carotene - 24 µg. per 100 ml.
(Range - 9 to 37 µg. per 100 ml.)

The sows in this work received no vitamin A supplements but were fed a supposedly adequate ration which contained 10% alfalfa hay (rich in carotene). No breed differences in the vitamin A and carotene contents of colostrum could be noted from the limited number of samples which were taken.

Bowland et al. (1949a) conducted an investigation with two groups of sows, one group carried through gestation on pasture and the other carried through gestation in drylot. The sows on pasture were Poland Chinas and Chester Whites, while all those in drylot were Poland Chinas. The mean values obtained for vitamin A in first-day colostrum from the two groups were:

Pasture sows - 144.8 µg. per 100 ml.

Drylot sows - 128.7 µg. per 100 ml.

Again using Poland China and Chester White sows, Bowland et al. (1949c) studied the effect of lactation and ration on the fat and vitamin A contents of/

of sow's colostrum and milk. The sows were grouped as in the previous experiment (Bowland et al., 1949a). The mean values obtained for vitamin A in first-day colostrum from the two groups were:

Pasture sows - 40.23 µg. per g. of fat.
Drylot sows - 25.41 µg. per g. of fat.
No breed differences were noted.

The seasonal variation in the vitamin A content of sow's colostrum was studied by Bowland et al. (1951). It was found that spring-farrowing sows showed lower average vitamin A values than did sows farrowing in the winter. Depletion of vitamin A stores was held to account for this variation. Sows which were kept in continuous drylot had lower vitamin A values than those which had access to pasture.

Heidebrecht et al. (1951) obtained colostrum samples during parturition from fifteen Hampshire gilts producing their first litters and one Duroc sow producing her third litter. The average value obtained for vitamin A in the samples was 132 µg. per 100 ml. The samples were found to contain essentially no carotene. It was found that supplementation of the diet with either vitamin A or carotene increased the vitamin A content of the colostrum.

Vitamin B_1 (Thiamine).

The first work on the thiamine content of sow's colostrum seems to have been that of Braude et al. (1946). These workers obtained seventeen samples of colostrum at parturition from Large White sows and found the mean thiamine content of these to be 145 µg. per 100 ml. The range of values was 81 to 260 µg. per 100 ml. On four occasions the free thiamine content was measured at the same time as the total thiamine content. The mean value obtained for free thiamine was 108 µg. per 100 ml., the range of values being 93 to 140 µg. per 100 ml.

In/

In a further study, Braude et al. (1947) measured the thiamine content of the colostrum of nine Large White sows over twelve lactations, six in summer and six in winter. The mean value for total thiamine in the samples was 96.8 ± 7.8 µg. per 100 ml., the mean value for free thiamine being 70.8 ± 7.8 µg. per 100 ml. There was no significant seasonal difference in thiamine content.

Luecke et al. (1947) obtained six samples of colostrum from six sows (two sows from each of the Chester White, Hampshire and Berkshire breeds) within the three hours following parturition. The mean thiamine content of the samples was 86 µg. per 100 ml., the range of values being 52 to 101 µg. per 100 ml.

Davis et al. (1951) obtained colostrum during two successive farrowing seasons from a total of thirty-five sows and gilts of Duroc, Chester White, Hampshire and cross-bred breeding. The average thiamine content of the colostrum samples was 60 µg. per 100 ml. In the spring experiment, the thiamine content of colostrum was higher than that of the subsequent milk, but in the autumn experiment the reverse was the case. No obvious correlation between breed and the thiamine content of colostrum was apparent. Likewise, no consistent age differences were noted. It was considered, however, that a larger investigation would be required to eliminate the possibility of breed and/or age differences occurring.

Nicotinic Acid.

Luecke et al. (1947) obtained the first results for the nicotinic acid content of colostrum. These workers took single samples from each of six sows (two sows from each of the Chester White, Hampshire and Berkshire breeds) within the three hours following parturition. The nicotinic acid content of the samples averaged 143 µg. per 100 ml., the range of values being 114 to 185 µg. per 100 ml.

Davis/

Davis et al. (1951) obtained colostrum during two successive farrowing seasons from a total of thirty-five sows and gilts of Duroc, Chester White, Hampshire and cross-bred breeding. The average nicotinic acid content of the colostrum samples was 170 µg. per 100 ml. No obvious correlation between breed and the nicotinic acid content of colostrum was apparent. Similarly, no consistent age differences were noted. It was considered, however, that a more extensive investigation would be necessary to eliminate the possibility of minor breed differences occurring.

Riboflavin.

In the original work on the riboflavin content of sow's colostrum, Braude et al. (1946) obtained sixteen samples of colostrum from Large White sows at parturition. The mean riboflavin content of these samples was 45.6 µg. per 100 ml., the range of values being 21 to 78 µg. per 100 ml. In a further study, Braude et al. (1947) obtained colostrum from nine Large White sows in the course of twelve lactations, six in summer and six in winter. The mean value for riboflavin in the samples was 44.9 ± 5.7 µg. per 100 ml. The riboflavin content of summer colostrum was significantly higher than that of winter colostrum. It was considered that the higher riboflavin levels in summer were possibly explained by the generous supply of fresh herbage received by the sows.

Luecke et al. (1947) obtained single samples of colostrum from six sows (two sows from each of the Chester White, Hampshire and Berkshire breeds) within the three hours following parturition. The mean value for riboflavin in the samples was 400 µg. per 100 ml. This value is very much higher than those obtained by Braude et al. (1946, 1947). The reasons for this are mentioned below.

Davis et al. (1951) obtained colostrum during two successive farrowing seasons from a total of thirty-five/

thirty-five sows and gilts of Duroc, Chester White, Hampshire and cross-bred breeding. The mean riboflavin content of the samples was 500 $\pm$ 270 µg. per 100 ml. These results are similar to that obtained by Luecke et al. (1947).

In an attempt to resolve the problem of the conflicting results obtained by workers in the U.K. and in the U.S.A., collaboration was undertaken and the results of this were published before those obtained separately by the American workers. In the combined work (Davis et al., 1950) it was found that the rapid and simple extraction method used by Braude and his colleagues in the determination chemically of riboflavin was not suitable for sow's colostrum and milk and that the values given by the English workers were much too low. It was shown that more drastic extraction of the samples yielded the same low results but if the last purification step was omitted, the results were much higher. Eventually, a method was devised, using which the value obtained approached the value arrived at microbiologically by Davis et al. (1951). It seemed clear, as a result of this work, that riboflavin was present in sow's colostrum and milk at least partly in a form different from those in cow's colostrum and milk (described by other workers) and that the riboflavin activity of sow's milk was much higher than originally reported by Braude and his colleagues.

Barnhart et al. (1954) conducted work designed to determine the effect of gestation and lactation rations on certain vitamins in sow's colostrum and milk. Twelve Duroc sows were selcted at random for this study, eight being used in a first experiment and four in a second. Colostrum samples were obtained on the second day of lactation. In the first experiment, there was no significant increase in the riboflavin content of the colostrum/

colostrum when 10% dehydrated alfalfa meal was added to plant or animal protein basal rations. The average riboflavin content of samples obtained from sows on all treatments was 255 µg. per 100 ml. In the second experiment, fortification of a basal ration with dehydrated alfalfa meal and meat and bone scraps increased the riboflavin content of colostrum significantly. The average values obtained from colostrum from sows on the two rations were:

Basal ration - 165 µg. per 100 ml.
Fortified ration - 225 µg. per 100 ml.

Pantothenic Acid.

Luecke et al. (1947) were responsible for the first estimates of the pantothenic acid content of sow's colostrum. Single samples of colostrum were taken within the three hours following parturition from six sows (two sows from each of the Chester White, Hampshire and Berkshire breeds). The average pantothenic acid content of the samples was 105 µg. per 100 ml., the range of values being 60 to 170 µg. per 100 ml.

Davis et al. (1951) obtained colostrum during two successive farrowing seasons from a total of thirty-five sows and gilts of Duroc, Chester White, Hampshire and cross-bred breeding. The mean pantothenic acid content of the samples was 70 ± 49 µg. per 100 ml. No obvious correlations between breed and the pantothenic acid content of colostrum were revealed, nor were there any apparent between age and the pantothenic acid content.

Barnhart et al. (1954) conducted work designed to determine the effect of gestation and lactation rations on certain vitamins in sow's colostrum and milk. Twelve Duroc sows were selected at random for the study, eight being used in a first experiment and four in a second. The colostrum samples were obtained on the second/

second day of lactation. In the first experiment, the addition of 10% dehydrated alfalfa meal to plant or animal protein basal rations increased the pantothenic acid content of the colostrum significantly. The average values obtained for the pantothenic acid contents of colostrum from sows on the four ration treatments were:

Plant basal	- 175 µg. per 100 ml.
Plant basal + 10% alfalfa meal	- 465 µg. per 100 ml.
Plant and animal basal	- 160 µg. per 100 ml.
Plant and animal basal + 10% alfalfa meal	- 282 µg. per 100 ml.

In the second experiment, there was no significant difference in the pantothenic acid content of colostrum from sows fed a basal ration and those fed the basal ration fortified with dehydrated alfalfa meal and meat and bone scraps. The average value for pantothenic acid in colostrum from sows on both rations was 195 µg. per 100 ml.

Pyridoxin.

As far as is known, the only estimate of the pyridoxin content of sow's colostrum available is that of Braude (1954). This estimate was obtained in work, the details of which have not been published. The value given is 2.5 µg. per 100 ml.

Vitamin B_{12} (Cyanocobalamine).

As far as is known, the only estimate of the vitamin B_{12} content of sow's colostrum available is that of Braude (1954). This estimate was obtained in work, the details of which have not been published. The value given is 0.15 µg. per 100 ml.

Vitamin C (Ascorbic Acid).

The first record of work on the ascorbic acid content of sow's colostrum occurs in a paper by Braude/

Braude et al. (1946). The ascorbic acid content of the colostrum at parturition proved to be very high. The mean value in seventeen samples obtained from Large White sows was 23.8 mg. per 100 ml., the range of values being 12.0 to 36.0 mg. per 100 ml. In a further study, Braude et al. (1947) obtained colostrum from nine Large White sows in the course of twelve lactations, six in summer and six in winter. The mean value found for the ascorbic acid content of colostrum was 30.6 ± 2.0 mg. per 100 ml. There was no seasonal variation in the ascorbic acid content.

Bowland et al. (1949a) conducted an investigation with two groups of sows, one group carried through gestation on pasture and the other carried through gestation in drylot. The sows on pasture were Poland Chinas and Chester Whites, while all those in drylot were Poland Chinas. The mean values obtained for ascorbic acid in first-day colostrum from the two groups were:

Pasture sows - 18.8 mg. per 100 ml.
Drylot sows - 24.6 mg. per 100 ml.

Heidebrecht et al. (1951) obtained colostrum samples during parturition from fifteen Hampshire gilts producing their first litters and one Duroc sow producing her third litter. The mean value obtained for the ascorbic acid content of the samples was 19 mg. per 100 ml.

Vitamin D.

No data are available.

Vitamin E.

Whiting and Loosli (1948) divided twenty-five sows into two groups, one receiving a basal ration and the other the basal ration plus pre-partum supplementation with 80 mg. of mixed tocopherols per 100 lb. of body weight per day. Colostrum samples (taken/

(taken before the sows had been suckled) from the basal group contained 186 ± 61 µg. of tocopherol per g. of fat, and those from the supplemented group contained 399 ± 175 µg. per g. of fat. The increase in tocopherol content caused by pre-partum tocopherol supplementation was highly significant.

(2) Milk.

(a) Antibodies.

Young and Underdahl (1950) obtained milk samples from three sows at weekly intervals throughout lactation. The sows had been immunised against swine influenza before breeding by intranasal inoculation with swine influenza virus. The milk samples were tested for antibodies capable of neutralising or causing haemagglutination inhibition of swine influenza virus. The titres of both of these antibodies, which had been high in colostrum, dropped considerably during the first four weeks of lactation. Thereafter, the rate of decline was less rapid.

(b) Total Solids.

TABLE 13. SOME EARLY ESTIMATES OF THE TOTAL SOLIDS CONTENT OF SOW'S MILK.

Number of Sows	Total Solids Content (%)	Authority
4	19.80	Henry & Woll (1897)
5	17.72	Woll (1899)
12	19.49	Carlyle (1903)
8	16.60	Hughes & Hart (1935)

Braude/

Braude et al. (1947) reported studies of the milk of nine Large White sows in the course of twelve lactations, six in summer and six in winter. The mean value obtained for total solids in the milk was 19.87 $\pm$ 0.14%. There was no significant difference between summer and winter values.

Bowland et al. (1949b) presented data from studies with two lots of sows, one lot carried through gestation on pasture and the second carried through gestation in drylot. The sows on pasture were Poland Chinas and Chester Whites, while those in drylot were all Poland Chinas. The mean values obtained for total solids in the milk of sows in the two groups were:

Pasture sows - 19.47%
Drylot sows - 20.69%

The higher total solids content of the milk of drylot sows was due to the higher fat content of their milk.

Heidebrecht et al. (1951) obtained milk samples, in the spring, from fifteen Hampshire gilts producing their first litters and one Duroc sow producing her third litter. In the autumn of the same year, samples were obtained from nine Duroc, five Chester White and five Hampshire gilts and sows. The samples were taken on the fifth, fifteenth and fifty-fifth days of lactation and the mean results at these times were:

5th day - 20.0%
15th day - 19.0%
55th day - 20.0%

Perrin (1954a) carried out analyses of the milk of forty-four sows in sixty-eight lactations. The majority of the sows were Berkshires but some of the later lactations involved cross-bred Large White - Berkshire animals. More than four hundred and fifty samples/

samples were taken between the seventh and fifty-sixth days of lactation and these provided an average value of 21.23% total solids. In a later paper, Perrin (1955) reported a detailed investigation of the milk of four Berkshire sows. Values are given for the total solids content at frequent intervals throughout lactation. The values given below are those obtained in mid-lactation (fourth week):

Sow A - 22.45%
Sow B - 20.42%
Sow C - 20.81%
Sow D - 19.77%

The average of these four values is 20.86%.

Lodge (1959) studied the composition of the milk of eight Wessex Saddleback sows. Samples were taken from each of the sows at weekly intervals during three eight-week lactations. The mean total solids content of the milk of the sows was 20.0%.

Kertesz et al. (1959) in a study of the milk of ten Hungarian White and ten Mangalitsa sows found an average value for total solids of 19.06%.

(c) Fat.

TABLE 14. SOME EARLY ESTIMATES OF THE FAT CONTENT OF SOW'S MILK.

Number of Sows	Fat Content (%)	Authority
4	7.06	Henry & Woll (1897)
5	5.97	Woll (1899)
12	6.89	Carlyle (1903)
8	4.90	Hughes & Hart (1935)

Willet/

Willet and Maruyama (1946) studied the fat content of the milk of eighteen sows, representing four unspecified breeds. These workers found that the fat content of the milk increased as the fat content of the ration was increased. The average value for fat in the milk of sows fed garbage only (high fat diet) was 9.6%, whereas that for fat in the milk of sows fed dry concentrates only (low fat diet) was 6.1%. Although it was considered that the absolute values given for fat content might not be representative because of the difficulty of obtaining suitable samples for analysis (this work was carried out prior to the application of oxytocin-induced let-down to the problem of obtaining suitable samples) the increase in fat content, with increasing fat in the diet, was believed to be real.

Braude et al. (1947) reported studies of the milk of nine Large White sows in the course of twelve lactations, six in summer and six in winter. The mean value obtained for fat in the milk was $8.17 \pm 0.17\%$. There was no significant difference between summer and winter values.

Bowland et al. (1949c) measured the fat content of the milk of two groups of sows, one carried through gestation on pasture and the other carried through gestation in drylot. The sows on pasture were Poland Chinas and Chester Whites, while all those in drylot were Poland Chinas. The mean values obtained for fat in the milk of sows in the two groups were:

Pasture sows - 6.12%
Drylot sows - 7.45%

Heidebrecht et al. (1951) obtained milk samples in the spring from fifteen Hampshire gilts producing their first litters and one Duroc sow producing her third litter. In the autumn of the same year/

year, milk samples were taken from nine Durocs, five Chester Whites and five Hampshires producing their first or second litters. The samples were obtained on the fifth, fifteenth and fifty-fifth days of lactation, and the mean values for fat in the milk at these times were:

5th day - 9.0%
15th day - 8.0%
55th day - 7.0%

Niwa et al. (1951) studied the milk of nine Middle White sows. The value given for fat in the milk is 9.97%.

Smith (1952) took milk samples, at weekly intervals, from five Berkshire sows in their third lactations. The average value obtained for fat in the samples was 7.7%.

Berge and Indrebø (1953) obtained a total of sixteen samples from eleven Norwegian Landrace sows. The average value for fat in the samples was 6.1%.

Perrin (1954a) carried out analyses of the milk of forty-four sows in sixty-eight lactations. The majority of the sows were Berkshires but some of the later lactations involved cross-bred Large White - Berkshire animals. More than four hundred and fifty samples were taken between the seventh and fifty-sixth days of lactation and these provided an average value of 9.58% fat.

Lodge (1959) studied the composition of the milk of eight Wessex Saddleback sows. Samples were taken from each of the sows at weekly intervals throughout three eight-week lactations. The mean fat content of the milk was 8.6%.

Kertesz et al. (1959) studied the milk of ten Hungarian White and ten Mangalitsa sows. The average value for fat in the milk was 6.73%.

(d)/

(d) Solids-Not-Fat.

TABLE 15. SOME EARLY ESTIMATES OF THE SOLIDS-NOT-FAT CONTENT OF SOW'S MILK.

Number of Sows	Solids-Not-Fat Content (%)	Authority
1	7.90	Gohren (1865)
4	12.02	Henry & Woll (1897)
5	11.75	Woll (1899)
12	12.60	Carlyle (1903)
1	10.20	Ostertag & Zuntz (1908)

Braude et al. (1947) reported studies of the milk of nine Large White sows in the course of twelve lactations, six in summer and six in winter. The mean value obtained for solids-not-fat in the milk was 11.67 $\pm$ 0.08%.

Bowland et al. (1949b) measured the solids-not-fat content of the milk of two groups of sows, one carried through gestation on pasture and the other carried through gestation in drylot. The sows on pasture were Poland Chinas and Chester Whites, while all those in drylot were Poland Chinas. The mean values obtained for solids-not-fat in the milk of sows in the two groups were:

Pasture sows - 13.16%

Drylot sows - 13.38%

Heidebrecht et al. (1951) obtained milk samples in the spring from fifteen Hampshire gilts producing their first litters and one Duroc sow producing her third litter. In the autumn of the same/

same year, milk samples were taken from nine Durocs, five Chester Whites and five Hampshires producing their first or second litters. The samples were obtained on the fifth, fifteenth and fifty-fifth days of lactation, and the mean values for solids-not-fat in the milk at these times were:

5th day - 11.0%
15th day - 11.0%
55th day - 13.0%

No correlation between the composition of the milk and breed or age was found.

Perrin (1954a) carried out analyses of the milk of forty-four sows in sixty-eight lactations. The majority of the sows were Berkshires but some of the later lactations involved cross-bred Berkshire - Large White animals. More than four hundred and fifty samples were taken between the seventh and fifty-sixth days of lactation and an average solids-not-fat value of 11.65% was obtained. In a later paper, Perrin (1955) reported a detailed investigation of the milk of four Berkshire sows. Values are given for the solids-not-fat content at frequent intervals throughout lactation. The values given below are those obtained in mid-lactation (fourth week):

Sow A - 11.30%
Sow B - 10.52%
Sow C - 11.51%
Sow D - 11.07%

The average of these four values is 11.1%.

(e)/

(e) Protein.

TABLE 16. SOME EARLY ESTIMATES OF THE PROTEIN CONTENT OF SOW'S MILK.

Number of Sows	Protein Content (%)	Authority
4	6.20	Henry & Woll (1897)
5	5.12	Woll (1899)
12	6.06	Carlyle (1903)
8	6.00	Hughes & Hart (1935)

Braude et al. (1947) reported studies of the milk of nine Large White sows in the course of twelve lactations, six in summer and six in winter. The mean value obtained for protein in the milk was $5.79 \pm 0.08\%$. There was no significant difference between summer and winter values.

Bowland et al. (1949b) measured the protein content of the milk of two groups of sows, one carried through gestation on pasture and the other carried through gestation in drylot. The sows on pasture were Poland Chinas and Chester Whites, while all those in drylot were Poland Chinas. The mean values obtained for protein in the milk of sows in the two groups were:

Pasture sows - 7.09%
Drylot sows - 7.42%

Heidebrecht et al. (1951) obtained milk samples in the spring from fifteen Hampshire gilts producing their first litters and one Duroc sow producing her third litter. In the autumn of the same year, milk samples were taken from nine Durocs, five Chester Whites and five Hampshires producing their first/

first or second litters. The samples were obtained on the fifth, fifteenth and fifty-fifth days of lactation, and the mean values for protein in the milk at these times were:

5th day - 6.0%
15th day - 5.0%
55th day - 7.0%

Smith (1952) took milk samples, at weekly intervals, from five Berkshire sows in their third lactations. The average value obtained for protein in the samples was 6.2%.

Berge and Indrebø (1953) obtained a total of sixteen samples from eleven Norwegian Landrace sows. The average value for protein in the samples was 5.4%.

Perrin (1954a) studied the composition of the milk of forty-four sows in sixty-eight lactations. The majority of the sows were Berkshires but some of the later lactations involved cross-bred Large White - Berkshire animals. More than four hundred and fifty samples were taken between the seventh and fifty-sixth days of lactation and the average value for protein in these was 6.11%. In a further study Perrin (1955) reported a detailed investigation of the milk of four Berkshire sows. Values are given for the protein content at frequent intervals throughout lactation. The values given below are those obtained in mid-lactation (fourth week):

Sow A - 5.48%
Sow B - 5.04%
Sow C - 5.38%
Sow D - 5.52%

The average of these four values is 5.36%.

Lodge (1959) studied the composition of the milk of eight Wessex Saddleback sows. Samples were taken from each of the sows at weekly intervals throughout/

throughout three eight-week lactations. The mean protein content of the milk was 5.7%.

Kertesz et al. (1959) studied the milk of ten Hungarian White and ten Mangalitsa sows. The average protein content of the milk was found to be 5.2%.

(f) Essential Amino Acids.

The only investigation which has been conducted on this subject is that of Beacom and Bowland (1951). These workers studied the essential amino acid (except tryptophan) content of the milk of two Yorkshire sows. Samples were taken at weekly intervals throughout lactation. The results shown in Table 17 are averages of the values obtained from samples of the milk of both sows, taken four weeks post-partum.

TABLE 17. THE ESSENTIAL AMINO ACID CONTENT OF SOW'S MILK (Beacom & Bowland, 1951)

Amino Acid	Content (Percentage of protein)
Leucine	7.93
Isoleucine	4.38
Valine	5.03
Threonine	3.63
Lysine	7.50
Histidine	2.30
Arginine	5.82
Tryptophan	No data
Phenylalanine	3.78
Methionine	1.44

(g)/

(g) Lactose.

TABLE 18. SOME EARLY ESTIMATES OF THE LACTOSE CONTENT OF SOW'S MILK.

Number of Sows	Lactose Content (%)	Authority
1	2.19	Gohren (1865)
4	4.75	Henry & Woll (1897)
5	5.81	Woll (1899)
12	5.64	Carlyle (1903)
1	4.59	Ostertag & Zuntz (1908)

Braude et al. (1947) studied the milk of nine Large White sows in the course of twelve lactations, six in summer and six in winter. The mean value obtained for lactose in the milk was 4.81 $\pm$ 0.05%. There was no significant difference between summer and winter values.

Bowland et al. (1949b) obtained milk samples from two groups of sows, one carried through gestation on pasture and the other carried through gestation in drylot. The sows on pasture were Poland Chinas and Chester Whites, while all those in drylot were Poland Chinas. The mean values found for lactose in the milk of the two groups were:

Pasture sows - 5.18%

Drylot sows - 5.08%

Smith (1952) took milk samples, at weekly intervals, from five Berkshire sows in their third lactations. The average value obtained for lactose in the samples was 5.0%.

Berge/

Berge and Indrebø (1953) obtained a total of sixteen samples from eleven Norwegian Landrace sows. The average value for lactose in the samples was 5.9%.

Perrin (1954a) studied the composition of the milk of forty-four sows in sixty-eight lactations. The majority of the sows were Berkshires but some of the later lactations involved cross-bred Large White - Berkshire animals. More than four hundred and fifty samples were taken between the seventh and fifty-sixth days of lactation and the average value for lactose in these was 4.62%.

Lodge (1959) studied the composition of the milk of eight Wessex Saddleback sows. Samples were taken from each of the sows at weekly intervals throughout three eight-week lactations. The mean lactose content of the milk was 4.7%.

(h) Ash.

TABLE 19. SOME EARLY ESTIMATES OF THE ASH CONTENT OF SOW'S MILK.

Number of Sows	Ash Content (%)	Authority
1	0.79	Gohren (1865)
4	1.07	Henry & Woll (1897)
5	0.82	Woll (1899)
12	0.98	Carlyle (1903)
1	0.63	Ostertag & Zuntz (1908)
8	1.00	Hughes & Hart (1935)

Braude/

Braude et al. (1947) measured the ash content of the milk of six Large White sows. The mean value obtained for ash in the milk was 0.94 ± 0.03%.

Bowland et al. (1949b) studied the ash content of the milk of two groups of sows, one carried through gestation on pasture and the other carried through gestation in drylot. The sows on pasture were Poland Chinas and Chester Whites, while all those in drylot were Poland Chinas. The mean values obtained for ash in the milk of sows in the two groups were:

Pasture sows - 0.99%
Drylot sows - 0.98%

Heidebrecht et al. (1951) obtained milk samples in the spring from fifteen Hampshire gilts producing their first litters and one Duroc sow producing her third litter. In the autumn of the same year, milk samples were taken from nine Durocs, five Chester Whites and five Hampshires producing their first or second litters. The samples were obtained on the fifth, fifteenth and fifty-fifth days of lactation, and the mean values for ash in the milk at these times were:

5th day - 0.9%
15th day - 0.9%
55th day - 1.3%

Berge and Indrebø (1953) obtained a total of sixteen samples of milk from eleven Norwegian Landrace sows. The average value for ash in the samples was 0.8%.

Perrin (1954a) studied the composition of the milk of forty-four sows in sixty-eight lactations. The majority of the sows were Berkshires but some of the later lactations involved Large White - Berkshire animals. More than four hundred and fifty samples were/

were taken between the seventh and fifty-sixth days of lactation and the average value for ash in these was 0.92%. In a further study, Perrin (1955) reported a detailed investigation of the milk of four Berkshire sows. Values are given for the ash content at frequent intervals throughout lactation. The values given below are those obtained in mid-lactation (fourth week):

Sow A - 0.86%
Sow B - 0.77%
Sow C - No value given.
Sow D - 0.84%

The average of the three values is 0.82%.

Lodge (1959) studied the composition of the milk of eight Wessex Saddleback sows. Samples were taken from each of the sows at weekly intervals throughout three eight-week lactations. The mean ash content of the milk was 0.89%.

(i) Ash Constituents.

Calcium.

Hughes and Hart (1935) obtained fifty samples of milk from twenty-eight sows at various stages of lactation. The average calcium content of these was 0.252%. Braude et al. (1947) measured the calcium content of the milk of six Large White sows. The mean value for calcium in all samples taken after the tenth day of lactation was $0.250 \pm 0.006\%$. Perrin (1955) measured the calcium content of the milk of two Berkshire sows frequently throughout lactation. In mid-lactation, the milk of one sow contained 0.255% calcium (twenty-eight days post-partum) and the milk of the other contained 0.268% calcium (thirty days post-partum).

Phosphorus/

Phosphorus.

Hughes and Hart (1935) obtained fifty samples of milk from twenty-eight sows, the breed of which is not stated, at various stages of lactation. The average phosphorus content of these was 0.151%. Braude et al. (1947) measured the phosphorus content of the milk of six Large White sows. The mean value for phosphorus in all samples taken after the tenth day of lactation was 0.166 ± 0.002%. Perrin (1955) measured the phosphorus content of the milk of two sows frequently throughout lactation. In mid-lactation, the milk of one sow contained 0.143% phosphorus (twenty-eight days post-partum) and the milk of the other contained 0.155% phosphorus (thirty days post-partum).

Magnesium.

Perrin (1955) measured the magnesium content of the milk of two Berkshire sows frequently throughout lactation. In mid-lactation, the milk of one sow contained 0.015% magnesium (twenty-eight days post-partum) and the milk of the other contained 0.011% magnesium (thirty days post-partum).

Chlorine.

Perrin (1955) measured the chlorine content of the milk of two Berkshire sows frequently throughout lactation. In mid-lactation, the milk of one sow contained 0.121% chlorine (twenty-eight days post-partum) and the milk of the other contained 0.097% chlorine (thirty days post-partum).

Iron.

Venn et al. (1947) obtained samples of milk from a number of Large White and first-cross Wessex/Large White sows. Four sows received a basal ration, others/

others were given a supplement of 12 g. of crude ferric oxide daily from the fourth week of pregnancy until farrowing, and others received the same supplement during pregnancy and 16 g. daily during lactation. Values are reported for the iron content of the milk for the periods five to seven days and ten to twelve days post-partum. The values for the period ten to twelve days post-partum are as follows: Milk from sows receiving the basal ration averaged 180 µg. per 100 g., milk from sows receiving supplementary iron during pregnancy only averaged 240 µg. per 100 g., and milk from sows receiving supplementary iron during both pregnancy and lactation averaged 181 µg. per 100 g. The feeding of iron to the sow during pregnancy or lactation was found to make no difference to the concentration of iron in her milk.

Manganese.

See under (1) Colostrum.

(j) Vitamins.

Vitamin A.

Schofield et al. (1942) were the first workers to study the vitamin A content of sow's milk. These workers reported figures which represented the vitamin A content of the milk as found by them, but omitted to state the volume of milk to which the figures referred. Braude et al. (1947), however, were able to state that, if the figures referred to 100 ml. of milk, they were of the same order as those obtained by them.

Braude et al. (1947) studied the milk of nine Large White sows in the course of twelve lactations, six in summer and six in winter. The mean value obtained for vitamin A in over seventy samples taken between the tenth and fifty-sixth days of lactation was 11.8 $\pm$ 0.4 I.U. per g. of fat. The vitamin A content/

content of the milk was significantly higher in summer than in winter.

Bowland et al. (1949a) presented data from studies conducted with two groups of sows, one group carried through gestation on pasture and the other carried through gestation in drylot. The sows on pasture were Poland Chinas and Chester Whites, while all those in drylot were Poland Chinas. It was found that milk from pasture sows was consistently higher in vitamin A than milk from drylot sows. The average values obtained for vitamin A in milk from sows in the two groups were:

Pasture sows - 52.7 µg. per 100 ml.
Drylot sows - 34.8 µg. per 100 ml.

In a further report, in which the fat content of the milk was also measured, Bowland et al. (1949c) found the average value for vitamin A in the milk of pasture sows to be 10.93 µg. per g. of fat and in the milk of drylot sows to be 5.69 µg. per g. of fat. The breeds of sows and treatments were as in the previously described study (Bowland et al., 1949a). No breed differences between the Poland China and Chester White sows were apparent.

Bowland et al. (1951) carried out an investigation of the seasonal variation in the vitamin A content of the milk of the sow. Forty-eight cross-bred Poland China/Hampshire gilts were divided into three lots in the spring: Lot 1 animals were placed in drylot and were fed a basal ration. Lots 2 and 3 were put out to pasture and were fed the same ration as the first lot. Half of the gilts in each of the three lots were mated in the autumn (Group A). In late autumn, lots 2 and 3 were transferred to drylot. Lot/

Lot 2 was continued on the same basal ration, while lot 3 was fed a ration containing 25% of ground dehydrated alfalfa meal. The second half of the gilts in each of the three lots were mated in mid-winter (Group B). Milk samples were obtained, at the end of the first, fourth and eighth weeks of lactation, from the animals in each lot and group. The results shown in Table 20 for vitamin A content are averages of the values obtained over the period one to eight weeks of lactation.

TABLE 20. THE VITAMIN A CONTENT OF THE MILK OF SOWS UNDER VARIOUS TREATMENTS. (Bowland et al., 1951)

Lot Number	Group	Vitamin A Content (µg. per g. fat)
1	A	4.2
	B	3.2
2	A	6.7
	B	4.1
3	A	7.8
	B	4.6

The treatment differences observed were held to be explainable on the basis of dietary intake of vitamin A precursors. The vitamin A content of the milk of sows farrowing in late winter, when compared with that of spring-farrowing sows, suggested a gradual depletion of the body store of the vitamin.

Heidebrecht et al. (1951) obtained milk samples in the spring from fifteen Hampshire gilts producing their first litters and one Duroc sow producing/

producing her third litter. In the autumn of the same year, samples were taken from nine Durocs, five Chester Whites and five Hampshires producing their first or second litters. The samples were obtained on the fifth, fifteenth and fifty-fifth days of lactation. The mean values obtained for the vitamin A content of the milk at these times were:

5th day - 33.0 µg. per 100 ml.
15th day - 22.0 µg. per 100 ml.
55th day - 19.0 µg. per 100 ml.

In the majority of samples no measurable amount of carotene was found.

In a further experiment, the effect of vitamin A and carotene supplementation of the ration upon the vitamin A content of the milk was studied. Supplementation with either vitamin A or carotene increased the vitamin A content of the milk. No consistent breed or age differences were noted.

Vitamin B_1 (Thiamine).

Braude et al. (1947) studied the milk of nine Large White sows in the course of twelve lactations, six in summer and six in winter. These workers obtained a mean value for total thiamine in the milk of 67.7 ± 1.8 µg. per 100 ml., and for free thiamine of 14.4 ± 1.2 µg. per 100 ml. in samples taken between the tenth and fifty-sixth days of lactation. Total, but not free, thiamine was significantly higher in winter than in summer. The reason for the seasonal change was not clear.

Davis et al. (1951) obtained milk samples during two successive farrowing seasons from a total of thirty-five sows and gilts of Duroc, Chester White, Hampshire and cross-bred breeding. The samples were taken on the fifth, fifteenth and fifty-fifth days/

days of lactation and the values obtained for thiamine at these times are shown below:

5th day - 60 ± 28 µg. per 100 ml.
15th day - 60 ± 28 µg. per 100 ml.
55th day - 70 ± 33 µg. per 100 ml.

No correlation between breed and the thiamine content of the milk was apparent.

Nicotinic Acid.

The only work on the nicotinic acid content of sow's milk which has been published is that of Davis et al. (1951). These workers obtained milk samples during two successive farrowing seasons from a total of thirty-five sows and gilts of Duroc, Chester White, Hampshire and cross-bred breeding. The samples were taken on the fifth, fifteenth and fifty-fifth days of lactation. The values obtained for nicotinic acid at these times are shown below:

5th day - 430 ± 260 µg. per 100 ml.
15th day - 700 ± 390 µg. per 100 ml.
55th day - 800 ± 430 µg. per 100 ml.

The nicotinic acid content of the autumn milk was nearly twice as high as that in the previous spring, although essentially the same ration and management practices were used. At the autumn farrowing, an enteric disturbance of the suckling young which had prevailed in the spring was not observed. In order to obtain additional data on the possible relationship between the nicotinic acid content of the milk and the growth of the piglets, samples of milk were taken during the following spring, on the fifth and twenty-fifth days of lactation, from fifteen sows and thirteen gilts (of unspecified breeding) for analysis for this vitamin The results obtained in the analyses are shown below:/

below:

5th day - Sows - 440 ± 190 µg. per 100 ml.
Gilts - 270 ± 190 µg. per 100 ml.

25th day - Sows - 690 ± 290 µg. per 100 ml.
Gilts - 670 ± 290 µg. per 100 ml.

These values were similar to those of the previous autumn, and the piglets were again relatively free of enteric infection. Whether there was any correlation between these two facts is unknown.

Riboflavin.

Braude et al. (1947) studied the milk of nine Large White sows in the course of twelve lactations, six in summer and six in winter. The mean value obtained for riboflavin in the seventy-six samples taken between the tenth and fifty-sixth days of lactation was 45.7 ± 1.7 µg. per 100 ml.

Davis et al. (1951) obtained milk samples, during two successive farrowing seasons, from a total of thirty-five sows and gilts of Duroc, Chester White, Hampshire and cross-bred breeding. The samples were taken on the fifth, fifteenth and fifty-fifth days of lactation, and the values obtained for riboflavin at these times are shown below:

5th day - 210 ± 90 µg. per 100 ml.
15th day - 220 ± 90 µg. per 100 ml.
55th day - 310 ± 70 µg. per 100 ml.

As in the case of riboflavin in colostrum, these values are much higher than those obtained by Braude et al. (1947). The collaboration undertaken by the two groups of workers involved, in an attempt to resolve the obvious conflict of results, has already been described in the section dealing with the riboflavin content of colostrum (page 37). The result of collaboration was the acceptance of the results of Davis/

Davis et al. (1951) as being those which were representative of the riboflavin content of sow's milk.

Barnhart et al. (1954) conducted research designed to determine the effect of gestation and lactation rations on the content of certain vitamins in sow's milk. Twelve Duroc sows were selected at random for this study, eight being used in a first experiment and four in a second. Samples were obtained on the seventh, twenty-first and fifty-sixth days of lactation. In the first experiment, there was no significant increase in the riboflavin content of the milk when 10% dehydrated alfalfa meal was added to plant or animal protein basal rations. The results obtained for the riboflavin content of the milk of sows on each of the treatments are shown in Table 21.

TABLE 21. THE RIBOFLAVIN CONTENT OF THE MILK OF SOWS ON VARIOUS RATIONS. (Barnhart et al., 1954).

Stage of Lactation (days)	Ration*	Riboflavin Content (μg. per 100 ml.)
7	A	140
	B	220
	C	145
	D	230
21	A	112
	B	200
	C	108
	D	160
56	A	135
	B	228
	C	145
	D	220

* A = plant basal ration
B = plant basal + 10% alfalfa meal
C = plant and animal basal ration
D = plant and animal basal + 10% alfalfa meal

In/

In the second experiment, fortification of a basal ration with dehydrated alfalfa meal and meat and bone scraps increased the riboflavin content of the milk significantly. The results obtained for the riboflavin content of the milk of sows on the basal and fortified rations are shown in Table 22.

TABLE 22. THE RIBOFLAVIN CONTENT OF THE MILK OF SOWS ON TWO RATIONS. (Barnhart et al., 1954).

Stage of Lactation (days)	Ration	Riboflavin Content (µg. per 100 ml.)
7	Basal	120
	Fortified	138
21	Basal	85
	Fortified	105
56	Basal	135
	Fortified	180

In view of the observations made in the work of Braude et al. (1947), Davis et al. (1950, 1951), and of other workers, Modi and Owen (1956) studied the partition of riboflavin between free riboflavin, flavin mononucleotide and flavin adenine dinucleotide in the milk of several species including the pig. It was found, by means of chromatography, that sow's milk usually contains only flavin adenine dinucleotide.

Pantothenic Acid.

Davis et al. (1951) obtained milk samples, during two successive farrowing seasons, from a total of thirty-five sows and gilts of Duroc, Chester White, Hampshire and cross-bred breeding. The samples were taken on the fifth, fifteenth and fifty-fifth days of lactation, and the values obtained for pantothenic acid at these times are shown below:

5th/

5th day - 190 ± 79 µg. per 100 ml.
15th day - 290 ± 180 µg. per 100 ml.
55th day - 540 ± 304 µg. per 100 ml.

Owen and Bowland (1952) studied the pantothenic acid content of the milk of ten Yorkshire gilts. The gilts were divided into four lots on weaning at eight weeks of age, and each lot was fed a ration containing a different level of pantothenic acid. Milk samples were obtained from each animal during the first lactation, the samples being taken one week and six weeks after farrowing. It was found that the pantothenic acid content of the ration had a very definite effect on the amounts of the vitamin present in the milk, as the milk levels increased consistently and quite markedly with the amount of calcium pantothenate added to the basal ration. Microbiological assay was used to determine the pantothenic acid content of the samples, after their preparation by one of two procedures, namely water hydrolysis and enzymatic digestion. Enzymatic digestion gave consistently lower values for pantothenic acid than were obtained by water hydrolysis. This was thought to be due to destruction of the vitamin during the former procedure. The values shown in Table 23 are those obtained using water hydrolysis and are the averages for each lot.

TABLE 23. THE PANTOTHENIC ACID CONTENT OF THE MILK OF SOWS ON VARIOUS RATIONS. (Owen and Bowland, 1952).

Lot Number*	Time After Parturition (weeks)	Pantothenic Acid Content (µg. per 100 ml.)
1	1	550
	6	619
2	1	608
	6	706
3	1	812
	6	1081
4	1	962
	6	1623

*
Lot Number 1 - Fed basal ration (2.5 mg. pantothenic acid per lb. of feed).
Lot Number 2 - Fed basal ration + 3.0 mg. calcium pantothenate per lb. of feed.
Lot Number 3 - Fed basal ration + 6.0 mg. calcium pantothenate per lb. of feed.
Lot Number 4 - Fed basal ration + 12.0 mg. calcium pantothenate per lb. of feed.

Barnhart et al. (1954) conducted research designed to determine the effect of gestation and lactation rations on the content of certain vitamins in sow's milk. Twelve Duroc sows were selected at random for this study, eight being used in a first experiment and four in a second. Samples were taken on the seventh, twenty-first and fifty-sixth days of lactation. In the first experiment, the addition of 10% dehydrated alfalfa meal to plant or animal protein basal rations increased the pantothenic acid content of the milk significantly. The results obtained for the pantothenic acid content of the milk of sows on each of the treatments are shown in Table 24.

TABLE 24. THE PANTOTHENIC ACID CONTENT OF THE MILK OF SOWS ON VARIOUS RATIONS. (Barnhart et al., 1954).

Stage of Lactation (days)	Ration*	Pantothenic Acid Content (µg. per 100 ml.)
7	A	245
	B	485
	C	220
	D	400
21	A	410
	B	585
	C	300
	D	555
56	A	470
	B	670
	C	265
	D	590

*
A = plant basal ration
B = plant basal + 10% alfalfa meal
C = plant and animal basal ration
D = plant and animal basal + 10% alfalfa meal

In the second experiment, there was no significant increase in the pantothenic acid content of the milk when a basal ration was fortified with dehydrated alfalfa meal and meat and bone scraps. The results obtained for the pantothenic acid content of the milk of sows on the basal and fortified rations are shown in Table 25.

TABLE 25. THE PANTOTHENIC ACID CONTENT OF THE MILK OF SOWS ON TWO RATIONS. (Barnhart et al., 1954).

Stage of Lactation (days)	Ration	Pantothenic Acid Content (µg. per 100 ml.)
7	Basal	260
	Fortified	250
21	Basal	280
	Fortified	245
56	Basal	455
	Fortified	360

Pyridoxin.

As far as is known, the only estimate of the pyridoxin content of sow's milk available is that of Braude (1954). This estimate was obtained in work, the details of which have not been published. The value given is 20.0 µg. per 100 ml.

Vitamin B_{12} (Cyanocobalamine).

Collins et al. (1951) obtained samples of sow's milk during the period one to thirty days post-partum/

partum. The vitamin B_{12} content of the milk was determined by microbiological assay. The mean value obtained was 0.105 µg. per 100 ml., the range of values being 0.003 to 0.270 µg. per 100 ml. The vitamin B_{12} content of the milk appeared to be affected by the dietary intake of vitamin B_{12} and the lower values in the range were obtained from animals on all-plant rations which were believed to be low in the vitamin. The higher values represented milk from sows receiving supplements containing vitamin B_{12}.

Gregory (1954) measured the vitamin B_{12} content of a bulked sample from four Large White sows in the third to eighth weeks of lactation. Microbiological assay was used. Several methods used for the preliminary treatment of the milk prior to assay (including that of Collins et al., 1951) failed to make the vitamin B_{12} available to the assay organism. Papain digestion did, however, prove suitable as a preliminary treatment, and a mean value, from two assays, of 0.17 µg. per 100 ml. was obtained.

Vitamin C (Ascorbic Acid).

The original work on the ascorbic acid content of sow's milk seems to be that of Nordfeld (1944-5). This worker found, for one normal sow, a value of 6.1 mg. ascorbic acid per 100 ml. of milk.

Braude et al. (1947) studied the milk of nine Large White sows in the course of twelve lactations, six in summer and six in winter. The mean value found for the ascorbic acid content of seventy-six samples taken from the tenth to the fifty-sixth days of lactation was 13.0 $\pm$ 0.3 mg. per 100 ml. There was no seasonal variation in the ascorbic acid content of the milk.

Bowland et al. (1949a) conducted an investigation/

investigation with two groups of sows, one group carried through gestation on pasture and the other carried through gestation in drylot. The sows on pasture were Poland Chinas and Chester Whites, while all those in drylot were Poland Chinas. The mean values obtained for ascorbic acid in milk from sows in the two groups were:

Pasture sows - 10.4 mg. per 100 ml.
Drylot sows - 12.2 mg. per 100 ml.

The ascorbic acid content of the milk was consistently higher, except in the fifth week of lactation, in the drylot group.

Heidebrecht et al. (1951) obtained milk samples, in the spring, from fifteen Hampshire gilts producing their first litters and one Duroc sow producing her third litter. In the autumn of the same year, samples were collected from nine Durocs, five Chester Whites and five Hampshires producing their first or second litters. Samples were obtained on the fifth, fifteenth and fifty-fifth days of lactation and the mean values for ascorbic acid in the milk at these times were:

5th day - 13.0 mg. per 100 ml.
15th day - 11.0 mg. per 100 ml.
55th day - 11.0 mg. per 100 ml.

Vitamin D.

Braude et al. (1947) provided the first data on the vitamin D content of sow's milk. These workers pooled samples of milk, surplus to their requirements for other purposes, between the months of July and December and used biological assay methods to determine the vitamin D content of the fat separated from this milk. The vitamin D content was found to be 0.55 I.U. per g. of fat.

Bowland/

Bowland et al. (1951) obtained values for the vitamin D content of sow's milk in assays of seven composite samples. The values obtained (expressed as I.U. per g. of fat) ranged from less than 1.02 to 2.18. Values are also given on a volume basis. Summer milk from sows on pasture was slightly higher in vitamin D than was either winter or spring milk. However, milk obtained from sows in February was still high in vitamin D, indicating considerable ability of the sow to store the vitamin.

Vitamin E.

No data are available.

Changes in Composition During Lactation.

The composition changes which occur are of two types: Firstly, there are the changes which occur during the transition from colostrum to milk, and secondly, there are the changes which take place, with advancing lactation, in the milk. The later changes are less dramatic than those occurring during the transition period, and usually take the form of gradual increases or decreases over a space of several weeks. During the transition from colostrum to milk, many of the changes are very marked and take place very rapidly.

It is impossible to state definitely the time in lactation by which the transition from colostrum to milk has been completed. The results obtained by Perrin (1955) suggest that the transition takes place within about three days of parturition. However, in this detailed study at the Ruakura Animal Research Station in New Zealand, samples were taken at three-hour intervals from parturition to thirty hours post-partum in addition to the normal suckling of the litters of the sows concerned, and it seems likely that a considerably increased amount of colostrum and transition fluid was withdrawn during this period. This may have resulted in an increased rate of change, although the order in which the changes occurred probably remained the same as under normal conditions. Earlier results obtained in work at the same research station, in which the first sample was taken between the fourth and sixth days, demonstrated the likelihood that the transition is not complete until the end of the first week. This observation is borne out by that of Lodge (1959) who, working at the Rowett Research Institute, found that the values obtained for the various constituents on the fourth day of lactation suggested/

suggested that the transition from colostrum to milk was not complete by that time. Since the next samples, taken on the tenth day, had a composition within the range found in milk, the transition must have been completed between the fourth and tenth days.

(1) Changes Occurring During the Transition from Colostrum to Milk.

Major Constituents.

The trends for major constituents have been established from a number of reports, particularly that of Perrin (1955).

The initial secretions from the sow are characterised by high protein and low fat and lactose values, and the transition period by the rapid decrease in total solids and protein and increase in lactose soon after parturition. The protein level decreases almost immediately after parturition and within twenty-four hours the original value may have been halved. The protein content then becomes more or less steady while the lactose and ash contents are still increasing. The lactose content, which is low initially, becomes doubled after three days. Fat increases rapidly during the first forty-eight hours after parturition, becoming almost doubled in this period, and then falls again until on the fourth or fifth day it has returned almost to the original level. The ash content rises steadily for about five days post-partum and then the rate of increase becomes less.

Ash Constituents.

There is a four-fold increase in the calcium content of the secretion from the udder from colostrum at parturition to milk eight days post-partum (Perrin, 1955). The phosphorus content increases slightly during the transition period, but milk is only slightly higher/

higher in phosphorus than colostrum is (Perrin, 1955). The calcium content remains higher than the phosphorus content throughout (Braude et al., 1947). There is a slight decline in magnesium over the first day after parturition, followed by a slight rise to the level in milk (Perrin, 1955). The chlorine content increases over the first two to three days of lactation (Perrin, 1955). Venn et al. (1947) found the iron content of colostrum to be generally higher than that of milk but no trends were reported. No trends have been observed for the manganese content during the transition period.

Vitamins.

Bowland et al. (1949a) found that the vitamin A content of colostrum rose until the third day of lactation, but by the seventh day it had fallen again to about half the value observed on the first day. Heidebrecht et al. (1951) observed that a marked decrease from the original high level had occurred in vitamin A content by the fifth day of lactation. Davis et al. (1951) found little change in the thiamine content as the composition of the secretion altered from that of colostrum to milk. It was observed by Davis et al. (1951) that the nicotinic acid content of colostrum rose rapidly over the first few days of lactation. Davis et al. (1951) found that the riboflavin content of colostrum fell for the first few days of lactation. Subsequent to the first few days, the riboflavin content of the milk appeared to become stabilised. Pantothenic acid was observed to rise steadily over the first few days of lactation by Davis et al. (1951). No trends in the pyridoxin content during the transition period have been recorded, but there must be a considerable rise since it has been reported that the value for milk is about eight times the value for colostrum (Braude, 1954). No trends in the vitamin B_{12} content during the/

the transition period have been recorded, but there appears to be little difference between the contents in colostrum and milk. The amount of ascorbic acid present in sow's colostrum is very high indeed. This high level was found by Bowland et al. (1949a) to drop very rapidly from the first to the third day of lactation and, by the end of the first week, it had reached the range for milk. Heidebrecht et al. (1951) found, similarly, that the original very high level of ascorbic acid had declined by the fifth day of lactation to about two-thirds of its original value. No trends in the contents of vitamins D and E during the transition period have been recorded.

(2) Changes Occurring in Milk with Advancing Lactation.

In addition to the changes occurring during the transition from colostrum to milk, the contents of most of the constituents are known to undergo changes as lactation advances and thus sow's milk is of continuously altering composition.

Major Constituents.

Few workers have taken samples of milk from the same sows frequently and regularly throughout lactation, but those who have done so (Braude et al., 1947; Bowland et al., 1949c; Bowland et al., 1951; Heidebrecht et al., 1951; Smith, 1952; Perrin, 1954a,b; Lodge, 1959) generally agree on the following trends: Protein content tends to decline until the second or third week of lactation and then rises. Lactose content tends to decline steadily throughout lactation. Ash content rises steadily throughout lactation.

Fat content is evidently very variable and fluctuates widely from week to week and possibly from day to day. Some workers have reported a tendency for fat/

fat content to decline during lactation (Braude et al., 1947; Bowland et al., 1949c, 1951; Heidebrecht et al., 1951; Smith, 1952; Barber et al., 1955; Lodge, 1959) and some have reported a tendency for it to rise (Hughes and Hart, 1935; Willet and Maruyama, 1946; Lodge, 1957b) while others (Berge and Indrebø, 1953) could observe no significant trend either way.

Lodge (1959) reported the existence of an inverse relationship between the contents of protein and lactose with advancing lactation, independently of normal lactation trends. The negative correlation was highly significant.

Ash Constituents.

After the transition from colostrum to milk has been completed, the calcium content continues to increase steadily throughout lactation (Braude et al., 1947; Perrin, 1955). The phosphorus content also continues to rise throughout lactation (Braude et al., 1947; Perrin, 1955). The rise is less steep than in the case of calcium (Perrin, 1955) and the calcium content remains higher than the phosphorus content throughout (Braude et al., 1947). The magnesium content rises slowly throughout lactation, in contrast to the chlorine content which declines gradually (Perrin, 1955). No trends in the iron or manganese contents of milk during lactation have been recorded.

Vitamins.

After the vitamin A content has fallen to the range for milk, it has been observed to remain more or less constant until the eighth week, a slight rise towards the end of lactation being noted by Braude et al. (1947) and Bowland et al. (1949a). Heidebrecht et al. (1951), however, noted a gradual decrease from the fifth to fifty-fifth days of lactation. The level of thiamine/

thiamine in milk was found by Davis et al. (1951) to be about the same as that of colostrum. No very marked change was observed after the fifth day of lactation, although there was a slight rise near the end of lactation. The trend observed by Davis et al. (1951) in the nicotinic acid content of milk was a rise which became more gradual as lactation advanced, values towards the end of lactation being only slightly higher than those for milk on the fifteenth day of lactation. After the high levels of the first few days of lactation, the riboflavin content of milk appears to become stabilised and then rises somewhat during the remainder of lactation (Davis et al., 1951). Davis et al. (1951) reported a steady increase in pantothenic acid content throughout lactation, and later work by Owen and Bowland (1952) and Barnhart et al. (1954) confirmed this observation. The trend for ascorbic acid in milk observed by Bowland et al. (1949a) was a gradual decline after the transition period, with a minimum reached in the third or fourth week, followed by a rise to a more or less constant level. Heidebrecht et al. (1951) found that the ascorbic acid level remained slightly lower than that seen five days post-partum, the five-day value being two-thirds of that in first-day colostrum. No trends have been recorded in the contents of pyridoxin, vitamin B_{12}, vitamin D or vitamin E in milk.

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THE REARING OF BABY PIGS AWAY FROM THE SOW.

The Use of Cow's Milk.

The early departures from the usual process of rearing baby pigs on their dam's milk were made in work designed to provide information on the nutrition of the infant human and in this work various forms of cow's milk were used. The baby pig was chosen for these experiments because of its rapid growth, vigorous metabolism and the fact that the pig, like man, is omniverous. The great muscular activity shown by the baby pig was considered to be the one great difference between its metabolism and that of a helpless infant.

The first of the attempts made to raise baby pigs away from the sow for this purpose may have been that of Sanford and Lusk (circa 1892) whose work is described by Wilson (1902). Sanford and Lusk, working at the Yale Medical School in the United States reared three new-born pigs of the same litter on centrifuged skimmed cow's milk. One pig received skimmed milk alone, a second skimmed milk plus 2% lactose, and a third skimmed milk plus 2% glucose. All three pigs had diarrhoea for a short time but Sanford and Lusk were able to conclude that baby pigs could thrive on a skimmed milk diet and that the addition of sugars was advantageous. Another pig of a different litter was successfully fed for a period of fourteen days on cow's whole milk.

Wilson (1902) also working on human nutrition raised three baby pigs from birth for sixteen days, one on a diet of skimmed milk alone, a second on skimmed milk plus 3% lactose and a third on skimmed milk plus 3% glucose. After the sixteen-day period had elapsed the pigs were slaughtered for analysis and comparison with three pigs of the same litter slaughtered at birth.

It/

It is of interest that the pigs in these two experiments are stated to have been "new-born" and may therefore not have received colostrum. It is obvious from later work that, if they did not, the environment into which they were born and in which they were reared must have been of a high standard of cleanliness.

Newlander and Jones (1935) designed trials to study the relative values, in infant nutrition, of normal cow's milk, evaporated milk, powdered whole milk (two brands) and remade milk, using baby pigs as experimental animals. In this case the piglets were removed from the sows two days after birth and thus received colostrum. On removal of each litter from the sow one of the piglets was slaughtered and analysed for body composition to act as a check for that litter. The remaining piglets were divided into two lots, one lot being fed normal cow's milk and the other the grade of milk under trial. Usually two piglets, one from each lot, were slaughtered and analysed when their weights had doubled, two more when they had trebled, and the remainder of each lot when four to five weeks old, by when they had at least quadrupled their weights. The milks were fed from bottles and were kept iced and then warmed before feeding. Each animal was fed an amount of milk proportionate to its weight. All four kinds of milks were successfully fed to the baby pigs. Compared with pigs on sow's milk, favourable dry matter gains were made on normal, evaporated, and one of the brands of powdered milk, less favourable gains on the other brand of powdered milk and least favourable gains on remade milk. Scouring occurred to varying extents in the trials and some deaths resulted. There were also instances of pigs refusing their food, but these were remedied by substituting skimmed milk during a few of the meals.

From/

From data given on the performance of pigs on two of the three most successful milks, and comparing their performance with that of pigs raised on sow's milk (Table 26), it is seen that the performance of pigs fed normal cow's milk and evaporated milk did not approach that of pigs reared by the sow.

TABLE 26. PERFORMANCE OF PIGS ON THREE MILKS (Newlander and Jones 1935).

	Average Number of Days to Double Weight.	Average Number of Days to Treble Weight.
Nine pigs on sow's milk	8.5	15.0
Nine pigs on normal cow's milk	11.0	19.0
Nine pigs on evaporated milk	11.0	20.0

Successful rearing using cow's milk was achieved by Green et al. (1947) who studied some of the habits of baby pigs and designed practical equipment for handling them after removal from the sow, with a view to providing a basis for research work on the physiology and nutritional requirements of young pigs, and providing a practical method of rearing pigs away from the sow. In these experiments difficulty was found in teaching the pigs to use nippled bottles, and the milk was fed in shallow dishes. The milk was at first fed warmed until the baby pigs, of up to one week old, had been taught to drink by submerging their mouths. From the second day the milk was fed at ordinary refrigerator temperatures. No digestive troubles were encountered. Attempts to feed gruels failed, the young pigs drinking the surface milk and leaving the residue. At about two weeks of age, they began to eat a little dry food which was offered, just as sow-reared pigs will/

will do. The results obtained in this work were good; of eleven pigs raised to eight weeks of age, eight weighed between 45 and 60 lb. and three weighed between 30 and 35 lb.

Weybrew et al. (1947, 1949) used cow's milk supplemented with minerals and vitamins in successful pig-rearing trials. Three essentially whole milk diets were compared:

Diet A - Evaporated milk.

Diet B - Reconstituted skimmed milk solids plus butter.

Diet C - Reconstituted whole milk solids.

At the beginning of the experiment all milks were mixed (or diluted in the case of the evaporated milk) to contain approximately 17% solids, a figure approximately 3% lower than the solids content of sow's milk. To assure high consumptions the solids contents of diets B and C were gradually increased to a maximum level of approximately 40% by the end of the third week and were maintained at this level. Diet A was also thickened but the solids content never exceeded that of the evaporated milk (25.9%). The milks were supplemented with a mineral mixture based on that of Wintrobe (1939) and containing ferric chloride, cupric acetate, manganous sulphate, zinc oxide, cobaltous carbonate, and potassium iodide. Magnesium citrate was later added to raise the magnesium content. The calcium and phosphorus levels in the milks were considered adequate. All diets were uniformly supplemented with cod-liver oil to provide vitamins A and D but there was no supplementation with B vitamins. It was found that diet A was markedly poorer than diets B and C, but that the contrast between the two superior diets was not significant. At eight weeks of age the mean weights of pigs on the three diets were:

Diet A/

Diet A - 35.1 $\pm$ 3.0 lb.
Diet B - 46.8 $\pm$ 2.1 lb.
Diet C - 48.6 $\pm$ 1.4 lb.

All hand-fed pigs weighed on average 9.6 lb. more, at eight weeks, than did a comparable number of suckled pigs with access to a self-feeder. Mortality during the experiment was 12.5%.

Good rearing results with supplemented cow's milk were also obtained by Anderson and Hogan (1950). The milk was fortified with 60 g. sucrose, 2.5 g. ferrous sulphate, 0.2 g. cupric sulphate, 0.2 g. manganous sulphate and 0.02 g. potassium iodide per litre. Two pigs which had been allowed to suckle for two days were fed the above diet and their performance was compared with that of other pigs fed an experimental synthetic milk diet. By the age of two weeks the pigs fed fortified cow's milk were definitely heavier than those on the experimental diet and by the time they were eight weeks old they weighed over 50% more than the experimental animals. This was said to be possibly explained by the unsuitability of physical texture or composition of the experimental diet. The average of the eight-week weights of the two pigs fed fortified cow's milk was 50.4 lb.

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THE USE OF LIQUID SOW'S MILK SUBSTITUTES.

Although it was the report of Johnson, James and Krider (1948) on their success in rearing baby pigs on a synthetic milk diet which stimulated a great deal of the work which was to be done in this field, successful attempts at producing such a diet had been made earlier.

Of note is the work of Wintrobe (1939) who produced an artificial diet which, when fed under laboratory conditions, permitted good growth in young pigs removed from the sow between the ages of two and twenty-three days. Several diets were formulated, the most satisfactory of which consisted of casein, lard, sucrose, cod-liver oil, yeast and a salt mixture. This diet contained 62.5% carbohydrate, 24% protein and 13.5% fat. The added mineral mixture was made up to imitate the mineral content of sow's milk as it was then known, but included extra iron and iodine. Vitamins were provided in the cod-liver oil and yeast. At first the diet was made up to resemble a milk, but this was abandoned when it was found that pigs only a few days old soon learned to take the food as a gruel from a trough. Suitable formulae for synthetic diets for baby pigs were thus in existence nearly ten years before the work of Johnson et al. (1948) was responsible for the opening up of research in this field.

In 1945 work had been begun on the development of a synthetic diet for young calves to be used in studying the water-soluble vitamin requirements of ruminants. Since the synthetic milk diet developed was used successfully in the rearing of calves (Wiese et al., 1947) it appeared to Johnson and his colleagues to be worthwhile to attempt the rearing of baby pigs on the same diet. The diet (containing 13% solids) was thus one made up to simulate cow's milk and/

and not sow's milk. It was hoped that by using very young pigs deficiencies might be produced which do not occur in older pigs. Very young pigs would not have had time to build up large body stores of vitamins from sow's milk, and it was thought that their rapid growth would make for high requirements. It was also hoped that studies on baby pigs would lead to useful information applicable to infant nutrition.

The composition of the synthetic milk ration used in these experiments and which had previously been used successfully to rear very young calves was :

Vitamin - free casein	30.0%
Cerelose (Glucose)	37.4%
Lard	26.6%
Salts	6.0%

The salt mixture contained Na Cl, K_2HPO_4, $CaHPO_4$, Mg SO_4, Ca CO_3, ferric citrate $6H_2O$, KI, $MnSO_4$, $ZnCl_2$, $CuSO_4 . 5H_2O$, $CoCl_2$, and CaF_2. The milk, as made up, contained the fat-soluble vitamins A, D_2, α-tocopherol acetate and 2 methyl-1,4-naphthoquinone. The water-soluble vitamins were not included in the milk as prepared and were added to the milk at each feeding. The water-soluble vitamins added were thiamine, riboflavin, pyridoxin, pantothenic acid, inositol, choline, p-amino benzoic acid, pteroylglutamic acid (folic acid), biotin and nicotinic acid.

The pigs in the first experiment were two weeks old at the start and were housed in individual wire-bottomed cages, the milk being fed in shallow dishes from which they were taught to drink by submerging their mouths in the warmed milk. The milk was thereafter fed at refrigerator temperature, feeding being ad lib. An attempt was made to produce a pteroylglutamic acid deficiency by inhibiting intestinal/

intestinal synthesis with sulphathalidine, but this had little effect on growth, there being practically no difference between the group receiving PGA and the PGA-free group in this respect. The average eight-weeks weight of all ten Duroc-Jersey pigs used was 32.7 lb.

The success achieved in raising pigs from two weeks of age led to a second experiment in which ten Duroc-Jersey pigs were removed from the sow at four days of age. These were also raised successfully in the same manner as before, attaining an average weight at about eight weeks of 35.5 lb.

In a third experiment, six Chester White pigs were raised on the synthetic milk from one day old and three Duroc-Jerseys were raised from four days of age. The experiment was again successful, one of the Duroc-Jerseys reaching a weight of 53 lb. at eight weeks.

Thus a number of pigs which had received colostrum for a minimum of twenty-four hours were successfully raised to eight weeks of age on a synthetic ration made up to simulate cow's milk. In view of the latter fact, the comparison made by Braude (1954) between the quantities of nutrients obtained by a piglet consuming 850 g. of sow's milk per day (based on data obtained at Shinfield Experimental Station), and those obtained from a like quantity of milk substitute prepared as recommended by Johnson and his colleagues, is interesting. A good measure of agreement exists between the two sets of values (Table 27).

TABLE 27./

TABLE 27. NUTRIENTS RECEIVED BY A PIG CONSUMING DAILY 850 g. OF MILK (Braude, 1954).

	When Suckling.	When Fed Substitute as Used by Johnson et al. (1948).
Total Solids	169 g.	170 g.
Fat	71 g.	45 g.
Protein	49 g.	51 g.
Lactose	41 g.	64 g.
Ash	8 g.	10 g.
Calcium	2.1 g.	1.7 g.
Phosphorus	1.4 g.	1.2 g.
Vitamin A	770 I.U.	850 I.U.
Vitamin D	39 I.U.	85 I.U.
Vitamin C	111 mg.	-
Thiamine	575 µg.	552 µg.
Riboflavin	1165 µg.	1105 µg.
Nicotinic Acid	7106 µg.	2210 µg.
Pantothenic Acid	3630 µg.	6630 µg.
Pyridoxin	170 µg.	552 µg.
Biotin	12 µg.	8.5 µg.
Vitamin B_{12}	1.4 µg.	-

Lehrer et al. (1949) also based their synthetic milk ration closely on that of Wiese et al. (1947) in an attempt to obtain a normal growth response from young pigs fed the artificial diet. The baby pigs were allowed to suckle for forty-eight hours, and were then placed on the synthetic milk, which was fed from bottles. Growth over the eight-week period was normal and no deficiency symptoms were observed. The diet was therefore presumed adequate for raising baby pigs.

At about the same time as the appearance of these papers on the successful rearing of baby pigs which had been allowed to suckle their dams, Bustad et al. (1948) reported their failure to raise baby pigs on synthetic milk for longer than twenty-two days when they had not received colostrum.

In/

In this work, homologous blood serum and plasma were used as colostrum substitutes, and the synthetic milk was made up to simulate sow's milk, as the latter had been described by Hughes and Hart (1935), but modified to contain 15.71% solids. The milk was prepared by a method similar to that used by Wiese et al. (1947). The compositions of the two variations of the synthetic milk used were:

	1	2
Vitamin test casein	39.6%	-
Crude casein	-	39.6%
Sucrose	25.5%	-
Lactose	-	25.5%
Salt Mixture	6.2%	6.2%
Lard	28.7%	28.7%

Each milk was supplemented with fifteen vitamins.

The piglets were housed in cages similar to those described by Green et al. (1947) and were taught to drink right after birth from bottles equipped with rubber nipples, the milk being fed at 37°C. Within the first six days of life all piglets were given orally 55,000 I.U. of vitamin A, 5,500 I.U. of vitamin D and 300 mg. of ascorbic acid.

Severe diarrhoea developed in all the piglets which were fed synthetic milk and homologous serum and plasma as substitutes for colostrum. The therapeutic measures which were attempted were useless in controlling the condition. Penicillin, sulphathalidine, sulphamezathine and Kaopectate were used, but the piglets failed to survive longer than twenty-two days. It was found that baby pigs fed no colostrum substitute such as serum or plasma died very shortly after birth. The addition to the ration of crude casein, lactose, liver powder or anti-pernicious anaemia liver extract did not appear to have any effect in prolonging life or improving the appearance of the pigs.

These/

These reports stimulated work in three fields of research using baby pigs. These were:

(A) The investigation of the quantitative requirements of baby pigs for specific nutrients and the effects of the inclusion in the diet of various supplements.

(B) Further attempts to raise baby pigs which did not have access to colostrum.

(C) The investigation of the possible use of artificial rearing in pig farming practice.

(A) The Investigation of the Quantitative Requirements of Baby Pigs for Specific Nutrients and the Effects of the Inclusion in the Diet of Various Supplements.

Most of the work in this field of research was carried out using liquid synthetic milks similar to that of Johnson et al. (1948) and consisting of casein (or "α-protein" made from the soyabean, plus methionine), glucose, lard, minerals, vitamins and antibiotic. The diets varied slightly, depending on the purpose of each group of workers, but generally the milks contained 14 to 20% total solids and were fed either *ad lib.* from troughs, or, on fewer occasions, from bottles equipped with nipples. Research carried out with baby pigs started on these synthetic milks at two to three days of age was concerned with:

(1) The effects of different dietary levels of protein.

(2) The requirements for certain of the essential amino acids.

(3) The effects of different sugars in the diet.

(4) The requirements for and symptoms resulting from deficiences of various vitamins.

(5)/

(5) The effects of the inclusion in the diet of antibiotics, sulpha drugs, surface activating agents, arsenicals and enzymes.

(1) The Effects of Different Dietary Levels of Protein.

Synthetic milks varying in protein content from approximately 24% to 28% on a dry matter basis were used successfully by various groups of workers (Neumann et al., 1948b; Lehrer et al., 1949; Sheffy et al., 1952). However, no specific attempt to evaluate the protein requirement of the baby pig, with a view to providing a sounder basis for the formulation of synthetic milk diets, was made until that of Sewell et al. (1953a).

The trials conducted by Sewell et al. (1953a) were designed to obtain information on the protein requirement of the pig during the first month of life. To this end, α-protein and casein synthetic milks containing various levels of protein were fed in four separate trials.

In the first trial, levels of 16, 20 and 24% protein on a dry matter basis were studied, and in the second trial the levels used were 20, 24, and 28% protein, both trials being with α-protein synthetic milks. In both trials the pigs on the highest level of protein grew most rapidly and made the most efficient use of their feed during the twenty-eight day periods of each trial.

Two additional trials were then conducted using casein as the protein source. In the third trial the protein levels were 16, 20, 24 and 28%, and in the fourth trial a 32% level was also used. In the third trial it was found that as the protein content of the diet increased from 16 to 28% there was a progressive/

progressive increase in the weight gains of the pigs, accompanied by increased economy of feed utilisation. These results corroborated those obtained in the first two trials. In trial four it was found that the pigs receiving the 32% level grew at a faster rate and showed better economy of feed utilisation than any of the others.

Overall, diets containing only 16 or 20% protein gave slowest growth rates and the pigs on these levels were retarded. Levels of 24 and 28% protein gave satisfactory results and fastest growth, and most efficient feed utilisation occurred on the 32% level. The data obtained also suggested that casein provided a more satisfactory source of protein than did α-protein, since the casein diets resulted in slightly faster rates of growth.

Reber et al. (1953) also investigated the effects of the protein level fed to baby pigs on growth and efficiency of feed utilisation. Casein synthetic milks were used throughout. In the first of the two trials conducted, levels of 15, 20 and 25% protein were used and in the second trial the levels were 25, 33 and 41%.

The weight gains were greatest in those pigs fed the highest level of protein in each trial. The ration containing 41% protein produced maximum weight gains and feed efficiency in the very young pigs. As the pigs approached eight weeks of age, a level of 20% protein appeared to be used as efficiently as higher levels.

Possible reasons for the wide range of estimates of optimum protein level obtained in the above, and in other experiments, are discussed in a later section (page 154).

(2)/

(2) The Requirements for Certain of the Essential Amino Acids.

Research has shown that of the twenty-two or so amino acids known, pigs require a dietary source of ten. The quantitative requirements of baby pigs for all ten have been estimated by indirect methods, but experimental determinations are lacking for several. The ten essential amino acids will be considered below under a suitable classification. In this section, determinations involving the use of liquid diets are dealt with, while those in which dry diets were fed are to be found in a later section under "The Use of Dry Diets" (page 157). In both sections, values obtained by the two indirect methods described below, and expressed as a percentage of dietary protein, are included for comparison with the experimental results. In cases where the indirect estimates constitute the only information available on the requirement, these are given in the present section.

The first of the two indirect methods employed in the determination of the amino acid requirements of baby pigs was that described by Becker et al. (1954b). This method is based on the amino acid intakes of baby pigs fed experimentally determined optimum levels of protein, the source of protein having a high biological value. It is emphasised that values obtained by this method are estimated needs to support satisfactory performance and are not to be construed as minimum requirements.

The second indirect method is that based on carcass analyses. Williams et al. (1954) published details of the amino acid composition of pigs at birth and at weaning. From these figures the amino acid composition of the live-weight increase during this period can be calculated. If the proportions of the various amino acids are then related to the known/

known (experimentally determined) requirement for a particular one, then requirements for the other amino acids can be estimated. Manners and McCrea (1958) used the requirement for lysine, as determined by Hutchinson et al. (1957), as the basis for their estimation of the minimum requirements for the other nine essential amino acids.

The Essential Amino Acids.

(a) Neutral Amino Acids.

Leucine.

The leucine requirement was studied by Eggert et al. (1954). Baby pigs were fed a semisynthetic milk in which the base protein was casein, and crystalline amino acids were used to raise the dietary content of each essential amino acid, other than leucine, to a level considered adequate for good growth. L-leucine was added in varying amounts to provide five dietary levels, namely 1.00, 1.25, 1.50, 1.75 and 2.00% of the diet.

Growth and feed efficiency data obtained over the twenty-one-day experimental period indicated the L-leucine requirement as more than 1.00% but not more than 1.25% of the diet. This is equivalent to not more than 5.00% of the dietary protein.

Estimates obtained indirectly:

9.82% of the dietary protein (pigs 1-4 wk. old) (Becker et al., 1954b).

5.60% of the dietary protein (Manners and McCrea, 1958).

Isoleucine.

The determination of the isoleucine requirement will be dealt with under "The Use of Dry Diets".

Valine./

Valine.

The only data available on the valine requirement are indirect estimates:

7.05% of the dietary protein (pigs 1-4 wk. old) (Becker et al., 1954b).

4.80% of the dietary protein (Manners and McCrea, 1958).

(b) Hydroxy Amino Acids.

Threonine.

Sewell et al. (1953b) used α-protein synthetic milks as the experimental diets in their investigation of the threonine requirement. Baby pigs were fed a casein synthetic milk for an adjustment period of two days after separation from the sow and were then placed on their experimental diets. The protein contents of the diets ranged from 24.17% to 25.50% and the levels of L-threonine tested were 0.36, 0.54, 0.73, 0.92 and 1.12% of the diets.

Growth and feed efficiency data, used as criteria of measurement over a twenty-one-day experimental period, suggested that the L-threonine requirement of the baby pig is approximately 0.90% of the diet. This is equivalent to 3.6% of the dietary protein.

Estimates obtained indirectly:

5.00% of the dietary protein (pigs 1-4 wk. old) (Becker et al., 1954b).

3.00% of the dietary protein (Manners and McCrea, 1958).

(c) Basic Amino Acids.

Lysine and Histidine.

The determinations of the requirements of these amino acids will be dealt with under "The Use of Dry Diets."

Arginine./

Arginine.

Arginine can be synthesised by the pig at a rate sufficient to permit 60% of normal growth, but to attain maximum growth a dietary source of this amino acid is required. (National Research Council, U.S.A., 1959).

The only data available on the arginine requirement are indirect estimates:

2.73% of the dietary protein (pigs 1-4 wk. old) (Becker et al., 1954b).

5.40% of the dietary protein (Manners and McCrea, 1958).

(d) Aromatic Amino Acids.

Tryptophan.

There is a relationship between tryptophan and the vitamin nicotinic acid, and high levels of tryptophan have been shown to satisfy completely the nicotinic acid requirement. The values obtained for the tryptophan requirement in feeding trials will thus depend on the extent to which the nicotinic acid requirement of the pigs is satisfied in the diet by nicotinic acid itself. The feeding of nicotinic acid in excess of the requirement of the pigs obviates this difficulty.

Firth and Johnson (1956) conducted experiments to determine by growth studies the DL- and L-tryptophan requirements in the presence of excess nicotinic acid. The baby pigs were fed a hydrolised casein synthetic milk for a period of four weeks. Initially, in the determination of the DL-tryptophan requirement, dietary levels of DL-tryptophan of 0.100, 0.125, 0.150, 0.175, 0.200, 0.250 and 0.300% were tested. In this experiment both gain and feed efficiency showed a nearly linear increase up to the 0.300% level of DL-tryptophan, indicating that the requirement was at 0.300% or above. Pigs/

Pigs receiving less than 0.200% of DL-tryptophan were obviously deficient. Differences between the 0.200, 0.250 and 0.300% levels were reflected in increased growth and food consumption from the first to the last.

In a second experiment, levels of DL-tryptophan grouped more closely around the 0.300% level were compared. These levels were 0.250, 0.275, 0.300, 0.325, 0.350 and 0.400% of the diet. Growth and feed efficiency showed less variability in this experiment than in the previous one, since the levels of DL-tryptophan tested were close to the requirement. The estimated requirement was 0.290% LD-tryptophan. The L-tryptophan requirement, determined similarly, was found to be 0.190% of the diet.

The values obtained for the DL- and L-tryptophan requirements are equivalent to 1.04 and 0.68% of the dietary protein, respectively.

Estimates obtained indirectly:

1.27% of the dietary protein (pigs 1-4 wk. old) (Becker et al., 1954b).

0.60% of the dietary protein (Manners and McCrea, 1958).

Phenylalanine.

Another aromatic amino acid, namely tryosine, exerts a sparing effect on the phenylalanine requirement of the pig but the exact nature of this effect has not been completely determined. (National Research Council, U.S.A., 1959).

The only data available on the phenylalanine requirement are indirect estimates:

At least 4.32% of the dietary protein (pigs 1-4 wk. old) (Becker et al., 1954b).

2.90% of the dietary protein (Manners and McCrea, 1958).

(e)/

(e) Sulphur-Containing Amino Acids.

Methionine.

Half of the methionine requirement can be replaced with another of the sulphur-containing amino acids, namely cystine. (National Research Council, U.S.A., 1959). There is also a relationship between methionine and the vitamin choline, the former, when fed in sufficient quantity, being able to replace the latter completely. (Nesheim et al., 1949). Thus if a choline-deficient diet is fed, the apparent methionine requirement will be higher than if the choline requirement is satisfied with choline itself.

The only data available on the methionine requirement, apart from the demonstration by Nesheim et al. (1949) that a dietary level of 1.6% methionine was sufficient to supply both the choline and methionine requirements, are indirect estimates:

At least 2.64% of the dietary protein (pigs 1-4 wk. old) (Becker et al., 1954b).

1.4% of the dietary protein (Manners and McCrea, 1958).

(3) The Effects of Different Sugars in the Diet.

Johnson et al. (1948) employed glucose as the carbohydrate source in their diet for baby pigs. This example was folloed by many of the later workers (e.g. Lehrer et al., 1949; Wahlstrom et al., 1952; Sewell et al., 1953a), and Johnson (1949) and Becker et al. (1954c) found this sugar to provide very satisfactory performance when compared with others.

The finding of Wintrobe (1939) that sucrose was satisfactory as the carbohydrate source was not that of later workers. Johnson (1949) conducted trials comparing several sugars and found that when sucrose was fed the baby pigs developed acute diarrhoea, which resulted in a rapid loss of weight and/

and death within forty-eight hours unless the diet was changed. Affected piglets showed haemorrhagic kidneys. When the diet was quickly changed to cow's milk, recovery occurred. This sucrose syndrome was also observed by Becker et al. (1954a), symptoms appearing in this case after about four days of sucrose feeding. About 40% of the piglets died from severe diarrhoea but the surviving animals gained efficiently and rapidly. Johnson (1949) also reported that if baby pigs were started on cow's milk they could be changed gradually to the synthetic milk containing sucrose and were then able to tolerate the sucrose. Becker et al. (1954a), however, found that ability to tolerate sucrose in the diet was more a matter of the age of the pigs, as it was noted that approximately 60% of their pigs developed the capacity to utilise sucrose by seven days of age. Becker and his colleagues postulated that the enzyme activity of the very young pig might be inadequate to enable it to absorb sucrose readily, this being responsible for the symptoms observed. In this connection, Johnson (1949) had found that the addition of sucrase enzyme to the diet of two baby pigs did not improve performance.

Lactose was compared with glucose by Johnson (1949), who found that although lactose was at first satisfactory, pigs on the lactose-containing diet eventually developed chronic diarrhoea and grew more slowly than pigs on the glucose-containing diet. Becker et al. (1954a), however, found that lactose produced body-weight gains and survival equal to those produced by glucose, increased efficiency of feed conversion and did not cause diarrhoea. In comparing lactose with maize starch the same workers found that a combination of the two gave superior weight/

weight gains and efficiency of feed utilisation to either one fed alone.

Of the other sugars tested, fructose was unsatisfactory as the carbohydrate source (Johnson, 1949) and Becker et al. (1954c) found that piglets on a fructose-containing diet failed to show body-weight gains and were subject to severe diarrhoea. The reaction of piglets to fructose was, however, less severe than the reaction to sucrose. Invert sugar (consisting of an equimolecular mixture of D-glucose and D-fructose) produced satisfactory survival, but piglets were subject to intermittent, moderate diarrhoea (Becker et al., 1954c). Dextrin and maize starch produced body-weight gains and survival equal to those produced by lactose, and maize starch caused little scouring (Becker et al., 1954a).

(4) The Requirements for and Symptoms Resulting from Deficiencies of Various Vitamins.

In considering the work done on these subjects with baby pigs, each vitamin is dealt with under the headings "Requirement" and "Deficiency Symptoms". In each case, results obtained by previous workers are referred to briefly at the beginning of the section. The early results were obtained, in almost all cases, in work with older pigs and are included for comparison with the results obtained in research with baby pigs fed liquid synthetic milks.

(a) Vitamin B_1 (Thiamine).

Requirement.

Hughes (1940b) stated the requirement of the older pig to be 1 mg. per 100 lb. of body weight. Ellis and Madsen (1944) found the requirement to be 47 µg. per kg. body weight.

In/

In work with baby pigs fed a casein synthetic milk, Miller et al. (1954a), in a preliminary report, and later Miller et al. (1955) found the dietary requirement for thiamine to lie between 1 and 1.5 mg. per kg. of solids intake. They further suggested that the 1.5 mg. level should be considered a practical minimum concentration of thiamine in the diet of the baby pig.

Deficiency Symptoms.

Hughes (1940b) and Ellis and Madsen (1942) found that thiamine deficiency in the pig resulted in a decrease in appetite and body weight, a subnormal body temperature, a slow pulse and weakness of the legs. Ellis and Madsen (1942, 1944) observed that symptoms of thiamine deficiency developed more quickly on a fat-free diet, fat having a sparing action on thiamine requirement.

Miller et al. (1955) presented observations on the thiamine deficiency symptoms appearing in baby pigs fed sub-minimal levels of the vitamin. The baby pigs were fed a casein synthetic milk.

Pigs receiving no thiamine showed no abnormalities and grew well for a period of twelve days after experimental feeding was begun. They then developed an increasing degree of anorexia, vomited frequently, gained more slowly and then began to lose weight, became weak and emaciated and eventually died. There was no appearance of abnormal gait, nor were there any outward manifestations of nervous disorders. Post-mortem examinations showed marked cyanosis in the skin, nose and mucous membranes. In many cases the heart was enlarged, pale yellowish grey and mottled and was less firm than normal. In severe cases it was rounded and resembled a myxoedematous heart. The left ventricle was usually contracted and the right ventricle/

ventricle was quite flabby. There was always excess of pericardial fluid and in many cases excess of fluid in the peritoneal and pleural cavities also. The weights of the adrenals, as well as that of the heart, were greatly increased in relation to body weight. The liver was congested and there was inflammation in the small intestine, caecum and colon. Microscopic examination of the organs showed that there was congestion, focal fragmentation and necrosis of the muscle fibres in the heart. However, studies of white cell counts and haemoglobin determination values revealed no significant trend which could be related to the level of thiamine in the diet. Another heart abnormality which was observed in living deficient pigs was the lengthening of the P-R and S-T intervals on their electrocardiograms. Thiamine injections cured all gross deficiency symptoms except in the case of one pig which still showed a few light-coloured areas on the heart.

(b) Nicotinic Acid.

Requirement.

The first study of the requirement of the pig for nicotinic acid (Hughes, 1943) set it at 5 to 10 mg. per 100 lb. body weight or 0.11 to 0.22 mg. per kg. body weight per day. The work of Powick et al. (1947), using younger pigs, showed the requirement to be 0.6 to 1.0 mg. per kg. body weight per day. High protein diets, and consequently high levels of tryptophan (to which nicotinic acid is related) have been shown to satisfy completely the nicotinic acid requirement (Powick et al., 1948).

Firth and Johnson (1956) conducted experiments, among the objects of which were the determination by growth studies of the L- and DL- tryptophan/

tryptophan requirements in the presence of excess nicotinic acid, and the determination of the nicotinic acid requirement in the presence of the minimum tryptophan level. This work was done with baby pigs fed, as the basal diet, a hydrolised casein synthetic milk assayed to be nicotinic acid- and tryptophan-free. It was found that the nicotinic acid requirement for maximum growth was near 20 mg. per kg. of diet when 0.3% of DL-tryptophan (the minimum requirement in the presence of excess nicotinic acid) was present in the diet. It was also found that approximately 0.45% of DL-tryptophan (equal to 0.3% of L-tryptophan) was required to supply the requirement of the baby pig for both tryptophan and nicotinic acid.

Deficiency Symptoms.

Powick et al. (1947) described nicotinic acid deficiency symptoms induced in growing pigs between three and nine weeks of age by feeding a diet practically devoid of nicotinic acid. The symptoms observed were depression of growth, impairment of appetite and diarrhoea. In the more severe cases these symptoms were accompanied by a general deterioration in the condition of the pig to the point of emaciation, extreme weakness and death. There were no noticeable neurological symptoms. On post-mortem examination, the only lesions which occurred with sufficient frequency among the deficient animals to enable them to be associated with the deficiency were necrotic lesions of the inner walls of the caecum and colon. Blood, urine and liver contents of nicotinic acid were, surprisingly, largely maintained within normal limits during deficiency. It was noted that occasional animals appeared to thrive with no nicotinic acid while others appeared to vary in their requirement for it.

In what is, apparently, the only piece of work with baby pigs fed a synthetic milk, Firth and Johnson (1956) observed the following symptoms of nicotinic/

nicotinic acid deficiency in baby pigs: Diarrhoea, vomiting, dehydration and weakness. These symptoms appeared after two to three days of feeding a hydrolised casein synthetic milk deficient in nicotinic acid, but containing the minimum requirement of tryptophan. (There is a relationship between nicotinic acid and tryptophan and high levels of tryptophan have been shown to satisfy completely the nicotinic acid requirement). The deficient animals responded within twenty-four hours to a dose of 1.3 mg. of nicotinic acid and thereafter developed no symptoms of the deficiency when fed the same tryptophan level.

(c) Riboflavin.

Requirement.

In work on the riboflavin requirement of older pigs, Hughes (1940a) reported a minimum requirement of between 1 and 3 mg. of riboflavin per 100 lb. body weight per day and Krider et al. (1949) found the practical minimum for weanling pigs to be 1.4 mg. of riboflavin per lb. of ration. Mitchell et al. (1950) reported that the riboflavin requirement of growing pigs was affected by environmental temperature. At 85°F. the requirement was about 1.2 p.p.m. of air-dry feed and at 42°F. it was about 2.3 p.p.m.

Lehrer and Wiese (1952), reporting work using baby pigs fed a synthetic milk, suggested the riboflavin requirement as being near 3.0 mg. daily per 100 lb. body weight. These workers found that supplementation with 1 to 1.5 mg. of riboflavin per day cured external symptoms of riboflavin deficiency but not internal tissue changes in deficient pigs.

Forbes and Haines (1952) concluded that the requirement for riboflavin of baby pigs fed a casein synthetic/

synthetic milk in a controlled temperature chamber at 85°F. and 70% relative humidity, lay between 1.5 and 2.0 µg. per g. of feed dry matter.

Miller and his colleagues described work on the riboflavin requirement of the baby pig in a preliminary report (Miller et al., 1953) and in a more detailed study (Miller et al., 1954b). These workers found that, under the conditions of their experiments, in which room temperature was maintained at 70°F. but no attempt was made to maintain a constant percentage of relative humidity, the riboflavin requirement of baby pigs fed a casein synthetic milk was approximately 3.0 mg. per kg. of diet. It is seen that this is definitely higher than the 1.5 to 2.0 mg. per kg. of diet reported by Forbes and Haines (1952). In view of the work of Mitchell et al. (1950), already referred to, this is probably due to the lower environmental temperature used by Miller and his colleagues. Other factors may have been the uncontrolled relative humidity and more liberal feeding employed by Miller, and genetic differences in the baby pigs.

Deficiency Symptoms.

Wintrobe and his colleagues were responsible for early work on riboflavin deficiency in young pigs. Wintrobe et al. (1938) found that symptoms of a vitamin B complex deficiency in suckling pigs could be relieved temporarily by the administration of crystalline riboflavin. Wintrobe et al. (1944) reported that riboflavin deficiency in young pigs resulted in growth impairment, rough, dry and thin hair coats, a mottled erythematous eruption together with scaling and ulceration of the skin, lens opacities, normocytic anaemia and abnormal gait.

In later work using baby pigs fed a casein synthetic/

synthetic milk, Lehrer and Wiese (1952) described, in detail, the deficiency symptoms which resulted when the diet contained no riboflavin. The deficiency was associated with poor growth, alopecia, rough hair coat, anorexia, dermatitis, scouring, ulcerative colitis, inflammation of the anal mucosa, vomiting and light sensitivity. Post-mortem examinations of the deficient pigs showed necrosis and sloughing off of the corium, with haemorrhage in the proliferative germinal layers of the skin. The liver showed leucocytic infiltration, and many polymorphonuclear leucocytes were in the liver and blood. The kidneys exhibited a subacute glomerulonephritis and cloudy swelling with destruction of the epithelium of the kidney tubules. Examination of the lungs showed pneumonia and leucocytic and erythrocytic infiltration. Supplementation of the ration with riboflavin cured the external symptoms but many of the internal tissue changes were not reversed. It was suggested that this might be due to the riboflavin being fed in insufficient amount or for too short a period.

Miller et al. (1954b) reported work on the riboflavin requirement of baby pigs fed a casein synthetic milk, and described deficiency symptoms and post-mortem observations, resulting from lack of riboflavin, which were mainly those described by Lehrer and Wiese (1952). In addition, lesions on the lens and cornea of the eye and on the eyelids were observed. No significant trends, which could be related to the level of riboflavin in the diet, in leucocyte counts and haemoglobin determination values were noted. The food intake of the group of baby pigs receiving no riboflavin gradually decreased until they were affected by a multiple nutrient deficiency. Supplementation with riboflavin alleviated deficiency symptoms.

(d)/

(d) Pantothenic Acid.

Requirement.

The minimum daily requirement of the pig for pantothenic acid was reported by Hughes and Ittner (1942) to be 250 µg. per kg. body weight and by Luecke et al. (1949) to be 15 mg. per lb. diet.

In their work with baby pigs fed a casein synthetic milk, Wiese et al. (1951) found that the feeding to pantothenic acid-deficient pigs of 1 mg. of calcium pantothenate per day resulted in an improvement of appetite and growth, and cessation of scouring, but no great improvement resulted in the other symptoms. This was thought to be due probably to the severe depletion of these animals. However, the daily supplementation of 10 to 20 mg. of calcium pantothenate resulted in complete recovery and great improvement in appetite and growth.

In a preliminary report on their work on the pantothenic acid requirement of baby pigs fed a casein synthetic milk, Stothers et al. (1952) put the requirement at between 1.0 and 2.0 mg. per 100 g. of solids in the milk. In a later, more detailed report, Stothers et al. (1955) stated the requirement for optimum growth and feed conversion efficiency as approximately 12.5 mg. of calcium pantothenate per kg. of milk solids.

Deficiency Symptoms.

In earlier work Chick et al. (1938) reported that weanling pigs fed a purified ration deficient in "the filtrate factor" lost weight, scoured, showed weakness in the hind quarters and walked with a swaying gait. This condition, which was not cured by thiamine, riboflavin or nicotinic acid, could be alleviated by administration of yeast and certain filtrate/

filtrate fractions of liver. Hughes (1939) reported a "goose-stepping" gait in pigs fed a ration known to be deficient in the filtrate factor. Wintrobe et al. (1942) and Follis and Wintrobe (1945) reported that pantothenic acid deficiency in the pig resulted in poor growth, alopecia, cough, excessive nasal secretion, diarrhoea, spastic gait and "goose-stepping" with the hind legs. These workers also observed ulcerative colitis, necrosis of the intestinal wall and degeneration of the myelin sheaths of the brachial and sciatic nerves. Maynard (1947) noted dermatitis and a dark brown exudate around the eyes in cases of pantothenic acid deficiency in pigs.

In work using baby pigs fed a casein synthetic milk from which pantothenic acid was absent, Wiese et al. (1951) produced deficiency symptoms similar to those observed by the earlier workers with older pigs. Pantothenic acid-deficient baby pigs showed poor growth, loss of appetite, scouring, alopecia, dermatitis, coughing, loss of the suckling reflex, the presence of a dark brown exudate around the eyes, spastic gait and "goose-stepping". Urinary excretion of pantothenic acid was lowered. Post-mortem examination failed to reveal any internal gross lesions. Deficient animals were observed to have little subcutaneous fat and internal fat was lacking. The long bones of the legs and the ribs were soft and easily fractured and the bone marrow was abnormally light in colour.

In an attempt to estimate the pantothenic acid requirement of the baby pig, Stothers et al. (1952) in a preliminary report, and later, Stothers et al. (1955) in a more detailed study, using baby pigs fed a casein synthetic milk observed some symptoms similar to those of Wiese et al. (1951). Pathological studies, however, showed lesions which had/

had not been found by Wiese et al. (1951) but were essentially those described by the earlier workers as being present in older pigs deficient in pantothenic acid. There was an increase in the connective tissue of the submucosa which was most marked in pigs which scoured for a long period of time. This tissue was still present in large amounts in the submucosa of deficient animals treated with calcium pantothenate. Myelin degeneration occurred and was still present in the sciatic nerves of treated animals. A decrease in the thickness of the glomerular layer of the adrenal glands was observed.

(e) Pyridoxin.

Requirement.

Among the workers who reported on the pyridoxin requirement of older pigs were Hughes and Squibb (1942), who stated the requirement to be up to 5 mg. per 100 lb. body weight, and McMillen et al. (1949) who found it to be 2.5 mg. per lb. diet.

Lehrer et al. (1951) found that a satisfactory level of pyridoxin supplementation to a pyridoxin-deficient synthetic milk was 0.65 mg. per kg. of liquid diet. At this level the pigs grew well and were thrifty.

Miller et al. (1956) found that an analysis of growth and feed consumption data, obtained in their work with a synthetic milk, indicated that the pyridoxin requirement of the baby pig did not exceed 0.5 mg. per kg. of dietary solids. However, data obtained on blood haemoglobin, red blood cell counts, lymphocyte population, and urine xanthurenic acid excretion indicated that the minimum requirement, when these factors were taken into consideration, is not less than 0.75 mg. of pyridoxin per kg. of solids.

Deficiency Symptoms./

Deficiency Symptoms.

Chick et al. (1938) were responsible for the observation that the pig required certain water-soluble vitamins found in the filtrate and eluate fractions of liver. In the absence of the eluate fraction, pigs on purified rations showed slow growth, epileptiform seizures and microcytic hypochromic anaemias. Upon the provision of the eluate fraction, these abnormalities disappeared. Wintrobe (1939) found that suckling pigs required certain growth factors found in yeast. When yeast was removed from the experimental diet, the pigs developed convulsions. Wintrobe et al. (1942) observed pyridoxin deficiency symptoms similar to those described by Chick et al. (1938). These symptoms were alleviated by the feeding of pyridoxin. Hughes and Squibb (1942) also demonstrated that the pig requires pyridoxin.

In work with baby pigs fed a casein synthetic milk, Wiese et al. (1948), in a preliminary report, and later Lehrer et al. (1951), reported pyridoxin deficiency symptoms produced as a result of the omission of this vitamin from the diet. The symptoms observed were poor appetite, poor growth, inco-ordination of the muscles, spastic gait, epileptiform fits, comas, a rough hair coat, the presence of a brown exudate around the eyes and the impairment of eyesight. The urinary excretion of pyridoxin fell to a low level. No post-mortem examinations were reported. The adequate supplementation of the ration with pyridoxin cured all symptoms except the impairment of eyesight.

Miller et al. (1956) observed classical deficiency symptoms in baby pigs fed a synthetic milk containing no pyridoxin. Studies of deficient pigs showed reduced blood haemoglobin levels, red blood cell counts/

counts, lymphocyte population, and urine xanthurenic acid excretion indicated that the minimum requirement, when these factors were taken into consideration, is not less than 0.75 mg. of pyridoxin per kg. of solids.

(f) Choline.

Requirement.

Prior to the work reported by Neumann et al. (1948a, 1949), no determinations of the choline requirement of the pig had been published. Estimation of the choline requirement is complicated by the relationship which exists between choline and other substances which act as "methyl" donors in the body (e.g. methionine) and which can, to a great extent, replace one another.

In their preliminary report, Neumann et al. (1948a) stated that the level of choline found to be required for optimal growth and freedom from fatty livers in baby pigs lay between 0.05 and 0.1% of the dry matter in the diet. The baby pigs in these tests were fed a casein synthetic milk containing 2 mg. of sulphasuxadine per litre of diet to inhibit intestinal synthesis. Neumann et al. (1949) reported the choline requirement of baby pigs fed a casein synthetic milk containing 0.8% methionine as being 0.1% of the diet. Nesheim et al. (1949) found that the baby pig does not require dietary choline when fed a casein synthetic milk containing 1.6% methionine. It was found that, under these circumstances, the pigs fed no choline were extremely thrifty, and no external or internal differences were observed between these pigs and those fed the same diet plus 0.1% choline.

Deficiency Symptoms.

Working with three- to four-months-old pigs, Wintrobe et al. (1942) produced a choline deficiency. The/

The symptoms observed were an increased amount of fat in the liver and some abnormality of gait. No growth retardation was apparent. Ellis et al. (1943) reported that choline was necessary, in addition to pantothenic acid and pyridoxin, for protection from locomotor inco-ordination resulting from nerve degeneration. No effect on growth was noted.

The first work on choline deficiency in which baby pigs fed a synthetic milk were used was that of Johnson and James (1948). One group of baby pigs was fed a casein synthetic milk from which choline was absent, while another received the "complete" synthetic milk. All pigs were fed sulphathalidine to inhibit intestinal synthesis. The baby pig was found to require choline. When choline was omitted from the diet, growth rate slowed down and fatty infiltration of the liver developed. Erythrocyte formation was not as good in deficient pigs as in those receiving the "complete" synthetic milk.

Neumann et al. (1948a) also observed fatty liver in choline-deficient baby pigs, and Neumann et al. (1949) reported more detailed observations on choline deficiency, the symptoms observed in baby pigs fed a casein synthetic milk, from which choline was absent, being unthriftiness, poor conformation (short-legged and pot-bellied), lack of co-ordination of movements, and a characteristic lack of proper rigidity in the joints, particularly the shoulders. The pigs also showed the typical fatty infiltration of the liver observed by the other workers, and a characteristic renal glomerular occlusion and some necrosis of the epithelium of the tubules of the kidney.

(g)/

(g) Vitamin B_{12} (Cyanocobalamine).

Requirement.

Little work had been done on the vitamin B_{12} requirement of older pigs before studies were begun with baby pigs fed synthetic milks, but Catron and Culbertson (1949) stated the requirement of vitamin B_{12} for older pigs as 5-10 µg. per lb. of diet.

Neumann et al. (1950b) fed an α-protein synthetic milk containing sulphasuxidine to inhibit intestinal synthesis of vitamin B_{12}. Several levels of vitamin B_{12} were fed, and optimum growth rates were obtained when 50 µg. of vitamin B_{12} per kg. of dry matter in the diet (1.5 g. per litre) were used. The addition of more vitamin B_{12} concentrate did not result in a further growth response, but even the highest levels of vitamin B_{12} did not induce completely normal haematopoiesis.

Anderson and Hogan (1950) used a casein synthetic milk, the "vitamin-free" casein of which contained 1.7 µg. per cent of vitamin B_{12}. These workers gave a tentative estimate of the quantitative requirement of vitamin B_{12}, when administered orally, as 0.26 µg. daily per kg. live weight, or not over 1.5 µg. per 100 g. of food. They also estimated that the pigs of Johnson and Neumann (1949) received 1.65 µg. vitamin B_{12} per 100 g. of food, this figure being the amount received by injection plus the amount calculated to be present in the α-protein used in the diet.

Nesheim et al. (1950a) reported values for the vitamin B_{12} requirement, when given by intramuscular injection and when given orally, and assessed the relationship between the two. An α-protein synthetic milk was used in this study. The oral vitamin B_{12} requirement was found to be approximately/

approximately 20 µg. per kg. of dry matter consumed. The requirement by injection was approximately 0.6 µg. of vitamin B_{12} per kg. of body weight daily, approximately half of the oral requirement.

Deficiency Symptoms.

Neumann et al. (1948b) showed that the baby pig required an unidentified growth factor contained in anti-pernicious anaemia liver extract. The deficiency in the basal diet used by these workers, the symptoms of which were cured by the liver extract, was later shown to be one of vitamin B_{12}, which had been discovered in 1948. This was proved by Johnson and Neumann (1949) in a preliminary report, a more detailed description of the work appearing later (Neumann et al., 1950a).

A combined deficiency of vitamin B_{12}, and pteroylglutamic (folic) acid was produced by Johnson and Nesheim (1949) in baby pigs fed an α-protein synthetic milk. These workers reported that there were some symptoms common to both deficiencies and that there was some overlapping of the therapeutic action of the two vitamins.

Neumann et al. (1950b) produced a vitamin B_{12} deficiency in baby pigs fed an α-protein synthetic milk. Gross symptoms observed in this study, which could be attributed to the deficiency, were hyper-irritability, posterior inco-ordination, pain in the hindquarters and voice failure. Post-mortem examination failed to show the presence of gross or microscopic lesions in the gastro-intestinal tract, and there was no splenic enlargement. Histological sections of the brain, spinal cord and sciatic nerve were made at different levels and were found to be normal. There was a slight normocytic anaemia.

Neumann/

Neumann et al. (1950a), using an α-protein synthetic milk, observed the following symptoms in deficient baby pigs: Listlessness and sluggishness, posterior inco-ordination, increased size and reddening of the tongue. In post-mortem the liver was enlarged and there were bone marrow and blood abnormalities. No demyelination of the spinal cord or sciatic nerve was found.

Anderson and Hogan (1950) observed emaciation and abnormal appetite, followed by mild lesions of the skin, in baby pigs fed a vitamin B_{12}-deficient casein synthetic milk.

Sheffy et al. (1952), using a "semisynthetic" milk in which casein was the protein source, observed symptoms similar to those described by Neumann et al. (1950b), hyper-irritability and posterior inco-ordination being in evidence.

(h) <u>Vitamin E (Tocopherol)</u>.

<u>Requirement</u>.

No quantitative requirements for this vitamin have been established.

<u>Deficiency Symptoms</u>.

Pigs have been found to be very resistant to a deficiency of this vitamin, although it is known to be essential for normal reproduction in pigs (National Research Council, U.S.A., 1959).

In the two investigations with baby pigs reported here, cod-liver oil was fed. This is known to play a role in precipitating vitamin E deficiency in several species of animals.

McCrea and Tribe (1956) made an unsuccessful small-scale attempt to produce a vitamin E deficiency in baby pigs. A litter of eight pigs was weaned at twenty-four/

twenty-four hours of age and fed a milk substitute (based on skimmed milk powder and lard) containing 4.5 ml. of cod-liver oil per litre. Four of the pigs were also given 40 mg. of α-tocopherol acetate each per day in tablet form. The pigs were killed at forty-two days of age. There was no significant difference between the two groups in the weights of the pigs or the weights of their organs. A histological examination of the hearts, livers, kidneys and testicles (uteri) revealed no differences or abnormalities. The teeth of all the pigs were also normal in appearance.

Forbes and Draper (1958) also conducted studies with the aim of producing and characterising vitamin E deficiency in baby pigs. These workers realised the necessity of using a stress factor in the production of the deficiency. Cod-liver oil was chosen because of its known role in precipitating the deficiency in other species. A vitamin E-low synthetic milk was fed to baby pigs from three to four days of age in two trials (in the second trial the liquid diet was replaced after three weeks by a dry diet). The pigs were divided into groups, and the effects of the addition, to the basal diet, of 2 to 10% of cod-liver oil on a dry matter basis and α-tocopherol acetate, in some cases, at a level of 10 mg. per 100 g. dry matter, were examined.

An unmistakable vitamin E deficiency was produced only under the conditions of a stress provided by at least 5% of cod-liver oil in the diet. The symptoms of the deficiency were: Death, creatinuria, degeneration of skeletal and cardiac muscle, degeneration of the liver, and the presence of a brownish-yellow substance in the adipose tissue. The P-Q, Q-R-S, and Q-T intervals of the electrocardiograms of/

of the pigs were not disturbed by the deficiency. The deficiency was not accompanied by the ability of dialuric acid to haemolyse red blood cells observed, in cases of vitamin E deficiency in rats but not in healthy rats, by Rose and György (1950). Supplementation with vitamin E prevented the appearance of the deficiency symptoms.

(5) The Effects of the Inclusion in the Diet of Antibiotics, Sulpha Drugs, Surface Activating Agents, Arsenicals and Enzymes.

(a) Antibiotics.

Almost all synthetic milks included antibiotics in their formulae, and indeed it has been said that the advent of antibiotics made the artificial rearing of pigs possible (Braude, 1957). The main function of antibiotics, when included in milk substitutes, is to protect the young pigs against the many infections to which they are prone, but the growth promoting properties of the antibiotics are also very important. A great deal of work on the effects of antibiotics on the growth and faecal microflora of baby pigs fed synthetic milks has been done, and among the antibiotics from which growth responses have been obtained are terramycin (e.g. Schendel and Johnson, 1952; Catron et al. 1953), streptomycin (e.g. Nesheim et al., 1950b; Nesheim and Johnson, 1950), penicillin (e.g. Schendel and Johnson, 1952), chloromycetin (e.g. Wahlstrom et al., 1952; Schendel and Johnson, 1952), and aureomycin. Since the last was the most widely used of the antibiotics, the work done on its effects, and in comparing it with other antibiotics, is reviewed briefly below.

Wahlstrom et al. (1950), using an α-protein synthetic milk, found that aureomycin stimulated the growth of baby pigs whereas penicillin did not. Neither/

Neither had any effect on the number of coliform organisms, lactobacilli or yeast cells present in the faeces. Shefchik et al. (1950) found that aureomycin gave a greater growth response, in pigs fed a synthetic milk from two days of age, than did streptomycin. A combination of the two antibiotics gave the best results. Results obtained by Sheffy et al. (1952) also indicated that aureomycin gave a greater growth response than streptomycin. Of the antibiotics studied by Schendel and Johnson (1952), aureomycin and terramycin exerted the greatest effect on growth, penicillin, streptomycin and chloromycetin also stimulated growth but rimocidin failed to produce a significant growth response. Wahlstrom et al. (1952) found that aureomycin increased the average rate of daily gain of pigs fed an α-protein synthetic milk (0.71 lb. as compared with 0.55 lb. for the control). There was no difference in efficiency of gain. No difference was found in the total numbers of aerobic or anaerobic bacteria present in the faeces. No evidence of spore-forming Bacteria or Clostridia was found in the faeces of either the basal or aureomycin-fed pigs. In a second trial comparing aureomycin and chloromycetin, it was found that both stimulated the feed consumption and rate of gain of baby pigs on an α-protein synthetic milk. Whereas chloromycetin effected a temporary reduction in the number of coliform organisms present in the faeces of the young pigs, aureomycin had no effect on the faecal bacteria studied.

In contrast to the reports of the success of aureomycin supplementation, Nesheim et al. (1950a) found, under the conditions of one of their experiments, no significant increases in rate of gain or efficiency of feed utilisation on the supplementation of a casein synthetic milk with aureomycin, streptomycin or penicillin.

(b)/

(b) Sulpha Drugs.

Growth stimulation by sulpha drugs was first reported, by Moore et al. (1946), in chicks fed a purified diet, and most of the early work on this subject was done with chicks. The first use of a sulpha drug in a synthetic milk for baby pigs was as a possible inhibitor of the intestinal synthesis of pteroylglutamic (folic) acid in the attempt of Johnson et al. (1948) to produce a deficiency of this vitamin by feeding a diet from which it was absent. In this case sulphathalidine was used, and in later work with other vitamins sulphasuxidine was used for the same purpose. Bustad et al. (1948) reported the failure of sulphathalidine and sulphamezathine as therapeutic agents in controlling diarrhoea in baby pigs which had not received colostrum and were fed a casein synthetic milk.

Wahlstrom et al. (1950) conducted a study in which the growth stimulating effects of various antibacterial agents, including sulphathalidine, on baby pigs fed an α-protein synthetic milk, were observed. No statistically significant growth promoting effect was obtained from sulphathalidine.

Schendel and Johnson (1952) also obtained negative results using sulpha drugs. These workers found that neither sulphathalidine nor sulphisoxazole stimulated the growth of baby pigs fed a synthetic milk. Later Schendel and Johnson (1955) conducted an experiment in which an α-protein synthetic milk fed to baby pigs was supplemented with aqueous solutions of several substances including sulphisoxazole. The separate effects on growth and interactions of these were studied. As before, sulphisoxazole failed to stimulate the growth of baby pigs. There was, however, a significant interaction between sulphisoxazole and arsanilic/

arsanilic acid, another of the substances on trial. More feed was consumed when both were present than could be accounted for on the basis of their separate effects.

(c) Surface Activating Agents.

The evaluation of surface activating agents as growth promoters in the diet of the young pig began, as with sulpha drugs, after reports of their growth promoting effects in chicks, in this case by Ely (1951).

Schendel and Johnson (1952) studied the growth promoting effects of surface activating agents on baby pigs fed a synthetic milk diet. They were unable to demonstrate any response of increased growth exerted by ethomeen C/15 alone, or by a mixture of ethofat C/15, ethomid C/15, arquad S, aerosol SE, aerosol OS and ultrawet K.

Tests by Williams et al. (1952) on the combination of a nonionic and a cationic surface active compound in a synthetic milk and in a creep feed also showed no growth promoting effect.

Schendel and Johnson (1955) studied the effects, both singly and in combination, of representatives of the nonionic, cationic and anionic classes of surface activating agents, including those used most widely as detergents, wetting and emulsifying agents. They were unable to demonstrate any growth promoting effects. The surfactants used in these tests were arquad S, ethomid C/15, ethofat C/15, aerosol CS, aerosol SE and ultrawet K.

(d) Arsenicals.

Morehouse and Mayfield (1946) and Morehouse (1949) reported that 3-nitro-4-hydroxy phenylarsonic acid stimulated the growth of chickens and turkeys respectively, and this was confirmed by later workers. These reports led to the work done with baby pigs.

Schendel/

Schendel and Johnson (1952) found that arsanilic acid (para-amino phenylarsonic acid) significantly increased the growth rate of baby pigs fed a synthetic milk. Later Schendel and Johnson (1955) reported, in detail, work in which a basal ration consisting of an α-protein synthetic milk was supplemented with aqueous solutions of arsanilic acid, sulphisoxazole, and the surface activating agent ethomeen C/15. The effects of these substances on growth and feed consumption were studied separately and also their interactions. It was found that arsanilic acid increased growth and feed consumption significantly and that the interaction of arsanilic acid and sulphisoxazole was also significant, more feed having been eaten when both were present than could be accounted for on the basis of their separate effects. On the other hand, the interaction of arsanilic acid and ethomeen C/15 depressed feed consumption significantly.

The level of arsanilic acid used in these trials was based on that used in the work with chicks. Analysis of two pigs which had received arsanilic acid, however, gave some indication that the pig retains roughly three times the amount of arsenic in the liver that chicks fed the same amount of arsanilic acid retained. This increased retention, suggesting a possibly increased toxicity, was held to be a possible reason for the deaths of some apparently healthy pigs. Toxic symptoms resulting from the feeding of 3-nitro-4-hydroxy phenylarsonic acid to older pigs had previously been reported by Carpenter (1951). Carpenter found that 3-nitro-4-hydroxy phenylarsonic acid stimulated the growth of pigs, but that after some time the toxic symptoms appeared, and the livers and kidneys of pigs fed the arsenical contained greatly increased quantities of arsenic.

(e)/

(e) Enzymes.

Amylolytic Enzymes.

It was found by Cunningham and Brisson (1955) that starch did not permit satisfactory growth of two-day-old pigs, although Becker et al. (1954a) had found it to be well utilised by pigs from seven to thirty-five days of age. Later, Kitts et al. (1956) reported that the pancreatic amylase activity of baby pigs increased from negligible levels at birth to high levels after twenty-one days.

Cunningham and Brisson (1957a) studied the effects of supplemental amylases on the digestibility and utilisation of starch by baby pigs. The effects of cooking the starch and the susceptibility of cooked starch to hydrolysis by supplemental amylases were also studied. In the two trials conducted, piglets were fed a casein synthetic milk from two days of age.

In the first trial, the piglets were divided into two groups, one group having enzymes added to the basal diet and the other being fed the latter alone. Pancreatic amylase, malt amylase and pancreatin were each added to the diet just before feeding. The duration of the experiment was four weeks. It was found that the amylolytic enzymes had no effect on the coefficient of digestibility of the starch or on the total quantity of starch digested. The digestibilities of protein, fat and ash were also unaffected by enzyme supplementation. Feed consumption was low, and all pigs appeared unthrifty and grew slowly at first. After two weeks, however, the condition of the pigs improved and by the end of the trial they were in satisfactory condition.

In the second trial, the effect of cooking on the digestibility of starch and the effects of supplemental/

supplemental amylases on the cooked starch were studied, a third treatment being raw starch. The response of the piglets to the raw starch diet was similar to that in the first trial, and some feed restriction was required to avoid the occurrence of scouring. The growth and general appearance of the piglets was not improved by cooking the starch, and they appeared even less thrifty and more difficult to raise than those receiving raw starch. None of the piglets receiving the cooked starch diet plus enzymes survived past the fourth week. Their performance in regard to both feed intake and weight gains was below that of the piglets on the other two diets. Although the piglets did not thrive on the starch diets, the starch was almost 100% digested in both trials.

The conclusion was reached that the orally administered amylases were either destroyed before they reached the portion of the gastro-intestinal tract where pH and other conditions would have been favourable for their action, or alternatively starch may require additional treatment with other enzymes or materials for its complete breakdown to glucose. In this connection, Cunningham and Brisson (1957c) found that the new-born pig is capable of digesting maltose and that after one week of age there was no difference in the performance of pigs fed maltose or glucose. It seems, therefore, that the very young pig possesses sufficient maltase to hydrolise any maltose released by supplemental amylases and that the hypothesis of the destruction of the amylases in the gastro-intestinal tract may well be correct.

Proteolytic Enzymes.

Cunningham and Brisson (1957b) studied the effects of supplemental proteolytic enzymes on the digestion of an animal protein and a plant protein by baby/

baby pigs. The effects of predigestion of protein on its utilisation by the pigs was also studied. Three trials were carried out:

In the first trial, the piglets after weaning at two days old, were divided into two groups. One group received the basal diet, in which the protein source was finely ground fishmeal, and the other group received the basal diet supplemented with pepsin and pancreatin.

In the second trial there were three groups. The first received the basal soyabean protein synthetic milk, the second received this diet plus inactive pepsin (autoclaved), and the third received the basal diet plus active pepsin.

In the third trial there were two groups. One was fed the inactive pepsin-supplemented diet used in the second trial, and the other group was fed the basal diet of the second trial with the soyabean protein predigested with pepsin.

Enzyme supplementation had no effect on the growth rate or on the digestibility of the plant or animal proteins. Soyabean protein predigested with pepsin caused severe diarrhoea and death.

Observations which were carried out on the gastric pH of the baby pigs demonstrated the possibility that a deficiency of hydrochloric acid might have produced conditions unsuitable for pepsin to act. (The optimum pH of this enzyme is approximately 2, and at pH 4 activity is very slight). These observations bore out the results obtained by Kvasnitskii and Bakeeva (1940).

(B) Further Attempts to Raise Baby Pigs which did not have Access to Colostrum.

The report of Bustad et al. (1948), that piglets removed from their dams at birth and fed a liquid milk substitute with plasma and serum as colostrum substitutes failed to survive longer than twenty-two days, was the first of a number concerned with this subject.

Catron et al. (1953) reported work in which attempts were made to raise colostrum-deprived baby pigs under farm conditions. These workers reported that, after the successful rearing of fourteen piglets which had not received colostrum in a preliminary experiment, transmissable gastro-enteritis broke out, and it was thereafter impossible to raise piglets without colostrum. Diets containing variable proportions of dried skimmed milk, lard, and casein, with added minerals, vitamins and antibiotics were fed in this work. The solids content of the diets containing these ingredients was 18% initially, this being increased to 24.4% at the end of the third week. From the eighteenth day a pig starter and shelled maize were self-fed.

Of a rather different type were the experiments of Young and Underdahl (1951). These workers required uniformly susceptible pigs for disease transmission studies, and this led them to try to rear colostrum-deprived baby pigs (the nature of the antibodies absorbed from colostrum by baby pigs varies according to the disease experience of the sow). A technique was evolved, employing which fifty-one out of sixty-two baby pigs started in twenty-two experiments were reared successfully from birth. It was found to be vitally important to protect piglets removed from the sow at birth from infections which /

which might be enzootic within the herd, even though these might not be apparent in the older stock or in young pigs which had received colostrum.

The technique used was, briefly, as follows: Each baby pig was caught, at birth, in a sterilised cloth bag held against the sow's hindquarters which had been cleansed with a mild antiseptic. The bag was then closed and the piglet transferred in it to an isolated environment. Vitamins A and K were then given, the vitamin A being given again on the second and third days. The diet fed consisted of modified cow's milk. A few pigs were kept on milk diets up to ninety days of age and many up to thirty days of age and these pigs remained thrifty.

In further trials, piglets which were allowed to drop naturally into the environment of their dams and were then isolated without having received colostrum, died within three or four days. Piglets isolated at birth by the technique described above and later returned to the environment of their dams also died.

This work was carried a stage further when the same workers succeeded in obtaining baby pigs by hysterectomy. These were successfully reared in isolation. The isolation units used for piglets obtained by either of the two techniques were described by Young and Underdahl (1953), and the hysterectomy technique by Young et al. (1955).

Whitehair and Thompson (1956) obtained baby pigs by caesarotomy and raised them successfully in an isolated environment on synthetic diets. This was done in an attempt to break the chain of disease-spread from the sow to her litter, and to enable the rearing of pigs from which certain diseases (especially complex chronic /

chronic digestive disturbances of infectious origin) were absent. A diet composed of 30% vitamin-free casein, 42% fat, 23% lactose and 5% mineral mixture on a dry matter basis and with a complete synthetic vitamin mixture added was fed as a 20% solids milk until five weeks of age, when it was replaced by a dry ration. In this way, seventeen out of twenty-three pigs were reared, growth rates being equal to, or better than, those of pigs reared by sows in the foundation herd. Diarrhoea and other disturbances observed in the herd from which the parent stock came were absent.

It has thus been demonstrated conclusively that baby pigs cannot be reared successfully under practical conditions unless they are allowed access to colostrum. However, the use of operative and isolation rearing techniques to obtain pathogen-free pigs has now become an established practice. Pathogen-free pigs are used for two main purposes at present:

(1) For repopulating farms which have had specific disease problems.
(2) As research tools in the study of disease.

(1) Repopulation of Farms.

Considerable success has been reported with this work in the U.S.A. Viability, rate of gain, and feed conversion efficiency have shown encouraging improvements. It seems that the main advantage accrues from the elimination of respiratory diseases, rather than disorders of the digestive tract. The pathogen-free pigs are introduced to the farm buildings after the latter have been disinfected and rested for a long period. Herds established in this way are known as minimal disease herds. Early fears that pigs in such herds would succumb to a multitude of infections /

infections have not been substantiated, and the technique, when operated under commercial conditions, seems to offer the possibility of eliminating certain diseases and reducing the incidence of others.

(2) The Study of Disease.

Pathogen-free pigs, obtained by operation and reared in isolation, are uniformly susceptible to disease. They are also free from sub-clinical infections and from diseases which, if similar to the one under investigation, might modify, complicate or obscure experimental results.

An example of the use of pathogen-free pigs in disease research is in the study of hog cholera (swine fever) at present being carried out in the U.S.A. (Weide et al., 1960). This is a case where there are several diseases with similar symptoms and where pathogen-free pigs are, therefore, particularly useful.

In addition to disease investigations, future studies in the fields of nutrition and genetics should benefit from the use of pathogen-free pigs. In these fields of research it is necessary to reduce extraneous variables to a minimum, and disease is an important variable. The techniques described above provide a satisfactory method of eliminating this source of error.

(C) The Investigation of the Possible Use of Artificial Rearing in Pig Farming Practice.

The practice of natural rearing, in which the piglets are reared on the sow, has a number of disadvantages associated with it and these will be considered briefly before dealing with the application of artificial rearing to pig farming practice.

Disadvantages Associated with Natural Rearing.

(a) The restriction which a lactation of eight weeks duration, as practised in this system, places on the number of litters which can be obtained from each sow in a year, namely a maximum of two. According to the Ministry of Agriculture and Fisheries (1954) the average number of litters per breeding female per year in Great Britain over the period 1949 to 1953 was only 1.78.

(b) The high death rate, amounting on average to about 22% of the piglets born alive, which occurs during the pre-weaning period due to the sow lying on members of her litter and to other causes (Ministry of Agriculture and Fisheries, 1954).

(c) The impossibility of rearing on the sow piglets born in excess of the number of functioning teats possessed by the sow.

(d) The fact that a sow which has a very small litter requires as much attention as one with a normal sized litter, so that the labour requirement and cost per pig reared is very high in the former case.

(e) Naturally reared litters frequently lack uniformity and runt pigs may be produced due to the different quantities of milk obtained from different teats.

(f) The nutritional deficiency trouble which occurs in piglets when the sow's milk contains insufficient amounts of some essential nutrient, such as iron.

(g)/

(g) The heavy feeding of sows during lactation which is required to provide sufficient nutrients for the production of milk.

(h) The severe losses in weight often sustained by sows during lactation, in spite of the heavy feeding already mentioned. The amount of the weight loss varies considerably among sows and is positively correlated with milk yield (Allen and Lasley, 1960). Cases have been reported in which weight losses in the region of 100 lb. have occurred (Niwa et al., 1951). Further heavy feeding is required after the sow has been separated from her litter to enable her to undertake the subsequent gestation and lactation.

The existence of these disadvantages led to considerable interest being aroused in the pig farming world in the idea of rearing baby pigs away from the sow from an early age instead of leaving them with the sow for the first eight weeks of life. It was anticipated that the types of diet and the techniques devised for use under laboratory conditions in various branches of research, if applied to practical pig rearing, might constitute a rearing system without some of the disadvantages of natural rearing. In particular, it was hoped that the production of three litters per sow per annum might be possible.

In investigations into the possible use of artificial rearing in pig farming practice, the piglets were generally weaned at two to three days of age. The liquid milk substitutes used were more variable in composition than those which were employed in the investigations described in section (A), but were based mainly on dried skimmed milk and lard, with minerals, vitamins and antibiotic added. The piglets were accommodated in pens, brooders or cages and feeding/

feeding was generally ad lib. Research with this type of milk substitute was done by experimental stations and by commercial firms, and many were put on the market. Their use was short-lived, however, because of the difficulties referred to later, and the system was replaced by weaning at a more advanced age on to dry diets.

Work in which liquid sow's milk substitutes of the type described above were used may be classified under four headings:

(1) The evolution of methods of management and types of accommodation and equipment suitable for artificial rearing.

(2) The investigation of the optimal levels of solids, protein and fat in the diets.

(3) The investigation of the effects of transferring piglets at different ages from the liquid milk substitutes on to dry diets.

(4) Observations on the growth and health of piglets weaned on to liquid sow's milk substitutes.

(1) The Evolution of Methods of Management and Types of Accommodation and Equipment Suitable for Artificial Rearing.

(a) Weaning Age.

In most of the investigations carried out, the age of the baby pigs when they were removed from the sow/

sow was generally two to three days, although there were departures from this procedure. Dyrendahl et al. (1953) used artificial rearing for "catastrophic" litters, where the sows died or were unable to nurse their litters for some other reason. In these cases there was of course no predetermined age at which the piglets were started on the milk substitute. These workers also removed litters from sows when the piglets were two to four days old and the sow was healthy. McCrea and Tribe (1956) favoured an earlier separation and established a routine procedure of removing litters at twenty-four hours of age. In contrast to this Williams et al. (1952) weaned pigs at one week old on to liquid milk substitutes.

(b) Accommodation.

Baby pigs were housed in pens, brooders or cages. Catron et al. (1953) used the first type of accommodation, the piglets, after two to three days with their dams in farrowing crates, being confined in radiant-heated, concrete-floored pens equipped with heat lamps suspended from above. Dyrendahl et al. (1953), on the other hand, used brooders to accommodate the baby pigs. Two types were employed, one type entirely of metal and the other of wood. The metal one was based on a model used for raising chicks and was built in one or two storeys. The roof had a hole cut in it to enable a heat lamp to project through and provide warmth. The floor was of galvanised wire mesh, and below was a dropping tray containing moss litter. The second type was a simple wooden box with the cover and four sides fastened together by hooks. There was a hole in the cover for a heating lamp and the floor was again wire mesh. Some trials were also conducted with the pigs kept in a small pen with a heating chamber in one corner and a wire mesh floor. This system was found to be adequate, but the brooders seemed/

seemed preferable. The wooden type of brooder was again used successfully by Dyrendahl et al. (1958), but later field investigations showed that piglets could be successfully raised artificially without using specially constructed brooders, as long as they were kept dry and warm. The practice of Dyrendahl et al. (1953) was to remove the piglets from the brooders at two to three weeks of age and transfer them to dry, draught-free pens preferably littered with cut straw and with a heating chamber equipped with a lamp in one corner. The lamp and heating chamber were later removed. McCrea and Tribe (1956) removed baby pigs from their dams and placed them in individual cages floored with wire mesh, below which was a dropping tray containing sawdust. Infra-red lamps were used to provide heat. When the piglets were three or four weeks old they were transferred to concrete-floored pens littered with sawdust and wood shavings and heated by infra-red lamps. Several litters were never placed in cages but were reared satisfactorily from the start in the pens.

(c) <u>Temperature Conditions</u>.

The necessity of meeting the great requirement of piglets for warmth is emphasised by all groups of workers. Catron et al. (1953) suspended heat lamps above pens also supplied with radiant floor heat. The type of heat lamp used is not stated. Initially floor temperature under the heat lamps was between 90° and 95°F. Floor temperature was gradually reduced after the first week by raising the lamps and these were removed at the end of the fourth week. The initial room temperature of 73°F. was gradually reduced to 58°F. by the time the pigs were eight weeks old. Dyrendahl et al. (1953) used 175 watt carbon-filament lamps in reflectors of light metal as heat sources in their brooders. The temperature in the brooders was at/

at first 77° to 81°F., but after a week it was possible to reduce this by about 9 to 13°F. After two to three weeks the pigs were removed to pens with a heating chamber in one corner, the heat source being again a carbon-filament lamp. The lamp was removed when the pigs were four to five weeks old. The same system was used by Dyrendahl et al. (1958), who stressed the necessity of providing warmth for piglets and advocated heating lamps as the simplest method of doing this. McCrea and Tribe (1956) found that immediately after the piglets were removed from the sow it was best to maintain an environmental temperature of about 80°F., although after the first few days this was decreased to 75°F. by altering the position of the heat source. The heat was provided by a 250-watt infra-red lamp. The temperature was progressively decreased until at six or seven weeks of age it reached a level of 60° to 65°F.

(d) Feeding Practice.

Feeding of the sow's milk substitutes was generally ad lib., although some workers found that this led to over-consumption of the liquid diet and to scouring. Catron et al. (1953) used the ad lib. system, feeding the liquid diet from a three-gallon automatic poultry water fountain. The diet was fed warmed for the first two days and at room temperature thereafter. Dry pig starter was provided in self-feeders when the piglets were considered old enough to eat dry feed, and after three weeks the liquid diet was gradually decreased until its feeding was stopped at the end of the fifth week. Water was provided ad lib. Dyrendahl et al. (1953) fed their liquid milk substitute six times a day at intervals of two to three hours, at first in shallow earthenware bowls and, after the piglets had learned to drink, in feeding troughs of galvanised sheet iron divided into sections by tin devices to prevent/

prevent the piglets crowding and stepping in the milk. After a week the number of feedings was cut to four or five. The piglets in these experiments were not allowed more food than was necessary for normal gain because experience showed that they ate too much and were troubled by scouring, lost weight and some died unless suitable measures were taken. These workers also stressed the importance of giving the piglets free access to fresh drinking water. A dry pig starter was provided in a self-feeder from two to three days of age. The piglets received mainly the milk substitute for the first two to three weeks and then they were moved to pens where the milk, fed from an automatic poultry feeder, was gradually thickened with pig starter to accustom them to the food they would receive when liquid feeding was stopped at about 22 lb. body weight. McCrea and Tribe (1956), who confined most of their piglets in individual cages, had a trough slotted into the front of each of these and this was used for both food and water. The liquid diet, of approximately the same consistency as sow's milk, was fed six times a day during the first week of life, the frequency of feeding being gradually decreased to three times a day at seven weeks of age. The diet was fed at approximately body temperature in order to achieve an adequate mixing of the fat throughout the food. A dry pig starter was introduced after the first seven days and was gradually increased until it replaced the liquid diet entirely when the pigs reached seven weeks of age.

(2) The Investigation of the Optimal Levels of Solids, Protein and Fat in the Diets.

(a) Total Solids.

Milk substitutes of this type were similar in total solids level to the casein and α-protein synthetic milks described earlier. Levels of about 14% to 25% were used with success by various groups of workers.

Investigation/

Investigation of the optimal solids level was described initially by Nelson et al. (1952), and more fully by Catron et al. (1953). Levels of 15, 20 and 25% solids were compared in a sow's milk substitute containing dried skimmed milk, lard, lecithin, minerals, vitamins and antibiotic. The 15% solids level was found to be superior to the 20% or 25% levels for growth, feed conversion efficiency and physical reconstitution of the milk. At eight weeks of age, the pigs fed the milk containing 15% solids averaged 54.0 lb., those on the 20% level averaged 50.1 lb., and those on the 25% level averaged 47.2 lb.

(b) Protein.

The protein levels used in these diets are sometimes not stated, but levels of protein (as D.M.) of about 28% and 32% were used by Dyrendahl et al. (1953) and Dyrendahl et al. (1958) respectively.

Becker et al. (1954b) conducted experiments to ascertain the level of protein required by the baby pig to support maximum body weight gains and efficiency of food utilisation when dried skimmed milk provided the only source of protein. The milk substitute was composed of dried skimmed milk, lactose, corn oil, minerals, vitamins and antibiotics. This diet was fed ad lib. from three to twenty-eight days of age. The levels of protein compared were 10.2, 14.3, 18.4, 22.4, 26.5 and 30.6% D.M. The 10.2% level yielded slow growth, low feed intake and inefficient weight gains. Performance improved, however, with increasing protein level up to 22.4%, but levels higher than this failed to yield improvement as judged by any of the experimental criteria. Further investigations were conducted with pigs from one to four weeks old using the equal feeding technique. Levels of (a) 18.0, 22.0 and 26.0 and (b) 20.0, 22.0 and 24.0% protein were compared. The result which/

which emerged from these trials was that the 22.0% level was optimum. Work was also conducted with older pigs and one of the striking findings was the marked decrease in protein required between three days and nine weeks of age, the pig from five to nine weeks of age requiring only 12% protein.

(c) Fat.

The fat levels used in liquid milk substitutes are not always stated. Dyrendahl et al. (1953) used a level of about 11% (as D.M.) and Dyrendahl et al. (1958) used about 10%.

Nelson et al. (1952) in a preliminary report and Catron et al. (1953) in a more detailed study, compared levels of 10, 20 and 30% fat in their diets. It was found that the 10% fat level produced the best growth. However, feed efficiency at this level was no better than at the other levels. At eight weeks of age the pigs fed the 10% fat level averaged 54.2 lb., those fed the 20% fat level averaged 52.4 lb. and those on the 30% fat level averaged 48.1 lb.

(3) The Investigation of the Effects of Transferring Pigs at Different Ages from the Liquid Milk Substitutes on to Dry Meal Diets.

The picture presented by this series of reports is one of a progressively increasing realisation of the difficulties associated with the use of liquid sow's milk substitutes, and a parallel reduction in the length of their feeding period. The increases in dry feeding which this trend brought about culminated in the adoption of early weaning on to dry rations and the abandonment of liquid feeding altogether.

During one of their experiments on artificial rearing, Catron et al. (1953) observed that there was a marked increase in growth rate during the transitional feeding/

feeding period from the liquid diet to the dry pig starter. An experiment was therefore conducted to determine the minimum age at which pig starter might replace the milk substitute, without adversely affecting the performance of the piglets. The feeding periods of the liquid diet which were compared were seven, six and five weeks. The quantity of milk fed was gradually decreased during the last week of milk feeding. Dry pig starter was provided in a self-feeder from one week of age. It was found that shortening the liquid feeding period from seven to five weeks did not reduce eight-week weights, but did result in lower milk solids consumption and a higher intake of pig starter.

Dyrendahl et al. (1953) found that it was desirable for the feeding of the liquid diet to be terminated when the piglets reached a body weight of about 22 lb. To accustom the piglets to this changeover, pig starter was mixed with the liquid diet from two to three weeks of age. Dyrendahl et al. (1958) attempted to reduce the amount of liquid diet used and increase the amount of dry pig starter. The starter was fed in increasing amounts in the milk substitute from two weeks of age, but feeding of the latter was still terminated at about five weeks of age.

McCrea and Tribe (1956) established an artificial rearing system in which a liquid diet was fed alone for the first seven days after weaning and then a dry diet was introduced. The quantity of the dry diet was gradually increased until it replaced the liquid diet entirely at seven weeks. This system had some disadvantages, and attempts were made to shorten the period of liquid feeding. By trial and error, it was found possible to cut out the liquid diet altogether by the time the piglets were seven days old, and a dry diet was fed thereafter. This system provided as good growth as the earlier one and was without the latter's disadvantages./

disadvantages.

Smith and Lucas (1956) obtained very poor results using liquid feeding from two to three days of age, and turned their attention to the feeding of dry diets from the age of ten days. They found that the practice of feeding the diet as a slop provided no increase in growth rate or efficiency of feed conversion over dry feeding, and a greater tendency to scouring was observed in pigs fed the wet diet. Wet feeding was therefore abandoned in favour of dry diets.

(4) Observations on the Growth and Health of Piglets Weaned on to Liquid Sow's Milk Substitutes.

Williams et al. (1952) reported that the employment of a milk substitute consisting of dried skimmed milk, lard and lecithin, with minerals, vitamins and aureomycin was "successful", but did not state eight-week weights or any other measure of growth.

Perhaps the most spectacular results obtained were those of Catron et al. (1953) who used a diet based on dried skimmed milk, lard, minerals, vitamins and antibiotics. In one of their experiments, ninety-seven out of the one hundred piglets started at two or three days of age were raised successfully to fifty-nine days of age. The best liquid milk substitute formula (10% fat and 15% solids) and the poorest formula (30% fat and 25% solids) produced pigs which averaged 57.7 and 43.4 lb., respectively, at that age. The performance of the pigs after eight weeks was also satisfactory.

Dyrendahl et al. (1953), using a diet composed of dried skimmed milk, lard, rapeseed oil, lecithin, dried sulphite yeast, glucose and cane sugar, with minerals, vitamins and antibiotics, achieved average eight-week weights in the region of 42 lb. There was, however, a tendency towards diarrhoea when this/

this diet was used, and Dyrendahl et al. (1958) removed the rapeseed oil and sugar from the diet to obviate this, and also increased the lecithin content. The quantities of the modified diet fed were reduced and this led to improved health but somewhat slower growth in experiments, although in later field trials no depression of growth resulted.

The diet used by McCrea and Tribe (1956) was also based on dried skimmed milk and lard, with minerals, vitamins and antibiotic. The diet gave satisfactory growth results, and eight-week weights averaged 34.8 lb., compared with an average of 33.8 lb. for littermates reared on the sow.

Probably the most disappointing results were those obtained by Smith and Lucas (1956). These workers fed a diet essentially similar to those used by others and based on cow's milk or dried skimmed milk, lard, casein, lactose and sucrose, supplemented with minerals, vitamins and antibiotic. However, most of the piglets began to scour shortly after being weaned on to the milk substitute, and many died a few days later. Attempts were made to prevent scouring and death by modifying the solids level, the antibiotic level and the feeding equipment, and by restricting the amount of food offered, but these were unsuccessful. In all, eight different diets were tested, but none gave satisfactory results. Of one hundred and eighty-one piglets from twenty-one litters weaned on to liquid milk substitutes, 61% died before they were eight weeks old, the majority of deaths occurring before two weeks of age. The growth performance of many of the piglets which survived was good, but of course the death rate completely outweighed this. The possibility that a high disease level in the environment might be responsible for the failure of most piglets to thrive was considered, but several attempts to isolate pathogenic bacteria from them were not successful.

The Failure of Artificial Rearing in Pig Farming Practice

As stated earlier, many sow's milk substitutes designed for liquid feeding were put on the market and their use was taken up by farmers. It soon became apparent, however, that the early promise of artificial rearing as a routine rearing system was not to be fulfilled. The main difficulties encountered are described below.

Difficulties Associated with the Use of Liquid Diets under Practical Conditions.

(a) The high incidence of disease.

Scouring, loss of weight and death of the piglets were reported in many cases, in spite of the inclusion of antibiotics in the diets as a routine practice.

(b) The failure of sows to recommence the oestrus cycle quickly enough after weaning to make three litters per annum possible.

It was found that although sows can be remated when oestrus occurs soon after the weaning of litters at two to three days of age, they will not conceive at this time as ovulation does not occur and the oestrus is not a true one. Sows will not conceive much earlier than three weeks after farrowing, when the subsequent oestrus, which is an ovulatory one, occurs. Weaning at two or three days of age did not, therefore, result in any higher productivity per sow than could be achieved by weaning when the piglets were somewhat older.

(c) The difficulty of maintaining the high level of hygiene necessary.

Apart from the high standard of sanitation required in the accomodation of the baby pigs, the utensils used in handling the liquid diets had to be kept/

kept scrupulously clean. This was necessary both from the point of view of disease prevention and in order that the baby pigs should receive a fresh and palatable feed. If cleaning was not thorough, the liquid diet went sour rapidly in the containers. The latter problem was particularly troublesome in the early stages of feeding the liquid diet, when the piglets did not clean up all that was put before them fairly quickly. The presence of fat in the diets made the feeding utensils very difficult to clean.

(d) The difficulty of maintaining homogeneity in the diets.

It was found that the fat tended to separate out to the top, and those ingredients in the supplements which were of low solubility sank to the bottom.

(e) The cost of the system.

The cow's milk solids, upon which the diets were based, were in short supply for purposes other than human consumption, and the diets were therefore expensive. The wastage which occurred increased the already high cost considerably. The labour cost was also very high, as the preparation of the diet for feeding and the cleaning of accommodation and utensils involved considerable work.

Thus, while the use of liquid diets under laboratory conditions for research purposes was well established, and their employment for the rearing of very young orphaned and surplus piglets was to be recommended, their use for routine artificial rearing under practical conditions was discredited.

By 1954, numerous reports of the successful rearing of piglets weaned directly on to dry diets at ages varying from about seven to twenty-five days were being published. As had been the case when liquid diets were introduced, considerable interest was aroused/

aroused in the practical application of the new diets. It was hoped that the difficulties found to be inseparable from very early weaning with liquid diets would be nullified by the use of dry diets and by the more advanced age of the piglets at weaning, while the advantages hoped for when artificial rearing was introduced would not be lost entirely.

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THE USE OF DRY DIETS.

Reports of the successful use of dry diets for early weaning first appeared in 1953:

Crane (1953) reported the finding that baby pigs could be removed from the sow and placed directly on a dry ration at an earlier age than had been thought to be possible previously. Crane developed a dry diet which provided satisfactory growth up to approximately six weeks of age in piglets weaned at an average weight of 10 lb. or less. This diet contained 35% dried skimmed milk, 10% dried whey, 4% lard, 1% soyabean lecithin, 25% rolled oats, 25% ground maize, and appropriate mineral, vitamin and antibiotic supplements.

The Quebec Provincial Feed Board (1953) published the formula of a dry meal diet suitable for self-feeding to pigs weaned at ten days of age. Using this meal, eight-week weights comparable with those of sow-reared pigs were claimed to be attainable.

It was, however, in the following year that great interest was aroused with the publication, from several centres, of detailed reports of the development of dry diets and of investigations conducted with them:

Crampton and Ness (1954) developed a dry meal mixture, on which they were able to raise pigs successfully under a self-feeding programme. Growth and development of the pigs were fully equal to those of sow-raised pigs of comparable breeding. In all, eight diets were fed, based on dried skimmed milk, cane molasses, ground wheat, ground oat groats, soya-bean oil meal, fish meal and dried brewer's yeast with minerals, vitamins and antibiotic.

Speer/

Speer et al. (1954) announced the development of "Pre-starter 75", a dry diet suitable for feeding to pigs weaned at seven to fourteen days of age, or at a minimum of 5 lb. L.W. The diet was designed to be self-fed, and it was claimed that eight-week weights 10 lb. above those attained by sow-reared and creep-fed pigs were possible. The diet was based on dried skimmed milk, sucrose, lactose, lard (stabilised), with minerals, vitamins and antibiotic.

Hanson et al. (1954) also reported the successful rearing of pigs weaned directly on to dry rations at ages, in this case, of from fourteen to twenty-five days. The diet, which was again self-fed, contained maize, solvent processed soyabean oil meal, dry rendered tankage, sucrose and lard-lecithin mixture, with added minerals, vitamins and antibiotic.

These early reports led to many more, and investigations were carried out with dry diets fed to pigs weaned at ages varying from about seven days to thirty-one days. In most cases the diets were fed as meals, in others they were fed in pellet form. They were generally self-fed, unlimited supplies of water being provided separately. The diets varied considerably in composition, but among the most commonly used ingredients were dried skimmed milk, soyabean oil meal, white fish meal, lard, and rolled oat groats, with minerals, vitamins and antibiotics.

The work done with dry early weaning diets will be considered under the following headings:

(1) Comparisons of levels and sources of protein in the diet.

(2) Investigations into the requirements for certain of the essential amino acids.

(3) The effects of adding various levels of sucrose to the diet.

(4)/

(4) Comparisons of levels and sources of fat in the diet.

(5) Investigations into the requirements for, and symptoms resulting from deficiencies of (a) Magnesium (b) Vitamin A.

(6) The effects of the inclusion in the diet of (a) Antibiotics (at various levels) (b) Enzymes.

(7) Descriptions of Types of Accommodation and Management Practices Suitable for Early Weaning.

(8) Descriptions of the growth and health of early weaned piglets.

(1) Comparisons of Levels and Sources of Protein in the Diet.

Levels of Protein.

Crampton and Ness (1954) compared levels of 26 and 30% crude protein in dry diets for piglets weaned at ten days of age. The 30% protein level produced significantly faster gains than 26% and increased feed conversion efficiency over the lower level.

Hanson et al. (1954) tested levels of 16, 20, 24 and 28% protein in rations for piglets weaned at fourteen to twenty-five days of age. It was tentatively concluded that the 20% level might be optimum, and this level was used in later experiments. Relatively good results were obtained with the low level of 16% protein which was quite unexpected.

Peo et al. (1954) fed protein levels of 15, 20, 25 and 30% to piglets weaned at about one week old and found that the best overall performance was shown by the piglets fed 20% protein.

Smith/

Smith and Lucas (1956) compared levels of 24, 29, 34 and 39% crude protein for piglets weaned at ten days of age and remaining on experiment up to 25 lb. L.W. No significant differences between growth rates were found which were attributable to the four levels of protein. Feed conversion efficiency was significantly improved by 10% when the crude protein level was raised from 24 to 29% but increasing it to 34 or 39% brought no further significant improvement.

Smith and Lucas (1957a) used a protein level of 29% for the period from birth to 25 lb. L.W. (in accordance with the results of their previous experiment - Smith and Lucas, 1956). From 25 lb. L.W. until eight weeks of age a level of 22% was used. Although growth performance under this regimen was satisfactory, varying protein levels had not been compared for the period from 25 lb. L.W. to eight weeks old, and it was thus unknown whether 22% protein was above or below optimum. Smith and Lucas (1957b) therefore compared protein levels of 18, 21, 25 and 28% fed, from 25 to 50 lb. L.W., to pigs which had previously received a 29% protein diet after weaning at about 8 lb. L.W. There were no significant differences in live-weight gain or feed conversion efficiency between these levels, and it was concluded that, with the type of diet fed in these experiments, there was no advantage in raising the crude protein content above 18%.

Peo et al. (1957a) compared protein levels of 15, 20, 25 and 30% in diets for baby pigs weaned at an average age of about eight days and remaining on trial for a period of twenty-eight days. The first two weeks of the twenty-eight day period were considered separately, and also as part of the total four-week test period. Response to the protein levels during the first two weeks showed maximum gains on 30% protein. For/

For the four-week period gains reached a maximum on the 20% level. Feed conversion efficiency improved with increasing protein levels in both the first two-week and total four-week test periods.

In a search for a more sensitive means of measuring protein requirements, Peo et al. (1957b) investigated the technique of protein depletion (using a protein-free diet) followed by repletion (using diets containing various levels of protein). Protein levels of 12, 14, 16, 18, 20 and 22% were compared for baby pigs weaned at an average age of fifteen days. After weaning the piglets were fed a 24% protein ration ("Pre-starter 75" - Speer et al., 1954) for a pre-experimental period of one week and were then put through three cycles of a one-week depletion and a one-week repletion. The greatest gains were made by the pigs repleted with 22% protein, and the least gains by those repleted with 12% protein. The feed required per lb. of repletion gain decreased as the levels of protein increased from 12 to 20%, the decrease being large from the 12 to the 14% level and relatively small per interval of protein increment thereafter.

Difficulties arise in the interpretation of results obtained from the use of the protein depletion - repletion technique because of the absence of any direct comparison with the uninterrupted feeding of diets covering the same range of protein contents.

Jensen et al. (1957) conducted three experiments to determine the minimum protein requirement of pigs for the period between weaning at twelve to sixteen days old and eight weeks of age. In the first two experiments, protein levels of 14.4, 16.6, 19.4, 22.0, 24.8 and 27.6% were compared. Since the data obtained from these experiments showed a trend of increasing feed conversion efficiency with each increment in protein fed, the third experiment was designed/

designed to enable the study of a wider range of protein levels, namely 10.0, 13.0, 16.0, 22.0, 28.0, and 31.8%. Results showed that the minimum protein requirement was approximately 17.0%. This estimate was based on the facts that (a) the 16.0 and 16.6% levels produced average daily gains comparable with those produced by the higher levels fed, and (b) statistical analysis of the feed data showed the optimum response to be at a level of 17.35 ± 0.52% protein.

Examination of these results and those obtained for the optimum protein level in work done with liquid diets (pages 91,136) shows that considerable variation exists among the estimates made with each type of diet. Two factors which may have played parts in causing this variation are:

(a) The differing calorific densities of the diets fed.

(b) The differing biological values of the proteins used.

(a) Calorific Densities.

McCrea and Tribe (1956) obtained evidence from limited experimental data that the calorific density of the diet may have a considerable influence on the optimal protein level.

Manners and McCrea (1958) also stated variations in calorific density to be the most likely explanation of the wide ranges of results obtained both with liquid and with dry diets. These workers compared their own results and diets with those of others who had used liquid diets in the study of protein levels (Sewell et al., 1953; Reber et al., 1953; Becker et al., 1954). They found that the results of these investigations were compatible with the hypothesis that the protein requirement of the baby pig depends on the calorific density of the diet.

(b)/

(b) Biological Values.

In liquid diets, as pointed out by Manners and McCrea (1958), the protein source used was, in many cases, mainly or entirely casein (Sewell et al., 1953; Reber et al., 1953; Becker et al., 1954; Manners and McCrea, 1958). Thus, although biological values may have played some part in causing the wide range of estimates of optimal protein level made, Manners and McCrea considered that the effect could not have been as important as that of varying calorific densities.

In dry diets, the protein sources used were more variable and thus biological values may reasonably be held to have played a more important role. Jensen et al. (1957) considered the different protein sources used to have been partly responsible for the variation in results obtained with dry diets. These workers postulated that the balance and availability of amino acids in the protein source used in their investigations may have been superior to those of sources used in previous studies, this being responsible for the low estimate of protein requirement obtained by them.

Sources of Protein.

The considerable variation which occurred among groups of workers in the sources of protein employed in dry diets has already been remarked upon. Examples of the sources used are given in Table 28.

TABLE 28. SOURCES OF PROTEIN USED BY DIFFERENT GROUPS OF WORKERS.

Source.	Percentage of Diet	Authority.
(dried skimmed milk (fish meal (soyabean oil meal	20 or 37* 10 10	Crampton & Ness (1954)
(dried skimmed milk (white fish meal (casein	41 10 5, 10 or 15*	Smith & Lucas (1956)
(dried skimmed milk (white fish meal	42 15	Smith & Lucas (1957b)
(dried skimmed milk (soyabean oil meal	15 15	Peo et al. (1957a)
(maize (68.4%) (crude casein (31.6%)	Variable*	Jensen et al. (1957)

* Depending on the level of crude protein required.

Comparisons between sources of protein were made by two groups of workers:

Peo et al. (1957b), in their study of the use of the protein depletion - repletion technique, compared repletion gains of piglets weaned at an average age of 11.4 days on protein from three sources. The dietary level of protein was 20% in each case. The sources compared were:

(a) Dried skimmed milk.
(b) Solvent processed soyabean oil meal unsupplemented.
(c) Solvent processed soyabean oil meal supplemented with 0.1% of DL-methionine.

The piglets which were repleted with dried skimmed milk diets showed greater repletion gains on less feed per lb. of repletion gain than those repleted with soyabean oil meal diets with, or without, methionine. There was little difference in repletion gains or feed conversion efficiency between the groups of pigs fed the two soyabean oil meal diets.

Lucas et al. (1959) conducted experiments designed to obtain information on sources of protein alternative to the expensive dried skimmed milk which had been used as the main protein source in previous work (e.g. Smith and Lucas, 1957b). The effects of replacing dried skimmed milk, wholly or partially, with white fish meal and rolled oat groats were studied. The proportions of these ingredients in the three diets compared (all containing 28 to 30% total crude protein) are shown in Table 29. The diets were fed from weaning at ten to thirteen days old until the mean weight of the piglets in each group was 26 lb.

TABLE 29. /

TABLE 29. PROPORTIONS OF CERTAIN INGREDIENTS IN THE DIETS OF LUCAS ET AL. (1959).

Diet	Dried Skimmed Milk	White Fish Meal	Rolled Oat Groats
A	42	22	15
B	20	34	25
C	0	47	32

The replacement of about half of the dried skimmed milk in diet A with white fish meal and rolled oat groats (diet B) resulted in 4% faster growth, but the replacement of all the dried skimmed milk (diet C) caused growth to be slower by 6%. These treatment differences were statistically significant. The slower growth with diet C was associated with a lower daily feed consumption and the improved growth rate on diet B was probably associated with an improvement in feed conversion efficiency. Treatment differences in feed conversion efficiency were not, however, statistically significant.

(2) Investigations into the Requirements for Certain of the Essential Amino Acids.

The requirements of baby pigs for certain of the essential amino acids were determined using liquid diets fed from two to three days of age, and this work has already been described in the appropriate section (page 93). Research into the requirements of baby pigs for others of these amino acids was carried out using dry early weaning diets and this work is dealt with below. The amino acids are again classified for convenience.

(a) Neutral Amino Acids.

Isoleucine

Becker et al. (1956) investigated the isoleucine /

isoleucine requirement of baby pigs weighing about 10 lb. at the start of the experiment. A 22% protein ration, deficient in isoleucine, was fed to these animals, and supplementary levels of isoleucine were compared. It was found that the baby pigs required a minimum of 0.76% L-isoleucine for maximum rate and efficiency of gain. This requirement is equal to 3.5% of the dietary protein.

Estimates obtained indirectly:

5.77% of the dietary protein (pigs 1-4 wk. old) (Becker et al., 1954).

3.20% of the dietary protein (Manners and McCrea, 1958).

(b) Basic Amino Acids.

Lysine.

Hutchinson et al. (1957) conducted an investigation to determine the minimum lysine requirement of the baby pig from two to six weeks of age. A dry diet containing 14.25% crude protein was used. DL-lysine monohydrochloride was added to the basal diet to supply rations containing L-lysine levels of 0.525, 0.625, 0.725, 0.825, 0.925 and 1.025%. From the results of previous work with rats and mice, it was assumed, in this study, that the D-isomer did not contribute any available lysine.

The results indicated that the baby pig from two to six weeks of age requires no more than 0.935% of L-lysine in a diet containing 14.25% protein. This is equivalent to 6.6% of the dietary protein.

Estimates obtained indirectly:

6.45% of the dietary protein (pigs 1-4 wk. old) (Becker et al., 1954).

Manners and McCrea (1958) used the requirement for lysine, as determined by Hutchinson et al. (1957), as the basis for their estimation of the minimum requirements /

requirements for the other nine essential amino acids, and thus no estimate of the lysine requirement made by this indirect method is available.

Histidine.

Rechcigl et al. (1956) conducted experiments designed to study the histidine requirement of the baby pig from ten to thirty-one days of age. Two experiments were conducted using rations containing 20% and 16% protein respectively.

In the first experiment, levels of L-histidine of 0.1, 0.2, 0.3 and 0.4% of the diet were compared. Growth response and efficiency of feed utilisation were used as measures of the adequacy of the diets. The 0.3% level of total L-histidine appeared to be optimum. This is equivalent to 1.5% of the dietary protein.

In the second experiment, levels of L-histidine of 0.03, 0.11, 0.16 and 0.24% of the diet were compared. In terms of growth, appetite and efficiency of feed utilisation, the optimal level of total L-histidine appeared to be 0.2%. This is equivalent to 1.2% of the dietary protein.

Estimates obtained indirectly:

2.64% of the dietary protein (pigs 1-4 wk. old) (Becker et al., 1954).

2.20% of the dietary protein (Manners and McCrea, 1958).

(3) The Effects of Adding Various Levels of Sucrose to the Diet.

Several groups of workers in the United States showed, initially, that the addition of cane sugar (sucrose) to creep meals designed for suckling pigs resulted in increased feed consumption and live-weight gain and improved feed conversion efficiency. Later, in experiments in which piglets were weaned

on /

on to liquid diets and later given access to dry diets, Nelson et al. (1953) demonstrated the value of levels of up to 15% of cane sugar in increasing the palatability of the dry diets. Working on a similar rearing system, Lewis et al. (1953) conducted preference studies which showed that piglets preferred the diet to contain 20% sugar when this level was compared with 0, 10 and 15%. These workers also showed that gains and feed conversion efficiency improved with increasing levels of sugar up to 20% of the ration.

Using dry diets, on to which piglets were weaned directly, three groups of workers investigated the effects of added sucrose:

Hanson et al. (1954) weaned piglets at fourteen to twenty-five days of age and compared several levels of sucrose (a refined table grade product) in preference trials. Levels of 0, 5 and 10% sugar were used, and it was found that the piglets preferred the feed with 10% sugar added. Of the total feed consumed, 81.5% was the diet with 10% sugar added, 13% was the diet with 5% sugar added, and 5.5% was the diet without added sugar. These results confirmed the findings of earlier workers as to the palatability of added sugar. The data, however, did not indicate that sugar had any significant positive effect on rate of gain or feed conversion efficiency.

Diaz et al. (1956) weaned their piglets at an average age of nine days on to "Pre-starter 75" (Speer et al., 1954), feeding this diet until the piglets were two weeks old. From two weeks onward, the experimental rations were fed, the object of the experiment being to establish a cheaper source of sugar than refined cane sugar. The levels and sources of sugar compared were:

(a) /

(a) 0, 5, 10 and 15% sugar from refined cane sugar.

(b) 0, 5 and 10% sugar from invert cane molasses.

(c) Combinations of the above sources at levels not to exceed 15% total sugar.

(d) 15% sugar from unrefined cane sugar.

It was found that both gains and feed conversion efficiency were significantly improved as the level of refined cane sugar increased from 0 to 15%, in agreement with the findings of Lewis et al. (1953). Unrefined cane sugar produced gains and feed conversion efficiency equal to those produced by refined cane sugar when each was fed singly at the 15% level.

The addition of sugar from invert cane molasses failed to improve performance, neither did it show significant additive effects on gains and feed conversion efficiency when added to refined cane sugar.

The improved gains due to the increased levels of refined cane sugar in the diet were thought to be due to increased daily feed intake or to other factors. The experiments were not designed to elucidate the reasons for the improved performance.

Smith and Lucas (1956) found, in their first trials with piglets weaned at ten days of age on to dry diets, that the piglets were slow to start eating, and having started, did not consume very much for some days. These workers, therefore, tested the effects on these features of the system of adding 10% sucrose to the diet.

The addition of 10% sugar to the diet did not affect the length of the check period which occurred on weaning, but over the total experimental period (ended at 25 lb. L.W.) there were significant improvements of 8%/

8% in growth rate and 10% in feed conversion efficiency. The addition of 10% sugar failed to result in increased food consumption and thus the improvements in rate and efficiency of growth were due to other factors.

(4) Comparisons of Levels and Sources of Fat in the Diet.

Levels of Fat.

Crane (1953) reported briefly upon comparisons of fat levels in a dry diet for weaning piglets at ten days old. Diets containing 7.5, 10, 12.5 and 15% fat were compared and it was found that piglets on the 10% fat diet made the most rapid gains.

Crampton and Ness (1954) found that improved gains and feed conversion efficiency resulted from the addition of 5% of maize oil to a basal 3% fat diet for piglets weaned at ten days old. Protein levels of 26 and 30% were used. Other tests demonstrated that the addition of 10% of certain oils to the 30% protein diet increased gains and feed conversion efficiency further. However, at this fat level (13%) the feed was noticeably oily, and feeding equipment could not be kept clean without special treatment.

Hanson et al. (1954) found that the addition of a lard-lecithin mixture, at a level of 5.1% of the diet, to a low-fat, 20% protein ration did not increase the rate of gain or feed conversion efficiency of piglets weaned at fourteen to twenty-five days of age.

Smith and Lucas (1956) studied the effects of the addition of arachis oil, at a level of 5% of the diet, to a basal early weaning mixture containing 3.7% fat and 29% protein. This basal diet had been used successfully for weaning piglets at ten days of age in a previous experiment. The results obtained showed no/

no significant differences between the diet with added oil and that without, but did tend to support those of Crampton and Ness (1954) in that piglets fed the 7% fat diet grew 4% faster and 6% more efficiently than those fed the 3.7% fat diet.

Peo et al. (1957a) compared four levels of fat (0.0, 2.5, 5.0 and 10.0%) added to a basal diet containing 0.45% fat. The four fat levels were each fed in combination with four protein levels (15, 20, 25 and 30%). Stabilised lard was used as the source of fat. The piglets, weaned at an average age of about eight days, remained on test for twenty-eight days. The first two weeks of the twenty-eight day period were considered separately and also as part of the total four-week test period. There was no significant difference in gains attributable to fat levels for either the first two-week or the four-week test period. However, when fat was added to the diets, the appearance of the pigs was improved. Fat also improved the physical characteristics of the ration, eliminating the dustiness and encrustation of the piglets' hair coats with feed which occurred without added fat. With increasing levels of fat, a significant linear decrease in feed conversion efficiency occurred in the first two-week test period, but there was no significant difference in feed conversion efficiency due to fat for the four-week test period.

<u>Sources of Fat.</u>

Among the sources of fat used in dry early weaning diets were: Maize oil (Crampton and Ness, 1954); lard-lecithin mixture (Hanson et al., 1954); arachis oil (Smith and Lucas, 1956); stabilised lard (Peo et al., 1957a, b) wheat germ oil (Jensen et al., 1957).

Lloyd/

Lloyd and Crampton (1957) studied the apparent digestibilities of twenty different fats and oils, each added to a basal dry early weaning diet at a level of 20% of the diet. The piglets used in this work were weaned at fourteen days of age. The fats and oils were divided into three categories on the basis of fatty acid chain length (mean molecular weight) using saponification values as the means of differentiation. The three classes were:

(a) Fats and oils containing a preponderance of short chain fatty acids (e.g. butter, lard, beef tallow, coconut oil).

(b) Fats and oils containing a preponderance of fatty acids of average chain length (e.g. soyabean oil, linseed oil, fish oil).

(c) Fats and oils containing a preponderance of long chain fatty acids (e.g. rapeseed oil).

It was found that as the fatty acid chain length increased, digestibility decreased, this inverse relationship being highly significant. On the other hand, degree of saturation (as measured by iodine values) appeared to exert only a minor influence on fat digestibility.

In further work on similar lines, Lloyd et al. (1957) compared the apparent digestibilities of thirteen fats and oils fed at the 20% level, by piglets at three and seven weeks of age. The fats and oils were again divided into three groups on the basis of fatty acid chain length. The effect of increasing chain length (a progressive decrease in apparent digestibility) was much more pronounced in piglets at three weeks of age than in the same animals at seven weeks of age. There thus appears to be a marked change/

change, before eight weeks of age, in the ability of the pig to digest fat. Since ample pancreatic lipase activity in pigs at birth, and as growth proceeds, was reported by Kitts et al. (1956), it was postulated by Lloyd et al. (1957) that the increasing ability of the pig to digest fats with advancing age is due to an increase in bile secretion, resulting in an improved absorbtive capacity for fat.

(5) Investigations into the Requirements for and Symptoms Resulting from Deficiencies of (a) Magnesium (b) Vitamin A.

(a) Magnesium.

Little is known about the quantitative mineral requirements of the baby pig, and in many cases the only information available is that summarised in the report of the National Research Council (U.S.A.) (1959). The probability that the rapidly growing baby pig has a higher mineral requirement per unit of diet than the older pig has been pointed out by Manners and McCrea (1958).

In the case of magnesium, an investigation involving baby pigs was carried out by Mayo et al. (1959). These workers conducted experiments, the objects of which were:

(i) To determine whether magnesium is required in the diet of pigs weaned at either three or nine weeks of age.

(ii) To characterise any deficiency symptoms.

(iii) To determine the quantitative magnesium requirement of pigs weaned at either three or nine weeks of age.

The results obtained with piglets weaned at three weeks of age, directly on to a dry diet were:

(i) Magnesium was found to be an essential nutrient in the diet.

(ii)/

(ii) Deficiency of dietary magnesium resulted in the following symptoms in order of appearance: Noticeably weak front pasterns, sickled hocks, a concave bowing back of the front legs due to extreme pastern weakness, knock-knees and hocks, hyper-irritability, muscular twitching, arched back, reluctance to stand and a continual shifting of the feet while standing, tetany and death. These symptoms were accompanied by statistically significant reductions in growth rate, feed consumption, feed conversion efficiency and serum magnesium. Post-mortem examinations failed to reveal any gross anatomical lesions which could be associated specifically with the deficiency. Examination of the digestive tracts showed some evidence of depraved appetite during the deficiency. Feeding deficient piglets on diets rich in magnesium resulted in rapid recovery.

(iii) The amount of dietary magnesium required to prevent the appearance of deficiency symptoms was greater than the amount necessary for maximum growth. The requirement for the former purpose was found to be 400 p.p.m. of the diet, and for the latter purpose 334 p.p.m. of the diet.

(b) Vitamin A.

As were the vitamins dealt with under "The Use of Liquid Sow's Milk Substitutes", vitamin A is considered here under the headings "Requirement" and "Deficiency Symptoms". Results obtained in studies with older pigs are again given for comparison.

Requirement.

Braude et al. (1941) considered the minimal vitamin A requirement of the pig of eight weeks of age and older to be 10 I.U. per lb. body weight per day.

Working /

Working with baby pigs weaned on to a dry diet, Frape et al. (1959) investigated the vitamin A requirement from seven days to eight weeks of age. The criteria of adequacy used were blood plasma and liver vitamin A levels, weight gains, feed conversion efficiency, cerebrospinal fluid pressure and gross clinical and histological symptoms of deficiency.

It was found that a detectable storage of vitamin A in the liver corresponded almost exactly with the same dietary vitamin A level (800 I.U. per lb. of feed) in all four experiments carried out. This was also the level at which the other criteria investigated attained normality. Since all the piglets had a negligible liver reserve initially, the occurrence of liver storage indicated that all bodily functions had been satisfied, and liver storage could thus be considered a very precise criterion for vitamin A adequacy. The minimum requirement was therefore judged to be 800 I.U. per lb. of feed under the conditions of the experiments. Normality in weight gain, however, occurred at as low a level as 100 I.U. per lb. of feed.

The interaction of temperature and vitamin A on growth approached statistical significance, suggesting an increased requirement at the higher temperature.

It was calculated by these workers that the result obtained by Braude et al. (1941), referred to above, when converted to the same denomination as their own, suggested the minimum vitamin A requirement of pigs of eight weeks and over to be 250 I.U. per lb. of feed, less than one-third of the requirement of baby pigs.

<u>Deficiency Symptoms</u>./

Deficiency Symptoms.

Braude (1954) summarised the deficiency symptoms found to be associated with vitamin A deficiency in older pigs:

Retardation of growth, lack of appetite, nervous disorders associated with nerve degeneration, a tendency to carry the head tilted to one side, inco-ordination of walk, spasticity with gradually increasing convulsive fits, paralysis, xerophthalmia and other eye abnormalities, failure to breed, or production of dead or non-viable offspring with malformations of many types.

Frape et al. (1959) produced vitamin A deficiency symptoms in piglets weaned at seven days of age on to a dry diet. The piglets used were from sows reduced considerably in their vitamin A reserves by feeding a vitamin A-low diet for a period of some months from shortly after breeding until the removal of the piglets. The symptoms, which appeared on feeding a vitamin A-low diet to the piglets for about four weeks after weaning, included a ruffling of the hair coat on the forehead, change in guttural tone, and xerophthalmia. However, obvious keratinisation of the cornea was observed in one piglet only (in an experiment not reported in detail in the paper). Between seven and eight weeks of age, the most striking deficiency symptom was observed. This was an acute paralysis of the hindquarters, particularly noticeable in those pigs which maintained a fairly rapid rate of gain. Death resulting from this extreme deficiency was, however, rare. Massive oral doses of vitamin A were found to be effective in many cases in bringing about recovery from the deficiency.

(6) /

(6) The Effects of the Inclusion in the Diet of (a) Antibiotics (at various levels) (b) Enzymes.

(a) Antibiotics.

The fact that antibiotics were recognised as essential ingredients in liquid diets led to their routine inclusion in almost all dry early weaning diets. Several investigations were, however, carried out with dry diets comparing various antibiotics, various levels of antibiotics, and in one case studying the effects of omitting antibiotics altogether.

Crampton and Ness (1954) from results of work with liquid diets assumed that an antibiotic was desirable in their dry diet for pigs weaned at ten days old. They obtained results from a comparison of terramycin and penicillin which indicated that the use of the latter resulted in more rapid gains as a consequence of greater feed consumption and perhaps a small increase in feed conversion efficiency.

Hanson et al. (1954) tested the value of procaine penicillin and aureomycin in a diet for pigs weaned at three weeks of age. In one trial, procaine penicillin was compared with arsanilic acid. Both increased the daily gains of the pigs by improving feed consumption but neither had any effects on feed conversion efficiency. Overall, penicillin appeared to be somewhat more effective than the arsenical. In another trial, both procaine penicillin and aureomycin increased feed comsumption and rate of gain significantly, but again there was no effect on feed conversion efficiency. The two antibiotics produced essentially the same response.

Levels of antibiotic supplementation were compared by Smith and Lucas (1956). These workers had used an antibiotic level of 18 mg. per lb. of diet, the antibiotic being aureomycin, but at this level scouring was prevalent in pigs weaned at about ten days/

days of age (8 lb. L.W.). It was therefore decided to see if a very high level of antibiotic was valuable in reducing this scouring. The antibiotic used was a mixture of three parts by weight of aureomycin to one part of procaine penicillin. The levels compared were that of 18 mg. per lb. of diet and the very high level of 112 mg. per lb. of diet.

In some litters in this trial, scouring was negligible but in others it was fairly bad. In those litters where scouring was prevalent, the high level of antibiotic had no visible effect in controlling it. Over the experimental period (up to 25 lb. L.W.) there was a significant increase in the live-weight gain per day when the high level of antibiotic was fed. The high level of antibiotic also increased feed conversion efficiency by 8% but this increase was non-significant.

The high level of antibiotic, found to give better performance up to 25 lb. L.W. by Smith and Lucas (1956), was expensive, and in investigations into means of lowering the cost of dry diets, Lucas et al. (1959) attempted to obtain more information on antibiotic levels. An experiment was designed to compare the effects on performance from 9 to 40 lb. L.W. of adding antibiotics at levels of 22, 45, 67 and 90 mg. per lb. of feed to diets for pigs of 9 to 26 lb. L.W. (nine to fourteen days old at weaning). At 26 lb. L.W. all pigs were changed over to a standard diet containing 18 mg. of antibiotic per lb. of feed. In the diets fed before 26 lb. L.W., the antibiotic was a mixture of three parts by weight of aureomycin to one part of procaine penicillin. From 26 to 40 lb. L.W. the antibiotic fed was aureomycin.

A high incidence of scouring was again met with and was difficult to control. Before 26 lb. L.W., increases/

increases in antibiotic level caused average increases of up to 5% in growth rate and 4% in feed conversion efficiency, but these were non-significant. However, taken in conjunction with previous results (Smith and Lucas, 1956) the improvement in growth rate in favour of the highest antibiotic level was significant. There were no carry-over effects of antibiotic levels on growth rate from 26 to 40 lb., but there was the suggestion of a linear trend whereby each increase in antibiotic level fed before 26 lb. L.W. caused a decrease in feed conversion efficiency between 26 and 40 lb. L.W. This fact, together with the high cost of the highest antibiotic level, led to the conclusion that an increase to this level of the antibiotic content was not warranted. The data did not suggest that there would be any financial advantage in feeding the intermediate antibiotic levels.

Calder et al. (1959) designed an experiment to find out the effects of omitting antibiotics from a diet for weaning piglets at about seven days of age (when the mean piglet weight of the litter was between 6 and 7 lb.). The basal diets used in this work had been found to give satisfactory results in previous experiments (Lucas et al., 1959). One basal diet was fed from weaning to 25 lb. L.W., and another from then until the pigs were removed from experiment at 40 lb. L.W. Piglets which had received antibiotic up to 25 lb. L.W. continued to do so in the diet fed up to 40 lb. L.W. The antibiotic used was a mixture of aureomycin and procaine penicillin added to the diet at the rate of 50 g. per ton.

Antibiotic supplementation provided a highly significant 15.7% increase in growth rate from weaning to 25 lb. L.W. Over the period 25 to 40 lb. L.W. there was no significant difference in rates of growth between those pigs receiving and those not receiving/

receiving antibiotics. The overall effect on growth rate of adding antibiotics was a highly significant 12.5% increase in rate of growth from weaning to 40 lb. L.W., brought about by reducing the incidence of scouring and by increasing feed consumption from weaning to 25 lb. L.W. Antibiotic exerted no effect upon efficiency of feed conversion. Economy of live-weight gain was thus the same whether antibiotic was fed or not, and the value of its inclusion in practice was, therefore, held to depend upon the economic return to be derived from a saving of about five days in the time taken to reach 40 lb. L.W. It was pointed out that the piglets in this experiment were weaned at earlier ages and lighter weights than would be considered normal in early weaning practice at the time, and it was probable that the saving in time would have been less if weaning had occurred later.

(b) Enzymes.

Studies of the qualitative and quantitative protein and carbohydrate requirements of early weaned baby pigs led Lewis et al. (1955) to believe that baby pigs may not possess fully developed proteolytic and amylolytic enzyme systems. These workers, therefore, attempted to improve dry diets, for piglets weaned at six to ten days of age, by enzyme supplementation. The diets contained soyabean protein in some cases and cow's milk protein in others, and the effects of supplementation with various proteolytic enzymes were studied. The enzymes used were pepsin, pancreatin, papain, a fungal protease and a diastatic-proteolytic enzyme obtained from the Ascomycete fungus genus Aspergillus.

It was found that the addition of pancreatin and pepsin, at the levels used, to soyabean protein diets stimulated growth and improved feed conversion efficiency./

efficiency. A combination of pancreatin and pepsin did not improve performance over either one fed alone. The addition of fungal protease had a growth-depressing effect. The addition of papain or the fungal diastatic-proteolytic enzyme proved as effective as a combination of pepsin and pancreatin. The addition of pepsin or pancreatin to a casein diet also improved performance but enzyme supplementation of a dried skimmed milk diet failed to improve growth. This latter, however, was thought to be a physical effect rather than a nutritional one.

It was pointed out by Lewis and his colleagues that enzyme supplementation of the soyabean protein diets did not give as good results as were obtained on a diet containing 40% dried skimmed milk in place of the soyabean protein. The possibility was admitted that part of the response to enzyme supplementation might have been due to unidentified growth factors in the crude preparations, or even to an improvement in amino acid balance, and further experiments would be needed to establish whether improved pig performance was due to enzyme activity or to other stimulatory factors.

Alsmeyer et al. (1957) reported four experiments with baby pigs weaned at nine to eleven days of age on to a number of diets containing various protein and carbohydrate sources. The effects of the enzyme supplementation of these diets were tested, using animal diastase, a combination of pepsin and pancreatin, a combination of pepsin and pancreatin plus a surface activating agent, pepsin, pancreatin, sucrase and various combinations of the last three. In two of the experiments, treatment differences were not significant after twenty-eight days. In a third, feed conversion efficiency, but not daily gain, was improved significantly by enzyme supplementation. In a fourth/

fourth experiment, the removal of enzymes after some time from the diets fed to one group did not significantly affect performance up to seven weeks when this was compared with that of the enzyme-continued group.

Calder et al. (1959) designed an experiment to test the effects of the inclusion of proteolytic and diastatic enzymes in a dry diet for pigs weaned at about seven days of age. The enzymes used were pepsin and an α-amylase. Supplementation with these was discontinued at 25 lb. L.W., when the change was made to a lower protein diet. The basal diets had been found to give satisfactory results in previous experiments. (Lucas et al., 1959).

Pepsin supplementation increased the incidence of scouring and reduced rate of growth whilst being fed and significantly so after it was omitted at 25 lb. L.W. Efficiency of feed conversion was significantly reduced when pepsin was fed and was also reduced after it was omitted at 25 lb. L.W.

α-amylase appeared to exert little influence upon either growth rate or efficiency of feed conversion, except in the presence of pepsin. It appeared to counteract the harmful effects of pepsin on growth rate from weaning to 25 lb., and on feed conversion efficiency from 25 to 40 lb. This resulted in a significant increase in growth rate during the first period and a significant improvement in feed conversion efficiency during the second period.

(7) Descriptions of Types of Accommodation and Management Practices Suitable for Early Weaning.

(a) Before Weaning.

While piglets remain with the sow they are always prone to injury and death from overlaying and treading. For this reason, Speer et al. (1954) advised the use of farrowing stalls in which the piglets could suckle the sow for the period before weaning./

weaning. Similarly, Smith (1955) advocated the use of the round farrowing houses designed in New Zealand. Both these types of accommodation were claimed to cut losses considerably.

(b) After Weaning.

(i) Siting of Accommodation Relative to that of Other Stock.

This was found to be a factor of some importance in the success of early weaning systems. Speer et al. (1954) advised that early weaned piglets should be housed in a separate building, or should at least be partitioned off from the accommodation of litters being reared naturally. It was found that the noise of sows nursing their litters unsettled the early weaned piglets. Serious trouble of this nature was also reported from the Agricultural Research Institute of Northern Ireland at Hillsborough (31st Annual Report, 1957-1958) where poor performance and, in many cases, death resulted from early weaned piglets nudging and sucking each other. The source of this trouble was eventually traced to the presence of sows nursing their litters in nearby pens, and separate housing for the early weaned litters overcame the trouble.

(ii) Floor Area Per Pig.

Early weaned piglets are usually housed in indoor pens. Speer et al. (1954) advised that not more than ten piglets should be accommodated in one pen, and that 6 sq. ft. of floor space should be allowed per piglet from one to five weeks of age. A rather greater area was allowed by Jensen et al. (1957) and by Hutchinson et al. (1957), both of which groups of workers confined piglets in lots of five in pens measuring 4 ft. by 10 ft. (i.e. 8 sq. ft. per pig). Smith and Lucas (1956), who housed early weaned piglets individually in cages for research purposes, provided a floor/

floor space of approximately 4 sq. ft. per piglet up to 25 lb. L.W. Workers at the Agricultural Research Institute of Northern Ireland developed a special type of insulated hut with a floor space of 4 ft. by 5 ft. for use in outdoor early weaning, up to twelve pigs being accommodated in each hut and the huts placed in a fenced paddock up to a tenth of an acre in size. (33rd Annual Report, 1959-60; Coey, 1960).

(iii) Bedding Materials.

While chopped straw is probably the most widely used bedding material for young pigs, wood shavings and sawdust have also been used. Practical difficulties have been reported in the use of the latter two materials for bedding early weaned piglets: Crampton and Ness (1954) observed that newly weaned piglets did not at first distinguish between a dry feed mixture and sawdust used for bedding, and were as likely to eat the latter as the former. The same observation was made by Smith (1955) in the case of both wood shavings and sawdust. Once the piglets began to eat bedding it was more difficult to interest them in their proper feed. It was advised that bedding of these types should not be placed in pens occupied by early weaned litters until the piglets have started to feed.

(iv) Temperature Conditions.

The importance of providing early weaned piglets with suitable temperature conditions is universally recognised. Crampton and Ness (1954) found that bed warmth was a critical factor in the success of the system and could affect the early progress of the piglets as much as the nature of the diet itself. The period between weaning and the time when the piglets learned to eat from a feeder was lengthened appreciably and sometimes excessively when pen/

pen and bed temperatures were below optimum. Piglets which were cold huddled together to provide warmth instead of feeding. It was also believed by these workers that scouring was related to unsuitable bed temperatures. This finding was borne out by that of Lucas et al. (1959) who found that the incidence of scouring shortly after weaning was lowered after the air temperature of the accommodation was raised from 70°F. to 80°F.

Various methods have been used to provide temperatures considered suitable for early weaned piglets: Speer et al. (1954) advised the suspension of a heat lamp near each feeder to provide a temperature of 80°F. five inches above the bedding at first, the temperature to be lowered by 5F.° each week by raising the lamp. Crampton and Ness (1954) found that environmental temperatures of 65 to 70°F., with no supplementary heating, were quite unsatisfactory. Thereafter, a number of means of providing supplementary heat were used, including infra-red and incandescent lamps, and radiant-heated, hover-covered concrete slabs. By these means, temperatures were maintained at about 75 to 80°F. Smith and Lucas (1956), who kept early weaned piglets individually in cages, attempted to maintain the environmental quarters of the cages at 70°F., falling to 60 to 65°F. as the piglets approached 25 lb. L.W. Diaz et al. (1956) housed early weaned piglets in a building in which the air temperature was 65°F. Heat lamps were used to provide restricted space heating, starting at 80°F. five inches above the floor until the piglets were four weeks old. The heat lamps were then replaced by 40-watt light bulbs. Smith and Lucas (1957a), who housed early weaned piglets in small wooden huts with outside runs on concrete, used a 2 ft. electric tubular heater in each hut/

hut to keep the internal air temperature at about 70°F. until the piglets each weighed about 25 lb. Thereafter the temperature was allowed to drop to about 65°F.

In some cases it has been found unnecessary to provide supplementary heating: At the Agricultural Research Institute of Northern Ireland, where early weaned piglets have been housed in insulated huts on grass, no heating has been provided except during severe winter weather, when oil lamps have been used (32nd Annual Report, 1958-1959). Longwill (1959) described an early weaning system used in New Zealand in which piglets weaned at twenty-eight days of age and housed indoors were provided with covered kennels in which they were able to keep warm without artificial heat.

(v) Hygiene.

The importance of maintaining a high level of hygiene, which was demonstrated so forcibly when liquid diets were used under practical conditions, was underlined when dry early weaning diets were fed.

A number of groups of workers went to considerable lengths to maintain cleanliness in their experiments: For example, Smith and Lucas (1956), who housed early weaned piglets individually in cages, established the following routine: Dirty feed and water troughs were removed daily and replaced with clean ones. The dirty troughs were then soaked and washed. Every third day, the wire screens on which the piglets stood were replaced by a clean set, then soaked and washed. After all the pigs in each litter were taken off experiment, the cages were soaked and scrubbed with disinfectant. The cage accommodation was also soaked and scrubbed. In spite of this routine a definite odour persisted which was difficult to remove, even with electric expeller fans. Whether this/

this odour harmed the piglets was not, however, discovered. In later experiments with early weaned piglets housed in small huts with outside runs on concrete, Smith and Lucas (1957a) used a cleaning routine whereby the bedding of the huts was replaced whenever it became damp or fouled, the outside runs were brushed on six days out of seven and hosed clean with water, and the huts were scrubbed out with disinfectant before beimng used for the next lot of piglets. The health of piglets under these conditions was good.

The effects of inadequate hygiene have been described in reports from the Agricultural Research Institute of Northern Ireland at Hillsborough and from the Rowett Research Institute at Bucksburn in Scotland. At Hillsborough the indoor rearing accommodation became heavily overloaded and there was insufficient time between groups of early weaned pigs for the proper cleaning and disinfection of pens. Severe scouring occurred, causing deaths and poor eight-week weights. The control measure which was successful in this case was to rear early weaned piglets outdoors on grass (31st Annual Report; Coey, 1960). At the Rowett Research Institute it was found that the incidence of scouring increased with the length of time the piglet accommodation was in continuous use. The most effective method of lowering the high incidence of scouring was to introduce breaks of a week or more when no pigs were kept in the pens, which were then cleaned thoroughly by scrubbing with hot water, liquid soap and a disinfectant (Lucas et al., 1959).

The reports described in the preceding paragraph, concerning the build up of infection under conditions of imperfect hygiene, typify the experiences of many farmers who adopted the practice of/

of early weaning. In a survey of a number of such farms, Smith and Littlejohn (1958) concluded that the very high degree of cleanliness necessary for the success of early weaning appears to be unattainable, or at least not sustainable for any long period, under farm conditions.

(8) Descriptions of the Growth and Health of Early Weaned Piglets.

Crampton and Ness (1954) reported that the average eight-week weight of all pigs under all their regimes was 29 lb. However, if the data for the first replicate, which was markedly poorer than later ones, were deleted, the average eight-week weight of the pigs was 31.6 lb. The average eight-week weight of the early weaned pigs was slightly above the herd average over twenty years of natural rearing. Scouring, thought to be related to unsuitable bed temperature, occurred in one group of pigs.

Smith (1955) reported an average eight-week weight for early weaned pigs of 42.7 lb. as compared with 42.5 lb. for sow-reared pigs. It was found that early weaned piglets did not grow as rapidly as those reared on the sow over the second to sixth weeks of life, but they then caught up and passed the sow-reared piglets. In addition, the early weaned pigs suffered no check at eight weeks of age as sow-reared pigs did on weaning.

Smith and Lucas (1956) found that after weaning at ten days of age, piglets exhibited a characteristic growth performance which was apparent both from the appearance of the pigs and from the live weight data. At first the piglets consumed only very small amounts of meal, and during this period they lost the fine glossy appearance they had shown when weaned. Occasionally a pig started to scour persistently and lost weight. After the check period, which lasted on average/

average for ten days, a sudden change occurred: Meal and water were consumed in ever increasing amounts and there was a marked change in the appearance of the pigs. A bloom appeared on the skin, although it remained noticeably white, and there was increased activity. After this, growth was very rapid although scouring occurred from time to time. Of three litters, each of eight pigs, whose growth performance was followed to eight weeks of age, one averaged 46.6 lb., another 48.0 lb. and the third 53.0 lb. at this time.

Smith and Lucas (1957a) reported excellent health among their early weaned piglets with negligible scouring. The check period described previously (Smith and Lucas, 1956) was again evident, but growth after the check was rapid, and average litter weights of between 45 and 51 lb. at eight weeks of age were attained.

Dyrendahl et al. (1958) reported that, in a first series of early weaning trials, pigs weighed on average 37.6 lb. at eight weeks of age. Acute diarrhoea occurred in these trials, and this was associated with a troublesome E. coli infection in the baby pig accommodation. In a second series of trials conducted elsewhere, no digestive disturbances, disease or deaths occurred, and average weights of litters at eight weeks of age in the region of 38 to 44 lb. were reported. These averages compared well with an average of 39 lb. for one hundred and nineteen naturally reared litters. Statistical treatment of the results showed that the smallest piglets of a litter developed better on early weaning than on natural rearing and that more uniform weights were associated with early weaning than with natural rearing.

It was reported from the Agricultural Research Institute of Northern Ireland (31st Annual Report, 1957-1958) that early weaning, which had proved successful/

successful in the previous year and during part of the year under consideration, suffered a considerable setback. Severe scouring caused many deaths and poor eight-week weights. This was thought to be a result of poor hygiene due to overloading of the indoor rearing accommodation. The scouring was controlled by rearing early weaned litters outdoors on grass in insulated huts. In the following year, indoor early weaning was continued (32nd Annual Report, 1958-1959). The one hundred and eighty nine litters farrowed, most of which were early weaned, averaged ten piglets born and eight reared per litter and the mean eight-week weight was 31 lb. Rearing results tended to be poor, largely because of scouring trouble. The scouring proved very difficult to treat, although the use of the outdoor huts for affected pigs provided almost complete control. Subsequently, the practice of weaning piglets at two to three weeks of age and moving them directly into the outdoor huts was established. An average advantage of about 8 lb. per pig at eight weeks in favour of outdoor rearing, when compared with indoor rearing, was obtained (32nd Annual Report, 1958-1959; Coey, 1960).

Lucas et al. (1959) reported that early weaned piglets in their experiments at the Rowett Research Institute were subject to a higher incidence of various disorders than had occurred in previous experiments in the series (Smith and Lucas, 1956; Smith and Lucas, 1957a,b). By far the most troublesome of these disorders was scouring. This proved extremely difficult to cure, although several therapeutic agents were tried. The incidence of scouring increased with the length of time that the piglet accommodation was in continuous use, and the most effective method of control was to introduce breaks of a week or more during which no pigs were kept in the pens, which were then cleaned thoroughly.

Reasons for the Widespread Abandonment of Routine Early Weaning with Dry Diets Which Has Now Taken Place in the United Kingdom.

The experiences of the workers at the Agricultural Research Institute of Northern Ireland and at the Rowett Research Institute in Scotland (described in the previous section) are typical of those of the majority of pig farmers who adopted early weaning as a routine practice. Frequently, a period of success lasting for up to two years has been followed by a breakdown in the health of the piglets, with persistent scouring causing poor growth and deaths.

Two workers who carried out an investigation into early weaning as practised under farm conditions were Smith and Littlejohn (1958). The farms under investigation were situated in the North-East of Scotland and ranged in type from those on which new buildings had been constructed specially for early weaning to those on which no adaption of existing buildings had been done before embarking on the system. These workers concluded that the main stumbling block in the way of the system was the high incidence of disease among the early weaned piglets. E. coli infections took a heavy toll of life, and although antibiotics were used to combat scouring these eventually lost their effectiveness. Trouble of this nature resulted in the abandonment (or proposed abandonment) of early weaning on several of these farms even before the investigation was completed.

Although the failure of early weaning has been the general rule, there are a few farms on which the system has been practised with great success from its inception up to the present day (e.g. Phelps, 1961). As far as is known, no investigation has been /

been conducted to determine the reasons for success in these cases. It is obvious, however, that a low disease level must be maintained in the environment, either by the provision of first class indoor accommodation coupled with excellent management, or by housing the piglets outside under more natural conditions conducive to the destruction of disease organisms and the prevention of the build up of infection.

Current Research with Dry Early Weaning Diets.
(Information obtained from the Agricultural Research Council Index of Current Research on Pigs (VII), February, 1961).

Investigations into various aspects of the early weaning system are at present being conducted in the United Kingdom by the following:

The Agricultural Research Institute of Northern Ireland, Hillsborough, Co. Down.
The Ministry of Agriculture Fisheries and Food at Trawscoed.
The National Institute for Research in Dairying, Shinfield, Reading.
The Rowett Research Institute, Bucksburn, Aberdeen.
A number of commercial firms.

In addition to the British work, early weaning investigations are being carried out in the following countries:

Australia, Canada, Germany, Italy, New Zealand, Poland, South Africa, Sweden, U.S.A. and Yugoslavia.

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"PARTIAL EARLY WEANING": AN INVESTIGATION OF THE EFFECTS ON THE GROWTH AND SUPPLEMENTARY FEED CONSUMPTION OF SUCKLING PIGLETS OF A SYSTEM OF REARING IN WHICH OESTRUS IS INDUCED AND PREGNANCY ESTABLISHED IN THE SOWS DURING THE NURSING PERIOD.

INTRODUCTION.

One of the main aims of early weaning systems is to increase the productivity of the sow by shortening the interval between litters. As has been described in the review of early weaning which precedes this report, it was hoped that by rearing piglets artificially from two to three days of age it would be possible to obtain three litters in a year. When this proved to be impossible in practice, the weaning of piglets at between ten days and three weeks of age replaced the earlier system. Although the production of five litters in two years by the use of the latter system was found to be possible, the incidence of disease among early weaned piglets was so high, in most cases, as to nullify the advantage gained through increased productivity, and early weaning is now practised on very few farms.

It is common knowledge that the cow and mare can be mated successfully during lactation. If this were possible in the sow, and if she continued to nurse her litter after mating without adverse effects on the developing embryos, the interval between litters would be shortened and, at the same time, the disease trouble which has been so prevalent in early weaned piglets might be absent as a result of the presence of the lactating sow, as in natural rearing.

In the spring of 1960 it was learnt that New Zealand workers had succeeded in inducing oestrus in nursing sows by separating them from their litters for a period of hours each day. The oestrus which resulted after a few days of this treatment was said to /

to be a fertile one, mating resulting in pregnancy and the birth of normal litters. The return of sows to their litters after mating did not, apparently, result in any abnormal behaviour. Previous attempts at establishing pregnancy in sows during the normal nursing period of eight weeks had been described by Maslov (1938), working in Russia, and by Burger (1952), working in South Africa. The former worker reported considerable success with his system, but the latter was unsuccessful in his attempts to induce oestrus early in the nursing period by separating sows and litters for a period each day.

It was decided to investigate the practicability, under British conditions, of the induction of oestrus in sows during the nursing period and the establishement of pregnancy in these animals.

REVIEW OF LITERATURE.

Sexual Activity in the Sow During the Nursing Period.

With the exception of post-partum oestrus, which occurs within a few days of farrowing and which is not associated with ovulation (Warnick et al., 1950; Burger, 1952; Baker et al., 1953), sows seldom exhibit any sexual activity during the normal nursing period of eight weeks. Out of a total of seventy-five nursing sows, Burger (1952) observed oestrus (other than post-partum oestrus) in only four. In three of these animals the periodicity of oestrus subsequent to the post-partum oestrus could be considered to be in the nature of the usual three-weekly cycle. Other workers have reported observing oestrus during the nursing period, indeed, the phenomenon was observed in two sows which were under observation in connection with the trials described in this report.

The /

The main factor responsible for the inhibition of oestrus during the nursing period appears to be the exogenous stimulus provided by the suckling piglet. It has been shown in the normally cyclic rat and mouse that mechanical stimulation of the nipple will cause disturbance in the rhythm of the cycle. It has also been shown in the rat that prolonged nursing inhibits oestrus. Burger (1952) considered that the same effect occurred in the pig and that stimulation of the nipple through suckling was the chief cause of the non-appearance of oestrus. Self and Grummer (1958) reached similar conclusions.

The Induction of Oestrus in the Sow During the Nursing Period.

Marshall and Hammond (1926) recommended that if it should be desired to have a sow come on heat before she has finished nursing, she should be shut away from her litter during the night or part of the day and be well fed. Burger (1952) was unable to account for the conviction that separation would induce oestrus since there appeared to be no experimental evidence to support it. Burger himself attempted to induce oestrus in a total of ten nursing sows by separating them nightly for twelve hours from their litters. Four of the sows exhibited oestrus after periods of separation ranging from six days to seventy-five days. However, the circumstances indicated very strongly that in these cases oestrus would have occurred spontaneously during the nursing period in any case.

The Establishment of Pregnancy in the Sow During the Nursing Period.

Marshall and Hammond (1926) stated that if a sow which is nursing does exhibit oestrus and is mated /

mated, she is very rarely fertile (i.e. rarely produces a litter) unless she loses her milk. These authors were of the opinion that the young which start to develop are probably absorbed as a result of the coincident demands made by the mammary glands on the nutrition available. Burger (1952) argued that this did not appear to have been demonstrated experimentally. On the contrary, the work of Maslov (1938) would seem to indicate that the establishment of pregnancy during the nursing period is not only possible physiologically in the pig but is also a commercial proposition. Maslov reported successful attempts at increasing the productivity of sows by mating them during the nursing period. No harmful effects on litter size, weight or viability resulted from such matings. Burger (1952) himself reported that the unintentional service of two sows which were under observation in separation trials resulted in conception in both cases, one sow conceiving to a service on the twenty-second day of lactation and the other conceiving to a service on the thirty-sixth day of lactation. The former produced a litter of six piglets, two of which were still-born, and the latter produced a litter of seven, two of which were still-born.

REPORT OF INVESTIGATIONS CARRIED OUT AT BOGHALL FARM.

PRELIMINARY TRIALS.

At the outset it was not known what period of daily separation had been used successfully in the New Zealand work. A number of preliminary trials were, therefore, conducted using various periods of separation in order to determine whether oestrus could be induced. A number of pens were available, in which there were doors dividing the bedding area from the remainder of the pen, and separation was effected by shutting these doors with the sow on one side and the piglets /

piglets on the other. Initially, periods of separation of:

(a) 2 hours daily rising to 8 hours in stages of 2 hours.

(b) 3 hours daily rising to 9 hours in stages of 1 hour.

(c) 8 hours daily

were tested, and the sows were observed for the onset of oestrus. In none of these cases was oestrus exhibited within ten days of beginning the treatments and separation was, therefore, terminated. Sows separated in the manner described were restless and made strenuous attempts to reach their litters, with which they were obviously in contact through the doors. When the above daily separation periods failed to result in the exhibition of oestrus, it was decided to try a longer period of separation each day and to remove the sows for this period to another part of the piggery. The first sow on this treatment was separated from her litter for a period of twelve hours each day (7 a.m. to 7 p.m.), the separation commencing on the eighteenth day of lactation. On the sixth day of separation this sow exhibited oestrus and was mated. After mating she was returned to her litter and observed. No difficulties were encountered and the sow settled down to nurse her litter at frequent intervals in the normal manner. After a second sow, separated for twelve hours daily from the twenty-first day of lactation onward, had behaved similarly, exhibiting oestrus on the fourth day of separation, it was decided that there was enough evidence to show that a separation of twelve hours per day was effective in inducing oestrus. Neither sow exhibited oestrus on weaning her litter at eight weeks of age and both were presumed to be pregnant on the basis of this and the evidence as to the fertility of lactational mating available /

available from the reports of Maslov (1938) and Burger (1952) and information on the New Zealand work.

MAIN EXPERIMENT.

It was decided to make a detailed study of the growth of a number of litters managed under a partial early weaning system such as established in the preliminary trials and to make comparisons with the growth and supplementary feed consumption of a number of litters reared naturally. Shortly after this experiment was under way, it was noted from the Agricultural Research Council's Index of Current Research on Pigs that D. M. Smith of the Ruakura Animal Research Station, Hamilton, New Zealand was about to publish a report on his work in this field. On request, he generously provided the text of the as yet unpublished report. This has made possible the series of comparisons made between the two pieces of work under "Discussion" below.

Materials and Methods.

Pigs.

The data reported herein come from a total of six sows and litters, three managed under a system of partial early weaning and three managed under natural rearing. The sows were all Large Whites from the Boghall herd which had been mated to either of two Large White boars.

Accommodation.

Sows in this experiment farrowed in the conventional type of farrowing pen, in which there was a covered creep area equipped with a heat lamp. The litters were housed in these pens until at least thirty-five days of age. At thirty-five days, the lamps were switched off and as soon as possible after this (depending on the availability of accommodation) each /

each litter was moved to a second type of pen which was larger and had a creep area separated from the rest of the pen by two horizontal tubular rails. The sows and litters remained in this type of pen up to fifty-six days, when weaning took place.

Cleaning.

The pens were cleaned out, according to the usual practice on the farm, on six days out of seven. Before an experimental litter was put into one of the pens of the second type described above it was cleaned out thoroughly with water unless scouring had occurred in the previous litter to occupy the pen, when it was cleaned out with water and then disinfectant and rested for two days. Overloading of the accommodation prevented a longer period of rest than this.

Feeding.

Sows.

The three sows whose litters were reared naturally were fed at the usual rate for lactating sows on the farm of 4 lb. meal for the sow and an additional allowance of 0.75 lb. for each piglet in her litter. The three sows whose litters were managed under the partial early weaning system were fed to a different scale: During the period of separation these animals were fed 2 lb. of meal per day less than the normal for lactating sows, and after their return to their litters they were fed at a rate of 3 lb. per day more than the normal lactation ration.

Piglets.

Feeding was ad lib. throughout. At fourteen days of age, all litters were given access to a commercial pelleted diet designed for three-week weaning. The chemical analysis of this diet is shown /

shown in Table 30.

TABLE 30. ANALYSIS ON AIR-DRY BASIS OF PELLETED EARLY WEANING DIET.

Constituent	Percentage
Crude protein	21.3
Ether extract	6.0
Crude fibre	1.8
Nitrogen-free extractives	54.8
Ash	5.2
Moisture	10.9

During the period fourteen to twenty-one days of age, no measurements of the amount of feed consumed were made, and the piglets did little more than nose about in the pellets. Beginning at twenty-one days of age, all litters were provided with a weighed quantity of the pelleted feed and a constant supply of water. At two-day intervals the uneaten feed was weighed back to provide feed consumption figures for each two-day period, and a further weighed quantity was given. The pelleted feed was fed throughout in earthenware troughs placed in the creep areas of the farrowing pens.

At thirty-five days of age, the diet fed was changed to a creep meal mixed on the farm. The composition and chemical analysis of this diet are shown in Table 31 and Table 32, respectively.

TABLE 31. COMPOSITION OF CREEP MEAL.

Ingredient	Percentage
Flaked maize	40.0
Barley meal	30.0
Parings (fine)	10.0
Fish meal	10.0
Soyabean meal	5.0
Yeast (dried)	5.0

TABLE 32. ANALYSIS ON AIR-DRY BASIS OF CREEP MEAL.

Constituent	Percentage
Crude protein	18.7
Ether extract	2.6
Crude fibre	1.9
Nitrogen-free extractives	60.7
Ash	4.0
Moisture	12.1

A vitamin-trace mineral supplement was added to the feed at the rate of 2.5 lb. per ton. The change of diet was made suddenly and at the same time self-feeders replaced the troughs. Feed weighings were continued at two-day intervals up to fifty-five days.

Earmarking, Dosing, Castration.

All piglets were earmarked and dosed with iron at three weeks and males were castrated.

Weighing.

All piglets were weighed at twenty-one days of age and at two-day intervals thereafter until thirty-one days of age, in order to establish whether piglets separated from their dams for twelve hours each day suffered any check relative to the naturally reared piglets. On the thirty-fifth day the piglets were weighed again. During the period twenty-one to thirty-five days, weighings were to the nearest oz. Weighings were continued at seven-day intervals up to fifty-six days, when weaning took place and the experiment ended. During the period forty-two to fifty-six days, weighings were to the nearest 0.5 lb.

Separation Procedure.

It was decided to begin the separation of the sows and litters for twelve hours daily at twenty-one days and to continue it, in each case, until the sow exhibited oestrus and was mated, when she would be returned to her litter to continue nursing in the normal way. During separation, sows were treated as in/

in the later preliminary trials. The period of daily separation was from 7 a.m. to 7 p.m.

RESULTS.

The Induction of Oestrus During the Nursing Period.

All three sows exhibited oestrus on the fifth to seventh days of separation (mean 5.7 days).

The Establishment of Pregnancy During the Nursing Period.

All three sows were mated successfully at the oestrus induced by separation. None exhibited oestrus on weaning their litters at eight weeks of age, and none has as yet returned to the boar.

Deaths.

One piglet, a member of a litter managed under partial early weaning died at twenty-five days of age. Growth data from this animal are omitted, but its presence from twenty-one to twenty-five days has been taken into account in arriving at the per piglet supplementary feed consumption figures for this period.

Health.

The health of piglets under both systems of rearing was good. The sudden change of feed at thirty-five days of age did, in both cases, elicit some scouring, but this was cured within two days by treatment with aureomycin in the drinking water.

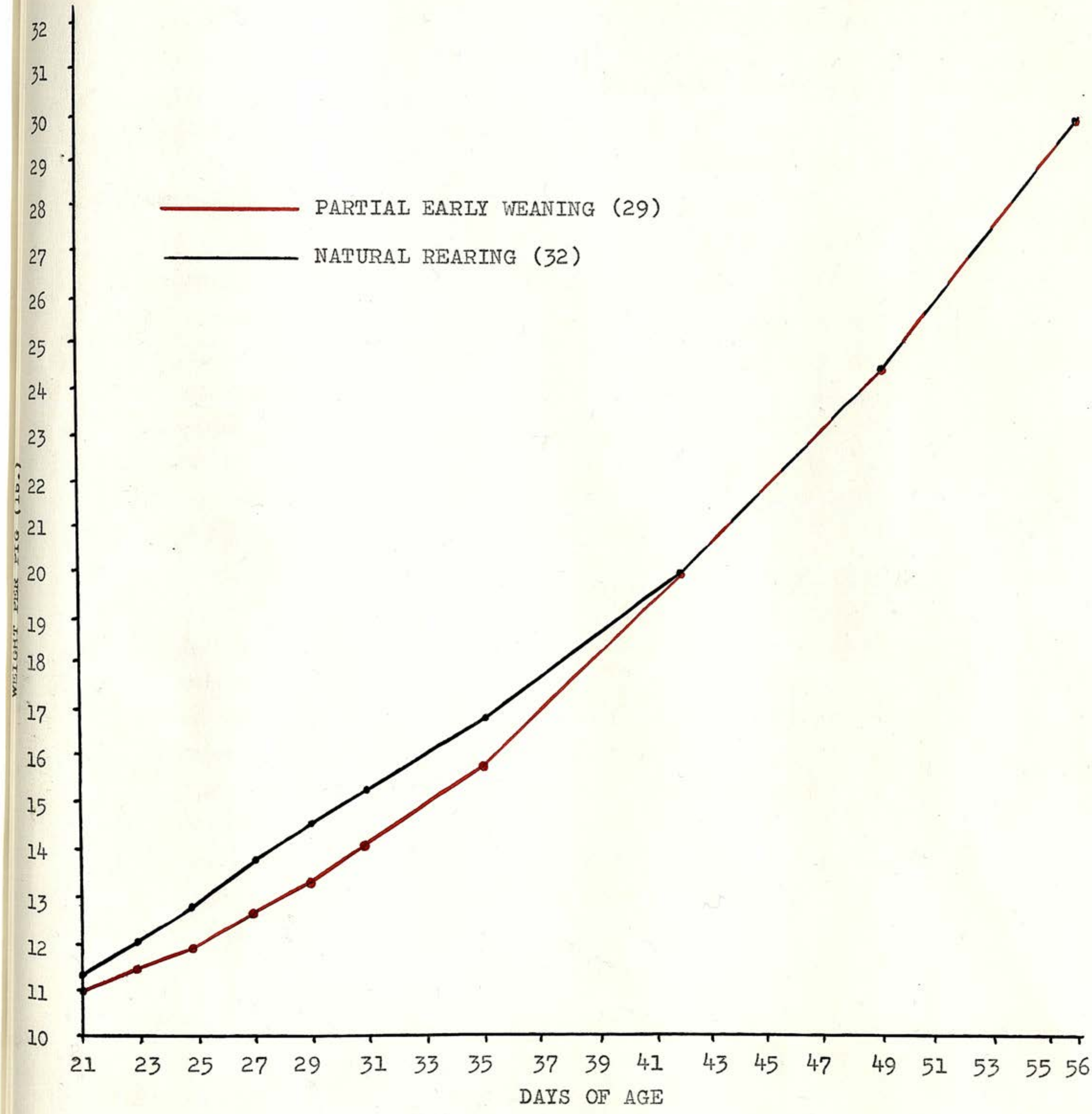
The Growth of Piglets Managed Under Partial Early Weaning.

The mean growth curves of piglets in the three litters which were separated from their dams and in the three naturally reared litters are shown in Figure 1.

It/

FIGURE 1. MEAN GROWTH CURVES OF PIGLETS UNDER PARTIAL EARLY WEANING AND NATURAL REARING.

Figures in brackets indicate numbers of pigs.



It is seen that separated piglets suffered a check in growth relative to naturally reared piglets. However, by forty-two days of age, the piglets which had been separated from their dams had regained both their initial disadvantage and also the ground lost during the check, and the mean weight of piglets on both treatments was the same. Thereafter, the mean growth curves are identical and piglets on both treatments reached the same mean weight of 30.0 lb. at fifty-six days of age.

Presentation of the growth data as in Figure 1 does, however, mask trends which are of interest. If the data obtained from the piglets on both treatments are divided into three categories on the basis of the twenty-one day weights of the animals concerned, these trends are seen clearly (Figure 2). It is seen that while there was a check in the growth of separated piglets in all three categories relative to the growth of the naturally reared piglets, separated animals in category 1 (weight at twenty-one days more than 12.0 lb.) and in category 2 (weight at twenty-one days 10.0 to 12.0 lb.) soon recovered and grew faster than naturally reared piglets. In category 3 (weight at twenty-one days less than 10.0 lb.) the piglets managed under partial early weaning did not recover from the check which they suffered during separation, and continued to lose ground to the naturally reared piglets up to eight weeks of age. The mean eight-week weights of piglets in the three categories are given below:

Category 1.

Partial early weaning - 38.5 lb.
Natural rearing - 34.5 lb.

Category 2.

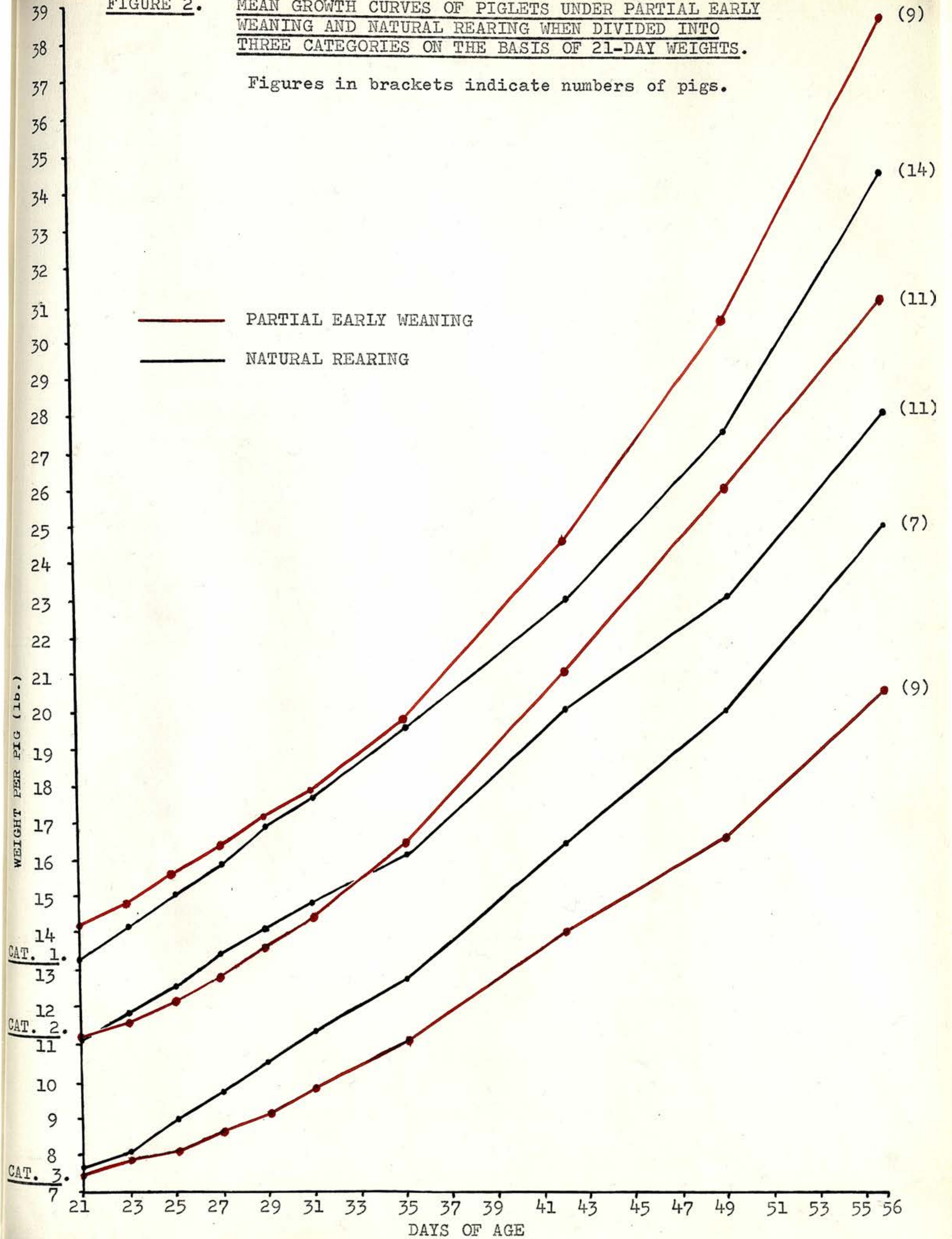
Partial early weaning - 31.0 lb.
Natural rearing - 28.0 lb.

Category 3.

Partial early weaning - 20.5 lb.
Natural rearing - 25.0 lb.

FIGURE 2. MEAN GROWTH CURVES OF PIGLETS UNDER PARTIAL EARLY WEANING AND NATURAL REARING WHEN DIVIDED INTO THREE CATEGORIES ON THE BASIS OF 21-DAY WEIGHTS.

Figures in brackets indicate numbers of pigs.



The Supplementary Feed Consumption of Piglets Managed Under Partial Early Weaning.

The mean supplementary feed consumption curves of piglets in the three litters which were separated from their dams and in the three naturally reared litters are shown in Figure 3.

It is seen that the supplementary feed consumption per piglet under partial early weaning was higher than that on natural rearing almost throughout. The exceptions were during the first two-day period from twenty-one to twenty-three days when the consumptions were the same, and during the period twenty-seven to thirty-one days of age when the naturally reared piglets consumed fractionally more than those under partial early weaning. A similar drop in consumption occurred under both systems with the sudden change over from pellets to meal at thirty-five days of age, but consumption rose rapidly thereafter. A maximum difference of 7.5 oz. per piglet between piglets on the two treatments was reached in the two-day period between forty-seven and forty-nine days of age. At this point, the mean consumption of the naturally reared piglets was only 55.1% of that of those under partial early weaning.

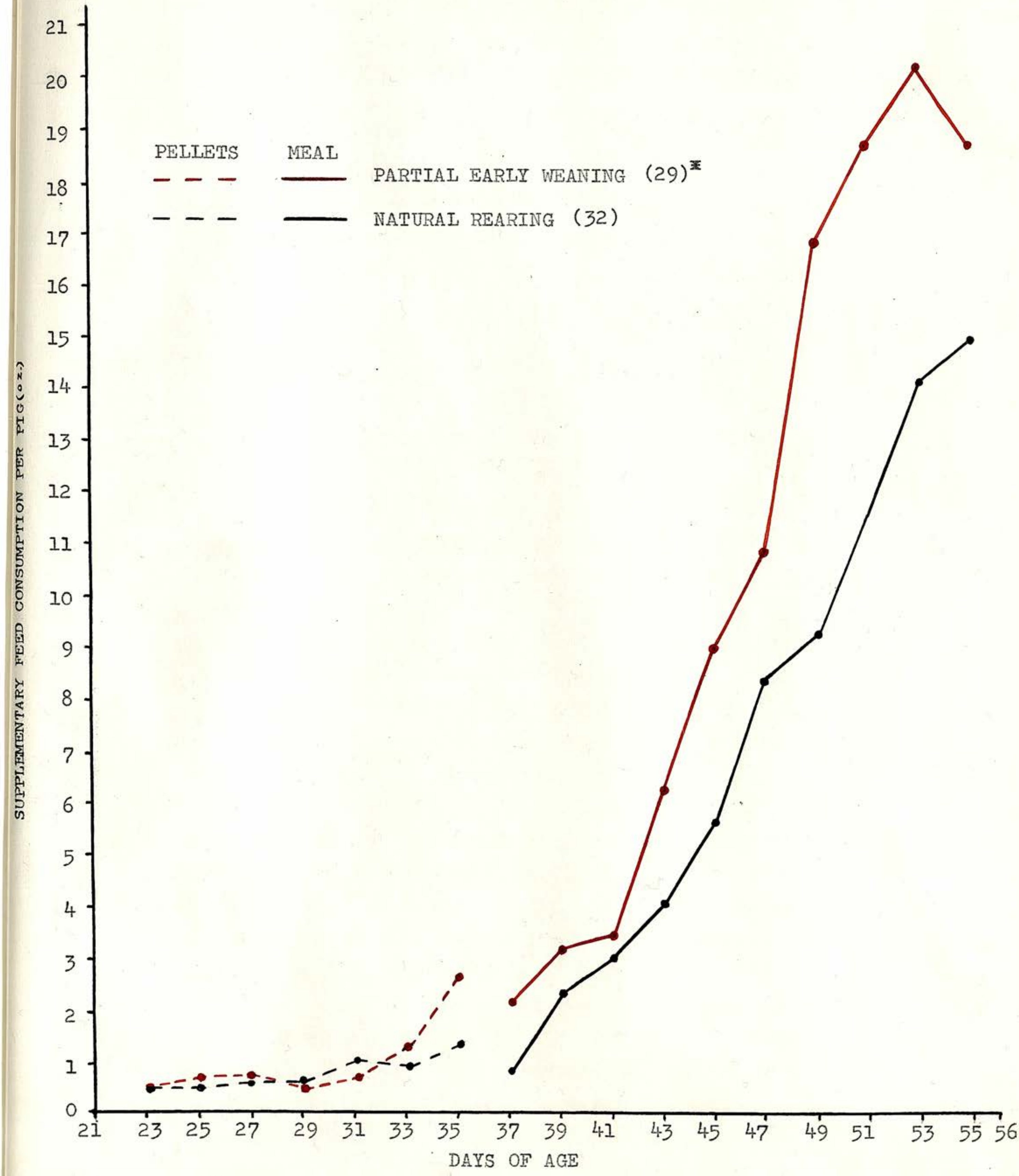
DISCUSSION.

The Induction of Oestrus During the Nursing Period.

The results obtained in this experiment confirm those of Smith (1961) in as far as all three separated sows exhibited oestrus within a short period of separation (mean 5.7 days). Smith conducted three experiments: In the first experiment, the object was to reduce the milk consumption of litters and consequently increase their intake of supplementary feed by separating them from their dams for a period of twelve hours each day. Separation was begun at ages ranging/

FIGURE 3. MEAN SUPPLEMENTARY FEED CONSUMPTION CURVES OF PIGLETS UNDER PARTIAL EARLY WEANING AND NATURAL REARING.

Figures in brackets indicate numbers of pigs.



* 30 pigs between 21 and 25 days.

ranging from thirty-one to thirty-five days. In the course of this experiment it was observed that the separated sows exhibited oestrus six to seven days after separation commenced (mean of four sows 6.5 days). The sows in the first experiment were second litter animals. In the second experiment, separation was begun at twenty-one days of age and it was decided to mate any sows showing oestrus. The sows in this experiment required thirteen to sixteen days of separation to exhibit oestrus (mean of five sows 14.0 days). The sows in the second experiment were first litter animals. In a third experiment using second litter sows separated for the first time on the twenty-first day of lactation, oestrus occurred five to six days after separation was begun (mean of five sows 5.6 days). No attempt was made to mate sows showing oestrus in the third experiment.

In one respect, the results obtained at Boghall differ from those of Smith: One of the three sows (1006) used in the present work was a first litter sow and this animal exhibited oestrus after only five days of separation (Appendix 1). The fact that only one animal is concerned makes it impossible to draw any firm conclusions in the matter, but the fact that all Smith's first litter sows exhibited oestrus within the narrow range of thirteen to sixteen days of separation suggests that some fundamental difference may exist between the stock used in the New Zealand experiments and the animal used in the present work. The sows used in the New Zealand work were Large White X Berkshire crossbred animals whereas those in the Boghall herd are purebred Large Whites. Smith has suggested that the time of onset of oestrus may be conditioned by the age of the sow, or perhaps by the level of milk production. Either of these factors might explain the difference in response obtained in New Zealand between first and second litter sows. Whether/

Whether the first litter sow used in the Boghall experiment differed from the first litter sows used by Smith in either of these features to such an extent as to cause the difference observed is unknown.

Smith has stated that the period of separation required to ensure oestrus may be quite critical. In trials supplementary to his main experiments Smith imposed an eight-hour separation period commencing after twenty-one days of lactation. None of the sows separated in this way showed any sign of oestrus until the eighth week of lactation. This finding is confirmed by the results of the preliminary trials described earlier. It is, of course, possible that the sows in the preliminary trials might have exhibited oestrus if subjected to a greater number of days of separation than were imposed.

The Establishment of Pregnancy During the Nursing Period.

The finding of Smith (1961) that pregnancy can be established during the nursing period has been confirmed by the present work. In his second experiment, Smith mated sows showing oestrus and returned them after mating to their litters. The sows continued to nurse their piglets until weaning and later produced normal litters (Appendix 2). The confirmatory evidence which is available from the present work is shown in Appendix 3.

The establishment of pregnancy during the nursing period provides an increase in the number of litters that can be farrowed per year. The saving of time with each litter, if mating is achieved on about the twenty-seventh day of lactation, is in the region of thirty-five days, since under natural rearing with weaning at eight weeks, sows usually go to the boar about five or six days after weaning. What exactly the long-term effects of lactational mating on the health/

health, fecundity and milk production of sows will be there is no means of knowing at present. Continued investigation over a long period will be required to elucidate these and other problems.

The Growth of Piglets Managed Under Partial Early Weaning.

Although the mean eight-week weights of piglets under partial early weaning and natural rearing were identical, the break-down of the data shows that piglets weighing over 10.0 lb. at twenty-one days were at an advantage under partial early weaning, as compared with natural rearing, but that the reverse was the case with piglets which weighed under 10.0 lb. at twenty-one days. The numbers of piglets from which the growth curves are constructed are too small to enable these differences to be considered as more than trends, but it is indicated that sow's milk yield in the first three weeks of lactation, which determines the weights of the piglets at twenty-one days of age, may be a factor of considerable importance in a partial early weaning system such as is described here. The danger that the incidence of "runt" pigs under partial early weaning might be higher than under natural rearing is also indicated.

The check period which occurred in piglets separated from their dams in this experiment was also noted by Smith (1961) in his second experiment. The second experiment is comparable with the present work in that separated sows were mated and returned to their litters after separation had induced oestrus, but not in the length of the period of separation, which was much longer (thirteen to sixteen days). Smith found that separation of sows and litters at the beginning of the fourth week resulted in a definite depression of growth rate during that week, but there was a complete/

complete recovery in the fifth week, by which time the piglets had become resigned to the absence of the sow and were satisfying their appetites from the creep. After the check period, the weekly growth rate of piglets which had been separated from their dams was greater than that of the non-separated controls up to the eighth week of age. It is not known whether there were any differences in the response of heavy and light piglets to separation, as was found in the present work.

<u>The Supplementary Feed Consumption of Piglets Managed Under Partial Early Weaning.</u>

The fact that after the thirty-first day of age the supplementary feed consumption of piglets managed under partial early weaning never fell below that of naturally reared piglets, and indeed for much of the period was substantially greater, requires some explanation. The same feature of the system was observed by Smith (1961), creep intake being increased substantially in his second experiment, which is in many ways comparable with the present work. It seems obvious that the establishment of pregnancy during lactation was responsible for lowering milk production considerably and that the increased supplementary feed consumption was the result of this. Unfortunately, no milk yield measurements were made in Smith's second experiment or in the present work.

Marshall and Hammond (1926) stated that when pregnancy is established in the sow during the nursing period, the developing embryos make demands on the available nutrition coincident with those of the mammary glands, and this normally results in the reabsorbtion of the developing young. Since the results of Smith (1961), and of the present work, show that reabsorbtion does not occur to a degree which prevents the birth of normal sized litters, it seems likely/

likely that, in the pig, pregnancy militates against lactation and not the reverse.

Smith (1961) mentions sow nutrition studies carried out at Ruakura which have shown that there is an inverse relationship between the milk energy yield of the sow and the creep energy intake of the litter. There is a great deal of other evidence to show that milk yield is inversely correlated with supplementary feed intake, and this evidence has been considered in the review of work on sow's milk yield contained in this volume (page 15).

SUMMARY.

Two phases in a series of experiments are described:

The first phase, comprising a number of preliminary trials, demonstrated the possibility of inducing oestrus in the sow during the nursing period by separating her from her litter for a period of twelve hours each day, and the possibility of establishing pregnancy in the nursing sow.

The second phase consisted of an investigation into the growth and supplementary feed consumption of piglets whose dams were mated during the nursing period at the oestrus induced by separation. A comparison was made with the growth and supplementary feed consumption of piglets reared naturally.

The growth performance of piglets managed under such a system of partial early weaning, as measured by the mean weight gain over the period between twenty-one and fifty-six days of age, was slightly superior to that of naturally reared piglets. However, a break-down of the growth data showed the growth of piglets which were of medium to heavy weight/

weight at twenty-one days of age to be markedly better under partial early weaning than under natural rearing, and that of piglets which were of light weight at twenty-one days of age to be markedly poorer.

In view of the encouraging nature of the results obtained in the present work, investigations are continuing on a larger scale. It is hoped that results may be obtained from between ten and twenty sows and litters managed under partial early weaning, with a view to publication. Eventually, sufficient data may be collected on the long-term effects of partial early weaning on both sows and litters to enable a decision to be made as to whether the system provides an alternative to natural rearing superior to that provided by early weaning.

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APPENDIX 1.

TIMES OF ONSET OF OESTRUS FOLLOWING SEPARATION IN THE PRESENT WORK.

	Sow Number	Separation Begun (days post-partum)	Period from First Separation to Oestrus (days)
PRELIM. TRIALS.	192	18	6
	932	21	4
MAIN EXP.	1006	21	5
	330	21	7
	951	21	5

APPENDIX 2.

NUMBERS OF PIGLETS FARROWED AND REARED BY SOWS MATED DURING LACTATION (Smith, 1961).

Sow	Number of Piglets Born	Number of Piglets Reared*
A	17	10
B	11	10
C	12	10
D	15	9
E	15	10

* Litter size was adjusted to 10 piglets within 12 hours of birth.

These litters had means of 14.0 born and 9.8 reared as compared with the means for the immediately previous litters of the same sows of 11.2 born/

born and 10.0 reared. The data indicated that the litters conceived during lactation were not significantly smaller than those of non-separated control sows which were mated after their litters had been weaned at eight weeks. No information on birth or other weights is given.

APPENDIX 3.

NUMBERS OF PIGLETS FARROWED AND REARED BY SOWS MATED DURING LACTATION IN THE PRESENT WORK.

Figures in brackets represent numbers of piglets in the immediately previous litters of the same sows.

	Sow Number	Number of Piglets Born Alive	Number of Piglets at 21 Days	Number of Piglets at 56 Days
PRELIM. TRIALS.	192	11(11)	9(10)	9(10)
	932	6(9)	5(8)	no data as yet(8)

MAIN EXP. None of the sows has, as yet, farrowed.