

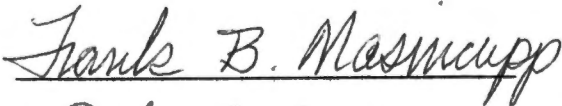
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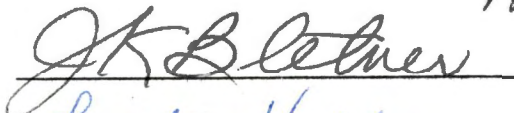
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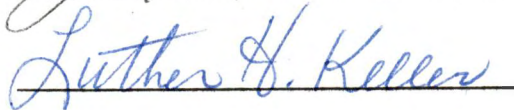
I am submitting herewith a dissertation written by Steven Philip Bertsch, entitled "Maternal Dietary Effects Upon Fetal Growth and Progeny Response in Limit-Fed Swine." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Animal Science.


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MATERNAL DIETARY EFFECTS UPON FETAL GROWTH AND
PROGENY RESPONSE IN LIMIT-FED SWINE

A Dissertation
Presented for the
Doctor of Philosophy
Degree
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Steven Philip Bertsch

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ABSTRACT

Data from 24 gilts starting their second trimester of gestation were used to evaluate reproductive performance of dam, maternal influence on baby pig composition and postnatal growth of progeny when maternal dam was limit-fed a standardized 16.0% protein diet during the last two-thirds of gestation and during lactation for three successive reproductive cycles. Gravid gilts (Sows) were maintained on concrete in open-fronted houses during the gestation period and individually fed 1.36 kg daily of a corn-soybean meal diet (C-SBM) formulated to provide 225.0 g protein and 4.6 Mcal digestible energy intake. Menhaden fish meal replaced 2.0% of meat and bone scrap in a second corn-soybean meal diet supplemented with 120.0 mg dl-alpha-tocopherol and 1200.0 mg choline chloride/kg diet (Vit E-Chol). Sow lactation feed intake was limited to 1.36 kg plus 0.45 kg/pig nursing. Chemical composition of two neonatal pigs per litter was used to assess maternal dietary influence throughout successive gestations.

Confinement limited-feeding during the last two-thirds of gestation, supported increased maternal weight gains for the first two pregnancies (14.6 and 21.1 kg), but an extremely low gain (1.6 kg) was made during the last gestation (winter). Sows were in a negative weight balance for the controlled feeding periods of the last two reproductive cycles. Vit E-Chol sows nearly maintained body weight for the second reproductive cycle (summer) by higher gestation gain ($P < .10$) and smaller lactation weight loss.

Reduced maternal backfat thickness during third trimester of winter gestation one, and last two-thirds of the third gestation, accompanied by weight gains (first farrowing), suggest daily feed intake level was not sufficient to maintain maternal condition and products of gestation, simultaneously. Increased adipose tissue deposition in the second fat layer, during summer gestation, could indicate adequate energy for continued maternal growth. Lactation caused a further decrease in condition. Low sow weights at end of the third lactation were further evidence daily feed intake was inadequate for maternal growth through three successive reproductive cycles.

Fifty percent of the gilts started on each diet remained after three reproductive cycles (52 total farrowings). Failure to conceive at first post-weaning estrus caused removal of more Vit E-Chol sows. Higher incidence of hypogalactia was evident in C-SBM sows and apparent malnutrition during the last gestation caused abortion.

Increased number of total and live pigs farrowed per litter at successive gestations, indicated that ovulation and embryo survival were apparently not affected by feeding regime. Third farrowing birth weights were reduced. Vit E-Chol sows farrowed 1.2 more pigs per litter at third farrowing, but average birth weight was significantly ($P < .05$) less. Through three reproductive cycles, birth weights were significantly correlated with limited-feeding gestation gains ($r = 0.42$, $P < .01$) and condition changes ($r = 0.40$, $P < .01$).

Three-week litter performance increased in favor of Vit E-Chol pigs with successive lactations, except third lactation average pig weight and gain were lower ($P > .05$). Fetal priority over extrauterine

maternal anabolism may have limited labile protein store of Vit E-Chol sows for subsequent milk production. Pre-weaning pig growth increased through the three lactations and more pigs were weaned per litter when creep diets included vitamin E. Higher creep feed consumption, per kilogram pig gain, indicated lower milking ability for third lactation sows.

Whole body gross energy and protein levels declined in succeeding farrowings with significantly ($P < .01$) lower levels in Vit E-Chol pigs at last farrowing. Over the three farrowings, Vit E-Chol carcass protein and moisture were significantly and negatively correlated ($r = -.37$, $P < .01$). There were no significant differences among neonatal pig liver chemical components, but percent hepatic fat in C-SBM pigs was higher. It was significantly ($P < .10$) higher on dry matter basis at first farrowing. Average liver fat declined (2.30 to 1.04%) over the three farrowings.

Gestation mineral levels fed appeared to meet needs for fetal growth as there were no clinical symptoms of mineral deficiency at birth. Neonatal pig plasma mineral concentrations generally did not reflect trends for liver and whole carcass mineral concentrations. Tissue minerals studied tended to be lower in Vit E-Chol pigs than C-SBM pigs and concentrations were lowest at last farrowing.

Season and diet were associated with suboptimum sow reproductive performance and dietary intake levels proved inadequate to maintain the sow through three successive reproductive cycles. The 225.0 g protein/day during gestation appeared to be sufficient for fetal development and growth, but pigs gestated by Vit E-Chol sows were less responsive, for some undetermined reason, in terms of their chemical and mineral

composition levels. Progeny growth, however, did not appear to be permanently curtailed by gestation diets or level of lactation feeding.

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CHAPTER I

INTRODUCTION

During the past two decades, it has come to be recognized by the N.R.C. (National Research Council 1950, 1959 and 1968) that the nutritional needs of gravid swine have been greatly over-estimated in terms of energy and protein. Studies during this period have been directed towards re-defining minimum intake levels of energy and protein necessary for optimum reproductive performance. A reduction in feed and/or energy intake during gestation would also lower the production costs.

Recommended changes that have occurred in the ecology surrounding gestating swine, improved management practices, and the feeding of uniformly balanced high energy and high protein diets have helped lead to these reductions. In 1950, the N.R.C. recommended that gravid swine receive 9.0 to 11.2 megacalories (Mcal) digestible energy (DE)/day. However, in 1968, the N.R.C. recommended a daily energy intake of 6.6 Mcal DE, representing a reduction of 35.0% from the 1950 energy allowance. One-third less daily protein intake was recommended in 1968 over 1959, decreasing the daily requirement from 409.0 g/day to 280.0 g/day, respectively.

Mineral and vitamin requirements for the gestating sow and the products of conception are practically void in terms of research for establishing minimum levels. Extrapolated data from growing-finishing swine research, however, have yielded guidelines from these essential nutrients. However, establishment of minimal levels has been compounded

by subsequent reduced gestation feed intake levels.

Following the success of growing-finishing swine production units, swine managers have moved their breeding herds towards confinement operations. This has led to the question, "How long can the gravid sow successfully protect her progeny against continued unknown nutritional deficiencies when fed low feed intake levels?" From an evolutionary standpoint, the maternal accumulation of body reserves during pregnancy has represented an insurance against adverse lactation nutritional stress. Also, some maternal weight gain has been desirable for the longevity and subsequent productivity of the sow.

Since 1965, swine production in Tennessee has moved steadily upwards towards the two million mark for number of pigs farrowed per year. At the same time, the percentage of these pigs marketed as feeder pigs has risen by more than 35.0%. Farmers interested in the production of quality feeder pigs, today, are caught between the cost-price squeeze and the fear of the "thin sow syndrome." This condition results from underfeeding during gestation and lactation, leaving the sow extremely thin at weaning and unable to recover body weight between pregnancies. It has been shown that feeding levels permitting only limited maternal gain have been reflected in reduced birth weight. Rat data (Chow, 1964; and Chow and Lee, 1964) also, have shown that restriction of gravid rats to 50.0% of ad libitum feed intake not only caused a reduction in birth weights of the pups, but exerted a deleterious progeny effect that persisted throughout the developmental period. Fortunately, a similar response has not been evident for swine.

Continued growth of the swine industry would be enhanced if quantity and quality of diets fed pregnant and lactating swine could be standardized so as (a) to prevent unnecessary extrauterine anabolism during gestation and (b) to maintain the body condition of the sow during lactation for the ensuing reproductive cycle. When this is done, the maternal efficiency for long-term reproduction will be maximized. These two conditions must be satisfied without detrimental effects to the progeny.

The objective of this study was to assess the long-term effects of limit-feeding a standardized 16.0% protein diet on sows during both gestation and lactation in an effort to establish definite guidelines for evaluating and quantitating minimum nutrient requirements for maximum reproductive performance. Criteria for evaluation have included reproductive performance of dam, the maternal influence on baby pig body composition, and the postnatal growth of offspring.

CHAPTER II

REVIEW OF LITERATURE

I. INFLUENCE OF DIETARY ENERGY LEVEL DURING GESTATION IN SWINE

Reducing energy intakes have been reported to reduce embryo mortality immediately post-coitum, improve reproductive efficiency, increase longevity of the sow in the breeding herd and to lower feed cost. No doubt, climatic conditions have contributed to the disagreement found in literature when various energy levels were considered.

Reproductive Performance

Gestation feeding levels below N.R.C. (1968) recommendations have not reduced reproductive performance to any great extent in first and second litter sows (Self et al., 1960; Clawson et al., 1963; Lidvall and Griffin, 1963; Brown and Tucker, 1966; Frobish, Speer and Hays, 1966; Meade et al., 1966; Lodge, 1969; and Scott and Thrasher, 1969).

However, the gravid female apparently has less capacity to buffer her offspring against an energy deficit than a protein deficit, as indicated by rather marked reductions in birth weight (but not in number of pigs born) when energy or total feed restriction is imposed during gestation (Hanson, Ferrin and Aunan, 1953; Clawson and Barrick, 1962; Henson, Eason and Clawson, 1964; Lodge, Elsley and MacPherson, 1966a; O'Grady, 1967; Baker et al., 1969; and Elsley et al., 1969).

On the other hand, several investigators (Self et al., 1960; Dean and Tribble, 1961; Lodge et al., 1966a; Baker et al., 1969; and Elsley et al., 1969) have reported that restrictions to as little as 1.36 kg feed/head daily did not reduce the number of total offspring per litter when compared to daily intakes of 2.27 or 2.72 kg. Others have indicated that the number of live pigs farrowed per litter was not reduced by similar levels of feed intake (Henson et al., 1964; Frobish et al., 1966; Baker et al., 1969; and Vermedahl et al., 1969).

In contrast, there has been work showing that increased energy intake during pregnancy can increase the number of pigs born as well as the number of pigs born alive (Frobish, 1968, 1970).

Some of the early studies (Hanson et al., 1953; Self et al., 1960; and Lidvall and Griffin, 1963) were conducted under pasture situations which would confound reproductive performance at lower energy intake levels, since some energy was undoubtedly derived from the pasture consumed. It has been recognized that the nutrient requirements of the fetus increase rapidly during the last one-third of pregnancy (Mitchell et al., 1931; Moustgaard, 1962; and Hansard, 1965). Therefore, attempts to improve reproductive performance by adjusting the level of feed intake to meet the demands of pregnancy have been tried. Two energy levels at breeding and during the last third of gestation were investigated by Mayrose, Speer and Hays (1966) through three reproductive cycles. During summer tests, the high level of feeding was 2.72 kg/day and the low level was 1.82 kg/day. The comparison was 3.18 vs. 2.27 kg/day during the winter season. Sows fed the higher energy level at breeding and during the last third of gestation farrowed significantly fewer pigs

than sows on the other treatment combinations. The higher energy intake levels at breeding resulted in sows farrowing significantly heavier pigs than those fed the lower level. The increased level of feed intake during the last third of gestation significantly increased sow weight gains, but had no significant effect on pig birth weight.

Frobish (1968) reported on first litter gilts fed either 3.2 or 6.0 Mcal metabolizable energy (ME) and 250 g protein/day throughout gestation, or changed 76 days post-coitum to the opposite energy level. There were significantly more total and live pigs per litter at birth and at weaning from gilts receiving the higher energy intake.

In an English study (Lodge, 1969) where gilts were fed a progressively reduced amount of feed daily to mid-gestation, followed by a corresponding increased level to parturition (2.27, 1.36, 0.91, 1.36, and 2.27 kg feed/day distributed throughout pregnancy), there was no difference in litter size or birth weight compared to gilts receiving either 1.81 or 2.72 kg feed/day during gestation. However, the combined measure of litter weight was significantly lower for litters from the pattern fed gilts.

In a previous study, Lodge et al. (1966a) compared sows that received (a) 1.36 kg feed/day for 76 days, followed by 2.72 kg/day until parturition to sows receiving either (b) 1.36 kg or (c) 2.72 kg feed daily throughout gestation. Over three successive farrowings, litter size was not affected by the scheme of daily intake, but there was a highly significant difference between treatment groups for mean pig birth weight. Pigs from sows fed the (b) feed regiment during gestation weighed significantly less than those from (a) or (c) dams and pigs

from (a) sows weighed significantly less than those from (c) sows, 1.17, 1.09 and 1.25 kg for treatments (a), (b), and (c), respectively. At eight weeks, there was no significant effect on either number or weight of offspring.

In a one litter study started in February and March, Vermedahl et al. (1969) fed 110.0 kg gilts either 1.36 or 2.27 kg feed (4.4 vs. 7.3 Mcal ME) daily during gestation. The low energy intake resulted in significant differences in total pigs farrowed (8.5 vs. 9.7), and in birth weight of offspring (1.38 vs. 1.48 kg). However, the number of live pigs per litter and pig vigor at birth were not significantly different.

To remove any influence due to ambient temperature fluctuations, Baker et al. (1969) fed bred gilts in an enclosed, heated building, five feed intake levels (0.9, 1.4, 1.9, 2.4 or 3.0 kg/day) throughout gestation. The lowest energy level (2,980.0 kcal ME) resulted in a reduced farrowing rate and reduced average birth weight, when compared to the higher energy intake levels. Because treatment was initiated after conception, it was postulated that the low farrowing percentage was the result of interference with embryo implantation 18 days post-conception. Birth and weaning weights of offspring increased as gestation diet intake increased, with birth weight plateauing at 1.9 kg and weaning weight plateauing at 2.4 kg. The conclusion that there was interference with embryo implantation was supported by the following study.

McGillivray et al. (1962) used year old gilts to evaluate the effects of starvation and two levels of energy intake on ovulation rate and embryo survival during the first trimester of gestation. When the gilts were scarified 25 to 30 days after mating, it was demonstrated

that even with starvation, ovulation can occur, as confirmed by the presence of viable embryos. However, conception rate was reduced to 58.0, 81.0 and 64.0% for gilts receiving no feed, 1.81 kg/day and 3.63 kg/day, respectively. Therefore, the contention that low energy intake influenced embryo implantation (Baker et al., 1969) appeared valid in view of the similar low farrowing percentages (60.9, 71.0, 82.3) these researchers reported at intakes of 0.9, 1.4 and 1.9 kg/day, respectively.

Subsequently, Frobish (1970) fed energy levels of 2.6 or 6.0 Mcal ME daily to gilts to observe the effect of energy on reproductive performance and estrus synchronization with AIMAX. Level of energy fed for 78 days had no significant effect on either ovulation rate or number of embryos 30 days post-breeding. In a second experiment, gilts fed 6.0 Mcal ME daily through all or part of gestation farrowed more live pigs, and those fed the higher energy intake continuously, weaned more pigs per litter than those receiving 3.2 Mcal ME throughout gestation. Birth weight and weaning weights were not appreciably affected by energy intake.

In a long term energy experiment, Frobish, Steele and Davey (1973) found that total pigs farrowed per litter decreased significantly, in a linear manner with increasing energy intake, but live pigs farrowed per litter were not significantly different between daily gestation energy levels of 3.0, 4.5, 6.0 and 7.5 Mcal ME. In contrast, birth weight of total and live pigs farrowed increased significantly with increasing energy intake levels.

The decrease in litter size with increasing energy intake levels was not in agreement with the results of Baker et al. (1969). In their

study, level of feed intake during pregnancy exerted no significant effect on number of pigs born, born alive or weaned at 21 days of age. Other published results by Clawson et al. (1963); Frobish et al. (1966); Lodge et al. (1966a); Vermedahl et al. (1969); and Anderson and Wahlstrom (1970) reported either no effect or an increase in total pigs farrowed with increasing energy intake levels. However, Elsley et al. (1969) reported that at the first farrowing, increasing the daily energy intake of gilts from 5.2 to 10.4 Mcal ME tended to reduce litter size at the higher energy intake. This difference was not evident at the second and third farrowings.

Based on the more recent results of Frobish et al. (1973) and others (Clawson et al., 1963; Lodge et al., 1966a; Baker et al., 1969; and Vermedahl et al., 1969), the daily energy intake of gravid swine could be reduced from the present requirement of 6.6 Mcal of digestible energy (N.R.C., 1968). From prevailing experimental conditions, it would appear that an energy intake of between 4.5 to 6.0 Mcal ME daily was sufficient for normal reproduction (Frobish et al., 1973). Although Baker et al. (1969) concluded that 1.91 kg (6,290.0 kcal ME) feed/head/day was a minimum level for first litter gilts to realize optimum reproductive performance and progeny development.

Weight Changes

The question of minimum maternal weight gain for efficient reproduction remains unanswered. A feeding regimen which maintained body weight during gestation and allowed a weight gain that could be accounted for by the developing fetuses and fetal membranes, with no

detrimental effects on reproductive performance, would improve the overall energetic efficiency of reproduction.

It should be brought out that in attempting to set a gestation feed intake level, consideration needs to be given to environmental temperature. Therefore, the most meaningful way of expressing such a requirement would be to do it in terms of a minimal level of gestation weight gain. However, for sows, the gestation weight gain is affected by length of the previous lactation and the weight loss during lactation.

Several studies (Salmon-Legagneur and Rerat, 1962; Clawson et al., 1963; Frobish et al., 1966; Mayrose et al., 1966; Meade et al., 1966; O'Grady, 1967; and Baker et al., 1969) have shown that weight gain during gestation had little effect on litter size at birth or at weaning, although birth weight was influenced in some trials.

A report from Ireland (O'Grady, 1967) indicated that both birth weights and weaning weights were influenced by gestation weight gain. In the study by Clawson (1968) pregnant gilts fed 2.27 kg feed/day gained twice as much as those fed 1.36 kg/day during the winter gestation. In subsequent pregnancies, sows gained less during the two winter seasons than during the summers, with the same trends in weight differences evident. An extremely low gain (5.90 kg) or even a weight loss (-4.54 kg) during gestation was apparently not harmful to litter size or to the livability of the newborn pigs. There was no reference to birth weights in this study, but weaning weights were not seriously reduced by low gestation gains as long as the sow was liberally fed during lactation. In another study, the notable effect of winter stress on gilt weight gain during the first two trimesters of gestation was clearly

demonstrated. Frobish (1970) reported average gilt weight losses of 10.4 and 15.3 kg for two winter trials on an energy intake of 2.6 Mcal ME/day, while in a third summer trial there was a weight gain of 3.4 kg at this energy level.

Considering the relationship between litter birth weight and sow gestation gain, Lodge (1969) presented evidence to suggest that total gestation gain was not the critical factor, but rather the stage of pregnancy at which the gain was made. Feeding either 1.81 or 2.72 kg daily to sows produced litters of similar weight, but sows fed the 2.72 kg daily had double the gestation gain of those sows fed 1.81 kg daily. Another group of sows fed a lower overall allowance distributed during pregnancy as 2.27 kg during weeks 1, 2, 15 and 16; 1.36 to 2.27 kg during weeks 3, 4, 13 and 14; and 0.91 kg during weeks 5 to 12, had gestation gains similar to those fed the 1.81 kg/day, yet produced litters with birth weights significantly lower than those fed the higher gestation feed intake levels.

Mayrose et al. (1966) observed that increasing the level of feed intake during the last third of gestation significantly increased sow weight gains, but had no significant effect on pig birth weights.

Baker et al. (1970b), in a dietary protein study suggested that the weight advantage at parturition of dams fed a 16.0% protein corn-soybean meal diet was transferred through increased milk yield to the offspring during the course of lactation.

Anderson and Wahlstrom (1970) controlled gilt gestation weight gains to either 0.0 to 10.0 kg or 10.0 to 20.0 kg to the 104th post-breeding day. During the last 10 days of gestation, three pre-farrowing

energy levels were fed. Level one met the resting metabolic requirement of the gilt; level two added 1000.0 kcal ME/day and level three had an additional 2000.0 kcal ME/day. Such variations in energy intake had no effect on total number of pigs born nor on birth weight. During the controlled feeding period, gilts on the higher gain treatment increased their body weight 12.44 kg, while those on the low treatment gained only 3.94 kg. However, these weight gains and weight differences were not as great as those reported by other authors (Clawson et al., 1963; Frobish et al., 1966; Meade et al., 1966; Lodge et al., 1966b; Baker et al., 1969; and Frobish et al., 1973).

Baker et al. (1969) reported that weight gain during pregnancy increased quadratically as gestation-diet intake increased from 0.9 kg/day to 3.0 kg/day, but decreased linearly during lactation. This supported the conclusion of Lodge et al. (1966b), that the greater the weight gain of swine in gestation, the lesser the subsequent weight gain during lactation.

It was demonstrated by Elsley et al. (1966a) that pregnant gilts gained over twice as much weight as nonpregnant gilts when fed the same quantity of diet. Part of this difference was due to the increased weight of the products of conception in the pregnant animal. Kline, Anderson and Melampy (1972) found that when the weights for the conceptuses were eliminated, the increases in body weight of pregnant and nonpregnant gilts treated alike during gestation were similar. However, it was evident that the pregnant gilt was more efficient than the nonpregnant. Heap and Lodge (1967), showed that the significant increase in carcass weight of the pregnant sow compared to the nonpregnant was

accounted for by muscle, fat and mammary tissue increases exclusive of the products of conception. Salmon-Legagneur and Rerat (1962) mentioned that when carcasses of pregnant and nonpregnant sows were compared, the increase in the weight of the uterus in the former was compensated by a diminuation of all the digestive organs. This may partly explain the difficulties encountered in digestion and resulting constipation that frequently occur in gravid females at parturition or shortly thereafter. Baker et al. (1969) were able to sustain pregnancy in gilts receiving 0.9 kg/day throughout gestation, and produce gestation weight gains of 5.9 kg, with average litter weights of 9.1 kg.

Thus, it appeared that a level of nutrition which supported only maintenance in the nonpregnant sow would support pregnancy and allow moderate gain in carcass weight of the pregnant sow. A possible exception to this might be the young gilt of less than 135.0 kg live weight, in which the continuing requirement for growth and development of body tissue other than reproductive, might exceed the lower requirement for maintenance (Cuthbertson, 1967).

At a gestation feed intake of 1.9 kg/day, Baker et al. (1969), observed an apparent change in the slope of the gestation weight gain curve. This suggested that feed utilization for weight gain was more efficient at or below 1.9 kg than at higher intakes. A possible explanation for the apparent decrease in feed utilization for weight gain at higher levels of gestation-feed intake, as suggested by these authors, was that maternal fat synthesis might have increased relative to protein synthesis. Elsley et al. (1969) also observed an apparent change in the gestation gain slope at an intake of 2.4 kg/day. However, there

were only three intake levels (1.6, 2.4 and 3.2 kg/day) in this study of gain from mating to 110 days postmating.

Frobish et al. (1973) noted that 6.6 Mcal DE was sufficient for normal reproduction, but resulted in a net body weight gain above that accounted for by products of conception. With this in mind, these researchers conducted a series of experiments to determine (1) the minimal energy requirement for normal reproduction and (2) the long term effect of such a feeding regimen on reproductive performance. A significant quadratic response of sow weight to energy intake was noted. Sows receiving 3.0 Mcal ME daily gained an average of 5.0 kg from breeding to 24 hr post-partum, whereas the net weight change was 17.1, 27.2 and 37.6 kg for sows receiving 4.5, 6.0 and 7.5 Mcal ME, respectively. The highest energy intake was not only detrimental to total number of pigs farrowed, but also to the feed cost to produce such a sow weight gain.

Lodge et al. (1966b) suggested that a total body weight gain of about 31.8 kg for gilts from breeding for their first litter to the end of the third lactation was both adequate and necessary. From Illinois data (Baker et al., 1970b), it was implied that minimal gestation weight gain (conception to immediately post-partum) of 36.1 kg was adequate for first litter gilts. No more than 20.3 kg of gain during gestation was required by second litter sows.

Condition (Backfat) and Longevity

As previously stated, one of the criteria for evaluating the effect of energy on reproduction is the weight gain of the pregnant animal during gestation. However, it is possible that there could be

some gestation weight gain accompanied by a decline in the physical appearance or condition of the animal. This could occur when the daily feed intake is set at a level such that the gestating female must utilize maternal stores of energy (Baker et al., 1969; and Frobish, 1970).

Changes in backfat thickness would be one method of further elucidating energy needs for reproduction above those for the products of conception, if it can be assumed that an increase occurs only after the needs of pregnancy are satisfied. In an early study of condition and its relationship to reproduction in swine, McKenzie (1928) used linear body measurements to assess the effects of plane of nutrition. Gilts fed 41.0 to 67.0% as much feed as a well fed group were retarded in growth, but not skeletal development. Waldorf et al. (1958) stated that a moderate restriction in the dam's nutrient intake should result in retardation of maternal tissue development, but not fetal.

Lerner, Mayer and Lasley (1957) obtained evidence to suggest that approximately 1.5 additional corpora lutea might be expected for every centimeter of additional backfat. They reported a significant correlation of ($r = 0.31$) between backfat thickness and total number of normal embryos present in gilts.

Dean et al. (1958) probed 46 bred gilts for backfat thickness at breeding, mid-gestation, farrowing and six weeks after parturition, to study effect of condition on reproductive performance. Gilts fed to gain 0.23 kg/day during gestation, lost condition during gestation, while those fed to gain 0.45 kg/day, maintained or gained in condition, as measured by backfat probe. A significant negative correlation

($r = -.21$) was obtained between the gain or loss in condition from breeding to farrowing and in number of pigs farrowed. Dean and Tribble (1961) subsequently reported on the condition changes in gilts and sows, limit-fed to gain slightly more than one-half the rate of gain of those fed to N.R.C. (1959) recommendations (normal-fed). In four trials, normal-fed gilts gained in backfat during gestation, with an average increase of 1.0 to 16.0 mm. The limit-fed gilts lost backfat during gestation in three of the four trials. Average losses were 4.0 to 5.0 mm. Limit-fed sows made only slight changes in backfat during gestation. A liberal lactation feeding regime made it possible for those sows and gilts which lost condition to regain backfat during the lactation period. Similar reductions in carcass backfat thickness, plus reductions in carcass weight and carcass length, were reported by Waldorf et al. (1958) in gestating gilts fed two-thirds ad libitum daily intake.

Smith (1960) concluded that condition and weight of the sow at farrowing had no effect on gain of offspring during lactation. However, sows draw on their own body reserves to offset a reduction in nutrient intake during lactation (Smith, 1959).

Pike and Boaz (1966) reported that backfat, shoulder fat thickness, eye muscle area and ham density of sows 70 days post-coitum were affected more by feed intake level during pregnancy than by condition at breeding, but the latter had the greater effect on fetal development.

In a protein anabolism study, Kline et al. (1972) found that on a daily feed intake of 1.82 kg, pregnant gilts had significantly less backfat when compared to nonpregnant cycling, hysterectomized or

ovariectomized gilts. Thus indicating the 1.82 kg daily intake to be inadequate to meet both reproductive and maternal tissue growth needs for the pregnant gilt. The small differences in ham fat content from these gilts suggest the intramuscular fat to be stable during pregnancy in the pig.

This confirmed earlier work of Elsley et al. (1966a), who found less subcutaneous fat plus skin in the carcass of pregnant gilts, compared to nonpregnant gilts. However, in this study there was more intramuscular fat plus muscle in the carcass of the pregnant gilt than in those nonpregnant, which had almost exactly the opposite amount of subcutaneous fat plus skin in greater quantities and less intramuscular fat plus muscle to counter balance each physiological state. In this study, the feed intake level was set at 2.2 kg/day for the 110-day period. At a feed intake of 2.0 kg/day, Heap and Lodge (1967) reported that pregnant sows deposited more fat in the back region than did their nonpregnant counterparts. Frape, Wilkinson and Chubb (1971) found that an additional 0.5 kg of feed/day during gestation doubled the sow empty live weight gain and backfat gain per week of pregnancy was more than doubled. These significant gains were obtained when the daily feed intake was increased from 1.8 to 2.3 kg.

It was apparent that state of maternal tissue development did affect the deposition of subcutaneous backfat, when gilts and sows were compared. Baker et al. (1969) proposed a daily feed intake of 1.9 kg and above resulted in an increased fat synthesis relative to protein synthesis in the gilt. While Elsley et al. (1966a) did not obtain an increase in carcass backfat at a daily feed intake of 2.2 kg, the change

in the gestation weight gain curve at a feed intake of 2.4 kg/day (Elsley et al., 1969) could be the point where this shift in fat synthesis occurred. Furthermore, the gilts used by Baker et al. (1969) should have required less energy to maintain body temperature, since they were housed in an enclosed environmentally controlled building; whereas, the data by Elsley et al. (1969) was summarized over three parities and more normal conditions.

In a previous study Lodge et al. (1966a), reported on the effects of feeding gilts and sows a daily allowance of either 2.70 kg (high), 1.35 kg (low) or 1.35 kg for 76 days, followed by 2.70 kg feed until parturition (low-high) through three successive pregnancies. These sows were subsequently slaughtered on the 100th day of the fourth pregnancy for body composition studies (Elsley, MacPherson, and Lodge, 1968). The mean subcutaneous fat content (kg) and backfat thickness (mm) of the carcasses were high (14.1 and 34.2), low (4.0 and 10.3), low-high (5.8 and 23.3), respectively. During the earlier pregnancies, it was thought that adipose tissue could have been utilized as a source of energy for the growth of more essential tissues, the maintenance needs of the sow or the requirements for reproduction. Although, if this mobilization did occur, it did not result in optimum reproductive performance, as measured by the birth weight of pigs from the low and low-high sows.

It is highly probable that continued reduction in subcutaneous fat deposits will lead eventually to either reduced reproductive performance or to difficulties in maintaining body temperature under severe environmental conditions. Elsley et al. (1968) stated that it may have been the extremely thin fat layers of backfat thickness (their low

group had 21.0, 6.3 and 3.8 mm of carcass backfat over the shoulder, back and rump, respectively) that were encountered under the condition termed the "Thin Sow Syndrome."

English farmers, adopting the research findings of Lodge et al. (1966a), were among the first to indicate the problems due to low energy intake during pregnancy. The "Thin Sow Syndrome" that describes this condition has been attributed to worm infestation, adverse environment, and low gestation feeding levels (Maclean, 1968). The syndrome has been characterized by a heavy weight loss during lactation and early pregnancy, followed by failure to regain sufficient body weight. The thinness is progressive, and if not checked, results in emaciation and eventual death. Other specific symptoms of the syndrome include emaciation, hypothermia (36.1 to 37.7°C), depraved appetite, craving thirst, resulting in excess urination; grinding of teeth, restlessness, leading to surface abrasions, dullness in later stages, hindquarter weakness, goose stepping and swaying gait, dirty, oily (greasy) skin, and course, long hair (Maclean, 1968).

One of the reasons often mentioned for reducing the level of feed intake during gestation, has been to increase the longevity of the sow in the breeding herd. Frobish et al. (1966) compared two energy intake levels (5,400.0 vs. 10,800.0 kcal ME/day) through three successive reproductive cycles. Of the 32 gilts started on the high energy program, only 14 completed three cycles, whereas 26 of 32 finished on the low energy regime. Examination of sows that failed to farrow and those that died, showed an extremely large amount of fatty tissue around the reproductive organs. Hawton and Meade (1971) reported that protein

quantity and quality play an important role in prolonging the productive life of sows when fed daily energy intake in the neighborhood of 5600.0 kcal ME.

In the study by Frobish et al. (1973), it was mentioned that sow weight changes over three successive reproductive cycles were greatly affected by energy intake. However, the most pronounced effect of the energy intake was on the number of animals completing the three reproductive cycles. Of 19 gilts starting per treatment, only 46.0, 52.5, 58.0 and 31.5% completed three successive cycles for the 3.0, 4.5, 6.0 and 7.5 Mcal ME treatment groups, respectively. Leg abnormalities due to the rough concrete floor and the excess weight gain were the major factors causing removal of sows receiving the highest energy intake. At the lower energy intakes, failure to conceive was the predominant cause.

II. INFLUENCE OF PROTEIN LEVEL AND DIETARY SOURCE UPON SWINE DURING GESTATION

The harmful effects of protein deficiency during pregnancy are less well understood; although, a lower birth weight in pigs, increased stillbirths, reduced viability, less udder development and milk production of the dam have been reported (Evvard, Arthur and Guernsey, 1914; Davidson, 1930; Hogan, 1932; and Hanson et al., 1953).

Protein Level

The experiments by Clawson and Barrick (1962) and Clawson et al. (1963) were among the first studies to indicate that a low level of protein intake would give satisfactory reproductive response. However,

Davidson as early as 1930, found no fetal atrophy when protein-deficient diets were fed to gravid sows. Pond et al. (1968b) were the first to report that a gestation diet, devoid of protein could maintain pregnancy by dependence on maternal tissue stores of amino acids. One gilt of three, started on a protein-free diet, had a litter of nine normal pigs, and individual pig birth weights averaged 80.0% of the weights of pigs from gilts fed a 12.0% protein diet or 9.0% protein corn diet. Ten and eleven clinically normal, viable fetuses were found in the other two gilts on the protein-free diet that died of perforated gastric ulcers. This was in contrast to the earlier rat work by Nelson and Evans (1953), who demonstrated that feeding a protein-free diet to young females during gestation resulted in fetal death around day 10 in the majority of the dams.

The importance of transitory protein during the implantation period has been demonstrated (Strachan et al., 1968; and Pond et al., 1969). Birth weight and postnatal growth rate of progeny from gilts given transitory protein during the period of implantation (16 to 20 days post-breeding) were greater than those of gilts deprived of protein throughout gestation. This was further evidenced by nonsignificant reduction in birth weight and postnatal growth of progeny from gilts deprived of protein from the 24th day of gestation to parturition. Nelson and Evans (1953) obtained similar results with rats, when the protein-free diet was introduced after implantation had occurred.

The perseverance of the sow to maintain pregnancy was previously reported by McGillivray et al. (1964). They found it necessary to feed a protein-free diet four to six estrus cycles before the number of

viable embryos was reduced when measured at 25 days postmating.

Since it was evident that a protein-free diet did not give optimum reproductive performance, it was desired to determine the protein level that would, and when in the cycle institution of protein feeding should begin. Nalbandov (1964) showed that fetal size and birth weight of the young depended upon the plane of nutrition during the second half of pregnancy. A low plane of nutrition during the first half of pregnancy did not affect ultimate fetal weight adversely, provided the dietary intake was adequate during the second half. An exception to this was pointed out by Strachan et al. (1968), who found that dietary protein at the time of implantation appeared to be an important factor for determining individual pig birth weight, but not in determining embryo survival.

According to Baker et al. (1970b), the sacrifice of maternal tissue, to provide for the products of conception, was not reflected in birth weight of offspring, but became apparent in growth rate of offspring from birth to weaning. This sacrifice of maternal protein sources for fetal growth was previously indicated by Rippel et al. (1965a). Nearly normal intrauterine development occurred in gilts fed a nitrogen-free diet from the 70th day post-coitum, even though they had a mean negative nitrogen balance of about 6.5 g/day during the last third of pregnancy.

It has been established that the labile protein source of the dam has the ability to provide protein for fetal development on a protein-free diet during gestation (Rippel et al., 1965b; Pond et al., 1968b, 1969; and Strachan et al., 1968). In the process, however, the

sow tissue proteins apparently were sacrificed to such an extent that subsequent lactation performance was impaired (Pond et al., 1968b, 1969; and Baker et al., 1970b). De Geeter et al. (1972) indicated that the protein level of the gestation diet, as well as that of the lactation diet, affected preweaning performance of the progeny. Therefore, a protein deficiency during gestation not so severe as to reduce birth weight, but sufficiently severe to impair the dam's milk production in lactation, might be overcome by adding adequate protein intake to the late rather than to the early gestation diet.

Rippel et al. (1965b) fed gilts and sows 1.82 kg/head daily of either a 5.0, 8.0 or 16.0% protein diet in which a constant ratio of corn to soybean meal of 4.4:1.0 was maintained. It was conclusively demonstrated that the conventional criteria of reproductive performance (total and live pigs farrowed, birth weight and livability) were unresponsive to such varied levels of protein fed during the final 50 to 60 days of gestation. Rippel (1967) reiterated this fact in his review of protein and amino acid nutrition of gravid swine. Reproductive performance of second and third litter sows fed 5.0% protein diets during gestation was unaffected, but this protein level was inadequate to support satisfactory litter gain during the subsequent two week nursing period (Rippel et al., 1965b). De Geeter et al. (1972), reported that even though the gestation protein level of 2.0% (45.0 g/day) was increased to 5.0% during lactation in first-litter gilts, and they were fed ad libitum during the nursing period, the offspring preweaning rate of gain was significantly reduced.

From recent results in literature (Clawson et al., 1963; Rippel et al., 1965b; Holden et al., 1968; Baker et al., 1970b; Hesby et al., 1970b; and Hawton and Meade, 1971), it was demonstrated that the amount of protein in the gestation diet for the entire pregnancy period, expressed in grams consumed per day, or a percentage of the diet, is not an important factor in affecting litter size, individual pig birth weight or the number weaned. In contrast, Frobish et al. (1966) reported significantly more pigs weaned from sows fed a high protein intake during gestation, compared to a low protein diet. Yet, there were no significant differences in number of pigs farrowed alive, birth and two week postpartum weaning weights, when sows received either 182.0 or 364.0 g protein daily throughout three gestations.

Holden et al. (1968) reported no significant differences in reproductive performance among sows fed 146.0, 218.0, 291.0 or 364.0 g protein daily through four successive reproductive cycles. However, there was a significant linear increase in pig gain from birth to two weeks with each increased protein level fed during gestation. This may be explained by the fact that crude protein level in sow's milk increased linearly with increasing dietary protein.

Hawton and Meade (1971) compared an all-corn diet with corn-soybean meal diets containing 13.7 and 18.8% crude protein, providing daily intake of 154.0, 250.0 and 341.0 g protein, respectively, throughout pregnancy. There were no differences in number of pigs farrowed among the treatments, but strength scores and average weight of pigs at birth from sows fed the 13.7% protein diet during the second reproductive cycle were significantly less than corresponding values of the

other treatment groups. Since there were no differences in number of pigs farrowed, average birth weight and vigor of pigs from sows receiving either 154.0 or 341.0 g protein/head daily, it was concluded that neither level nor quality of protein was the basic cause. However, pigs from dams fed the two lower protein intake levels gained less during the subsequent three week lactation period (4.1, 4.1 and 4.6 kg, respectively).

One of the other parameters used to measure the effects of protein intake was manifested through gestation weight changes of the sow. Nelson and Evans (1953) reported that feeding a protein-free diet to young rats during pregnancy would cause the dam to lose weight, and gain of the dam was reduced by protein levels below 10.0%. Rippel et al. (1965b) reported that gilts fed a 5.0% protein diet, gained significantly less than sows. Also, feeding a 5.0% protein diet during gestation and a 16.0% protein diet during lactation resulted in less weight loss during the nursing phase than their counterparts on the 5.0% level during both phases. And as might be expected, gilts fed a protein-free diet during any part of gestation lost weight, with the weight loss proportional to the length of feeding the protein-free diet (Pond et al., 1969).

Hawton and Meade (1971) found that protein intake during the first gestation had no effect on weight gain, but in the subsequent gestation, sows receiving 341.0 g protein daily had significantly greater weight gains than sows receiving only 154.0 g/head daily. Sows receiving 250.0 g protein daily were intermediate in gain (47.8, 43.8, and 33.8 kg), and not significantly different from either the high or low protein dietary levels. Others have observed increased weight gains with increasing protein intakes during pregnancy (Holden et al., 1968; and

Pond et al., 1968b, 1969). However, Frobish et al. (1966) reported no difference in gains of sows receiving either 182.0 or 362.0 g protein/day during pregnancy. Hesby et al. (1972) reported that sow gestation gain was influenced by increasing the lysine and protein contents of the diet, thus confirming lysine to be limiting in a normal corn diet for gravid gilts.

Sixty-four gilts and sows, used during four gestations, showed a significant quadratic regression of gain during the gestation period on protein levels. The gains observed on the 12.0 or 16.0% protein levels were greater than at the 8.0 or 20.0% levels (Holden et al., 1968). However, for 42 of the gilts completing the four gestations, protein level had a significant effect on sow weight, with sow gains increasing as protein intake increased. From both gilt and sow data (Baker et al., 1970b), it was suggested that the dam weight advantage at parturition, due to the higher protein levels was transferred through increased milk yields to the offspring.

The high incidence of failure to conceive for a second reproductive cycle, among gilts fed low levels of protein, was interpreted to mean that the productivity of the sow was sensitive to dietary protein quantity and quality during gestation (Hawton and Meade, 1971). However, in a long term protein study by Holden et al. (1968), no ill effects of low protein intake on breeding performance were mentioned. Over the four reproductive cycles only 66.7, 76.5, 40.0 and 45.0% of the sows on the 8.0, 12.0, 16.0 and 20.0% protein levels, respectively, remained in the herd at the end of the experiment. Frobish et al. (1966) cited energy as the cause of reduced longevity of sows, rather than the low

protein intake. None of the protein-free studies have been carried into the subsequent pregnancy; therefore, the effects of inadequate protein over repeated generations remains unknown.

The report by Livingstone et al. (1966) focused attention on the effect of protein level in the gestation diet upon post-weaning performance and carcass measurements of the progeny. There were no differences in weaning weight, post-weaning gain, feed per gain, cross-sectional area of the longissimus muscle, backfat thickness or specific gravity of the carcass of pigs from sows fed 10.0 or 18.0% protein throughout pregnancy (204.0 or 367.0 g protein/day for 84 days, followed by 250.0 or 450.0 g/day to parturition). Over two reproductive cycles, Hawton and Meade (1971) failed to show a difference in the post-weaning daily gain, feed per gain or carcass leanness of progeny of gilts fed 154.0, 250.0 or 341.0 g protein/day during gestation.

When a protein-free diet (9.0 g protein/day) was fed throughout pregnancy (Pond et al., 1968a), progeny weaning and slaughter weights were significantly reduced, compared to offspring from gilts fed a 16.0% control protein diet. Thus, a severe and prolonged protein restriction of the dam during pregnancy could induce a stunting effect on the progeny.

While the inferior postnatal performance of pigs from protein-deprived dams was not clearly reflected in conventional carcass measurements from these animals, there were differences in tissue RNA and RNA/DNA ratios. Pond et al. (1969) interpreted these differences to indicate reduced protein synthetic activity of the cerebrum and the longissimus muscle in progeny of protein-deprived gilts.

Frape et al. (1969) showed that with inadequate energy intake during pregnancy, gestation protein level influenced weight and vitamin A storage of piglet livers. However, when the gestation energy intake was adequate, the level of protein fed during gestation had no influence on these liver measurements. Maternal protein restriction during pregnancy in the rat resulted in both immaturity in kidney development of the newborn pup and in pathological changes symptomatic of protein deficiency (Zeman, 1968). Similar events have not been shown in the pig, but over several generations these pathological symptoms may appear and render such animals unfit for further growth and production.

Nitrogen Retention

Protein intake should be sufficient to take advantage of the pregnant animal's special ability to store nitrogen (N) in its body and the products of conception. Mitchell et al. (1931) found that first litter gilts, receiving a 10.9% protein diet retained only 17.8% of the daily nitrogen intake. Of this, 31.0% was used in the process of reproduction. The remaining 69.0% of the retained nitrogen was used by the growing dam.

Rippel et al. (1965a) used the daily nitrogen balance as the primary performance criteria to evaluate the nitrogen needs of pregnant gilts. A mixture of corn and soybean meal (weight ratio of 4.4:1.0, respectively) was diluted with various levels of corn starch to formulate diets varying in protein from 0.0 to 15.0%. When a broken line was fitted by the method of least squares to the combined data from four experiments, 12.2 and 12.4% protein levels accounted for the greatest

sum of squares at 85 and 105 days, respectively. These observations indicated that a daily intake of 230.0 g crude protein from a high energy, corn-soybean meal diet was sufficient to meet the essential amino acid and amino nitrogen needs of gilts during the last trimester of gestation. Miller et al. (1969a) subsequently reported that a protein intake of 285.0 g was near the minimum per day for maximum N retention. However, the efficiency of utilization of digestible nitrogen, expressed as 100 times (apparent N retention)/(N intake - fecal N), was 30.2, 37.0, 40.7, 40.7, and 34.1% for protein intakes of 114.0, 171.0, 228.0, 285.0 and 342.0 g/day, respectively. The greatest efficiency occurred at intake levels of 228.0 and 285.0 g protein. An excess of dietary amino acids was reflected at the 18.0% protein (342.0 g) level by the reduced efficiency.

Mitchell et al. (1931) found average daily deposition of crude protein in the uterus during gestation to be approximately 14.0 g, but it was more than double this figure during the last two weeks, ranging from 0.54 g in the first week to 33.0 g during the 16th week of gestation. Therefore, though it appears correct to increase protein intake late in gestation, the results of Rippel et al. (1965a), and Miller et al. (1969a) indicated that total nitrogen needs of the gravid gilt during the last 40 days of pregnancy, did not increase as a percent of the diet. However, the efficiency with which the absorbed nitrogen was retained did increase.

Allee and Baker (1970) supplemented an all-corn diet with lysine and tryptophan, the two amino acids suggested by Rippel (1967) as the most limiting in a corn diet for pregnancy. They found a significant

increase in nitrogen retention (11.2 vs. 7.5 g) when compared to gilts fed corn alone during the last one-third of pregnancy. This compared favorably to the nearly 10.0 g/day retention shown to be adequate by Holden, Ewan and Speer (1971). Similar nitrogen retention levels were reported by Hesby et al. (1970a) from 11.2% protein corn-soybean meal and all-corn diets (11.4 and 7.2 g/day, respectively). From the addition of methionine to a daily gestation feed intake of 1.82 kg, Holden et al. (1971) estimated 0.18% level of total sulfur amino acids to be adequate by nitrogen retention, and a level of 0.26% based upon plasma levels. When lactating sows consumed 4.54 or 5.45 kg of feed daily, the estimated sulfur amino acid requirement was 0.40% from plasma data (Ganguli et al., 1970).

Age at pregnancy also exerted effects upon sow nitrogen anabolism. Rombouts (1962), having corrected for the products of conception, found a greater nitrogen retention in gestating sows than in their nonpregnant counterparts. Salmon-Legagneur and Rerat (1962), and Elsley et al. (1966a) also reported increased nitrogen retention in gilts and sows during gestation. Hesby et al. (1970a) observed that gilts retained significantly greater quantities and percent nitrogen than sows, suggesting that gilts require more maternal nitrogen.

Due to gravid anabolism (Bourdel and Jacquot, 1959), large maternal tissue weight increases occurred during gestation. Pregnancy anabolism refers to the sow's weight gain, excluding the products of conception and all other weight gains Salmon-Legagneur and Rerat (1962). Extrauterine weight gain during gestation was almost twice the weight gain of the uterine content in 100 sows analyzed by Salmon-Legagneur

(1965). A net gain of 1,248.0 g N/sow was found, when compared to the N content of the nongravid sow. However, only 276.0 g of the nitrogen were accounted for by total uterine contents.

Holden et al. (1971) presented evidence to suggest that the daily retained nitrogen component ascribed to pregnancy anabolism was unnecessary for normal reproduction. Earlier, Baker et al. (1966) had suggested that exogenous amino acid requirements for maintenance of the nonpregnant gilt were quite low. For the pregnant gilt, it was recognized that there was a need for some nitrogen for tissue growth, but it was left unanswered as to whether the pregnant gilt or mature sow required that a portion of retained protein be directed toward pregnancy anabolism. When the N requirements for the products of conception and for uterine and mammary growth were estimated at 3.5 g daily (Elsley et al., 1966a), and nitrogen losses of hair, skin and hoof, usually unaccounted for, were estimated at 1.0 g daily, as suggested by Baker et al., (1966), then of the 9.5 g retained nitrogen (Holden et al., 1971), only 5.0 g remained for growth and pregnancy anabolism of the gilt. The retained N usually attributed to pregnancy anabolism alone has been considered to be more than this 5.0 g (Evans, 1929; Mitchell et al., 1931; and Rombouts, 1962). Yet, the gilts used by Holden et al. (1971) had a net body weight gain of 18.0 kg and farrowed normal size litters with pigs of normal birth weight. Reasoning that the major portion of this 18.0 kg represented true maternal growth, led to the conclusion that a large proportion of retained nitrogen in the pregnant gilt was unnecessary for normal reproduction.

Earlier, Rippel et al. (1965a) accounting for the deposition of N in fetal tissue, found approximately 8.0 to 10.0 g N/day remained for extrauterine tissue growth from day 82 of gestation to parturition when 12.0 and 15.0% protein levels were fed. Also, fetal weight apparently has little or no effect on N retention at such levels. Gilts were able to deposit extrauterine nitrogen at protein levels of 6.0% and possibly the 3.0% level, when supporting reduced fetal weight, whereas more normal fetal weight allowed for little extrauterine N storage at those protein levels.

Kline et al. (1972), while reporting increased N retention per day as pregnancy progressed, found no significant difference between pregnant and cycling nonpregnant gilts for the entire period. Pregnant gilts gained 53.0 kg; however, when the weights of the conceptuses were subtracted, there was an increase of 37.0 kg in body weight, which was similar to the 38.0 kg increase observed in nonpregnant cycling gilts. Salmon-Legagneur and Rerat (1962) and Elsley et al. (1966a) indicated that the difference in body weight between the pregnant and nonpregnant sow was not explained by additional weight of the conceptuses. Salmon-Legagneur and Rerat (1962) further suggested energy intake to be the limiting factor of pregnancy anabolism. Therefore, high energy intakes should favor high anabolism.

Protein Source

It has been recognized that as world population increases, many of the presently used protein sources will have increasing demand put on them for human use. Swine diet formulation, therefore, must eventually

be based on specific needs for amino acids. Total protein needs for each specific physiological and functional phase of swine production, as influenced by source, availability of amino acids and economics, must be quantitated.

The biological value of a 3.0% protein corn-soybean meal diet has been shown to be 69.0% for nonpregnant and 99.0% for pregnant gilts (Rippel et al., 1965a; and Baker et al., 1966). Clawson et al. (1963) demonstrated that as little as 140.0 g soybean protein/gilt/day did not adversely affect reproductive performance of gilts and sows. However, gilts receiving 560.0 g protein daily did gain significantly more weight during gestation.

Clawson et al. (1963) found no apparent benefit from feeding gilts dehydrated alfalfa meal during pregestation on subsequent reproduction. Seerley and Wahlstrom (1965) farrowed a higher percentage of their sows receiving diets containing 5.0 or 10.0% dehydrated alfalfa meal, compared to those fed alfalfa-free or 2.5% dehydrated alfalfa meal diets. Sows fed 10.0% dehydrated alfalfa meal farrowed an average of 0.97 more pig per litter than the alfalfa-free sows, and the pigs averaged 0.10 kg heavier at birth. During lactation, sows fed the 2.5% alfalfa level weaned heavier pigs, while the 10.0% level let sows wean the most pigs of the three levels. In contrast to these results, Clawson et al. (1963) reported no advantage for the inclusion of dehydrated alfalfa meal in the lactation diet, either on performance of the litter or on the subsequent reproduction of the rebred sows.

Protein of animal origin has frequently been suggested to have greater nutritional value for swine reproduction than protein of plant

origin. Most of the differences, due to the supplementation of plant protein diets with animal protein were eliminated when the all-plant diet was supplemented with vitamin B₁₂. The reports of Teague and Rutledge (1960) and Mayrose et al. (1964) indicated little if any beneficial effect on reproductive performance from replacing part or all of the supplemental protein in adequately fortified all-plant diets with protein of animal origin. Zimmerman, Peo and Hudman (1967) later reported no treatment differences between rations supplemented with meat and bone scrap and those supplemented with soybean meal fortified with vitamin B₁₂. Replacing 0.0, 35.0 and 70.0% of the soybean meal with animal protein was not beneficial in terms of age at puberty, ovulation rate at second estrus, embryo survival and litter size at 26 or 28 days of gestation.

Palmer, Teague and Grifo (1970) evaluated the effect of whole Menhaden fish meal (meal plus solubles) on reproductive performance. The inclusion of 6.0% fish meal in corn-soybean meal diets significantly increased the average daily gain of gilts and sows during two successive gestations, and resulted in an increase of 0.9 more live pigs per litter at birth. Total litter weight was also significantly greater at birth and at two weeks in litters from sows fed fish meal.

Gimenez, Bazer and Warnick (1972a) found that gestation protein source caused a difference in some of the protein components of the conceptus at 20 and 60 days post-coitum. Quantitative protein determinations showed the protein concentrate (mg protein/ml) of blastocoelic fluid at 20 days of gestation for gilts fed fish meal and soybean meal to be 26.26 and 19.00, respectively. The amniotic fluid followed the

same trend. Embryonic tissue protein content (mg protein/g tissue), at 20 and 60 days of gestation, was 4.54 vs. 27.68 for the gilts fed fish meal and 6.25 vs. 29.34 for those fed soybean meal. Corresponding values for placental membranes were 28.26 vs. 20.54 and 27.97 vs. 30.22, respectively. At protein levels of 15.0%, Gimenez et al. (1972b) found that the amino acid levels in uterine blood at 20 and 60 days of gestation were significantly higher in gilts fed fish meal.

For the last half of pregnancy, Pike and Boaz (1969) concluded that a low intake of crude protein from cereals (10.5% protein) was associated with decreased viability of the pig at birth and in early lactation, with less than optimal sow milk production. Studies by Allee and Baker (1970) indicated lysine and tryptophan in corn to be the first and second limiting amino acids, respectively, for both the gravid and nongravid gilt. Pond et al. (1968b) reported decreased 21-day weaning weights, and Hawton and Meade (1971) found a significantly reduced rate of gain in growing pigs from gilts fed normal corn diets. An all-corn diet fed from breeding to farrowing was compared to an opaque-2 corn diet and to corn-soybean meal diets containing 12.0, 16.0 and 20.0% protein by Baker et al. (1970a). There were no significant differences in the first-litter gilts for number of pigs born or pig weights at farrowing. Hesby et al. (1970b) reported reduced litter weight at birth (total litter weight adjusted to a constant litter size) from the feeding of all-corn, and an 11.2% protein corn-soybean meal diet, compared to opaque-2 corn and a 15.0% protein corn-soybean meal diet during gestation. During three successive pregnancies, there were no significant differences among diets for live pigs, total litter size farrowed and

litter weight. Baker et al. (1970a) reported that a corn diet fed to first-litter gilts at a level of 1.9 kg/day during gestation, would not permit optimum lactation performance. Weaning weight, but not birth weight was reduced in the offspring.

Baker et al. (1970b) subsequently fed a 16.0% corn-soybean meal diet during either the first or last third of pregnancy to observe if the suboptimal lactation performance, caused by feeding a corn diet throughout gestation, could be corrected by adequate protein intake. Feeding the corn-soybean diet during the last third of gestation, attained performance equal to feeding it the entire gestation period, as measured by litter and pig weaning weight (21 days), gestation gain of gilts and pig gain, birth to weaning. However, number of pigs farrowed (total or live) was not significantly different among treatments.

III. LACTATION PERFORMANCE OF SOW AND LITTER

Recent emphasis has been placed on determining the optimum feed intake for swine during gestation. In the meantime, little direct attention has been focused on the lactation phase of the reproductive cycle. The following review will take a closer look at some recent lactation research results.

Effects of Intake Level

For many years the most common recommendation has been to feed sows ad libitum during lactation to permit maximum milk production. However, Bowland (1964) reported that energy and protein intakes lower than recommended (N.R.C., 1959) were adequate for good reproductive performance.

According to McKenzie (1928), condition of the sow at farrowing and the amount of feed consumed during lactation, influenced greatly the growth of suckling pigs. Sows fed less than 2.27 kg of grain daily during lactation, weaned pigs averaging less than 9.07 kg, and those fed more weaned heavier pigs. Using sows treated alike throughout gestation, and to 10 days post-farrowing, Lidvall and Griffin (1962) reported effects of limited and full-fed sows during lactation. They found no significant difference in 56-day weaning weights of pigs, even though there were highly significant differences in the weight change of sows due to the lactation treatment (pasture limit-fed lost 2.35 kg; pasture full-fed gained 29.12 kg; concrete limit-fed lost 14.70 kg; concrete full-fed gained 22.73 kg).

Hitchcock et al. (1971b) reported on one of the first long term sow lactation studies to appear in literature. Results from limiting the daily feed intake of the lactating sow to 0.45 kg/pig nursing, compared to ad libitum feeding during a 49-day lactation period, resulted in a significant decrease in total sow feed consumption (183.4 vs. 340.9 kg), sow feed per pig weaned (22.7 vs. 49.0 kg), and a greater sow weight loss (37.8 vs. 3.9 kg) by the limit-fed sows. Total creep consumption per litter (68.1 vs. 58.9 kg) and per pig (8.3 vs. 7.0 kg) was significantly greater by progeny from the limit-fed sows. The lactation treatment did not affect the number of pigs at 21 or 49 days of age nor did it affect litter or individual pig weights. Thus confirming the earlier results of Smith (1959), Elsley et al. (1969) and Vermedahl et al. (1969) that level of feeding imposed during lactation had no significant influence on progeny, lactation gain, or weaning weight.

Lidvall and Griffin (1962), Parker and Clawson (1967), and Lodge (1969) also reported that pigs from dams fed a limited amount of feed during lactation, consumed more creep feed than those nursing dams fed ad libitum. Vermedahl et al. (1969) found a 6.0% improvement in the feed/gain ratio for the period from 21 days post-farrowing to an average pig weight of 22.7 kg, among pigs from dams fed a lesser energy level during gestation. This improvement was not evident when the sow lactation treatment only, was considered. The limit-fed sows utilized by Hitchcock et al. (1971b) were probably more energetically efficient, since the nursing pig's feed intake was increased and sow feed consumption was reduced. Similar conclusions were reached by Smith (1960) and Bowland (1967).

Lidvall and Griffin (1962) mentioned that a higher percentage of full-fed sows bred back at the first estrus period following weaning, than did the limit-fed sows. Hardy and Lodge (1969) found that increasing the feed intake during lactation improved ovulation and conception rate during the first post-lactation estrus. Hitchcock et al. (1971b) reported no significant difference in the percentage of sows that conceived at the first estrus following weaning. This was true, despite the fact that sows fed to scale during lactation lost 33.9 kg more body weight than sows fed ad libitum.

Baker et al. (1969) obtained results which would indicate that lactation performance was indeed influenced by diet intake during pregnancy. In their study, pig weaning weights at 21 days had a significant linear increase as the diet intake during pregnancy increased. Frobish et al. (1973) reported a similar trend at the end of a two-week

lactation period, over three reproductive cycles. Based on litter size and weight at three weeks, Frape et al. (1971) suggested that milk production may be affected equally by extra feed intake during pregnancy or lactation. Rook and Witter (1968) reviewed the research dealing with the effect of diet and sow milk secretion. They pointed out that milk yields were dependent on the plane of energy during lactation, irrespective of the level of feeding during the gestation period. Low energy feeding was associated with a decline in milk yield, which was accompanied by a fall in the percentage of lactose, and an increase in the percentage of fat, protein and ash. However, in terms of net yield, only ash was reported as being directly unaffected by energy undernutrition.

The voluntary selection of diet components by gestating and lactating sows was studied by Friend (1971). The observed changes in amounts and proportions of feed components selected were in line with what one would expect, based on quantitative needs for different physiological functions. Total energy and other nutrient transfer to sow milk during a five-week lactation, was much greater than the amount transferred to the fetus and associated membranes during a 16-week pregnancy.

Effects of Protein Level

Protein requirements during lactation, until recently, have received little attention, although 30 years ago Work, Henke and Harris (1942) demonstrated a marked effect of dietary protein intake by the dam on 8-week pig weaning weight and sow gain.

Early in lactation a negative nitrogen balance frequently occurs, despite feeding high level protein diets. At such times, the body protein reserve of the dam is drawn upon to supply a part of the protein secreted in the sow's milk. However, the sacrifice of maternal tissue to provide for the products of conception may have already precluded the use of maternal protein sources for lactation. While birth weight was not adversely affected, the apparent growth rate of the offspring to weaning was deterred (Baker et al., 1970a). Another consequence of the gilt's limited body reserves, due to reduced gestation protein intake, was demonstrated by De Geeter et al. (1972). The increased stress on protein deprived sows, during the third and fourth weeks of lactation, magnified sow weight changes, even though protein content of the diets fed during lactation was increased from 2.0 to 5.0%.

Pond et al. (1968b, 1969) and De Geeter et al. (1972) presented evidence that low dietary protein intake during gestation adversely affects subsequent lactation performance, when compared to higher protein diets. The lower six-week weight of pigs from low protein fed gilts, and of pigs transferred to them at two days of age, indicates that milk production was significantly affected. The adverse effects of low protein intake on subsequent reproductive efficiency have been reported by Svajgr et al. (1970). Anestrus, prolonged estrus cycle intervals and reduced ovulation rates, were evident in first-litter gilts after a 14-day lactation.

Mahan, Becker and Jensen (1971a) obtained maximum litter weight gains at 2, 3, or 4 weeks in first-litter sows (8 pigs/litter), when a 16.0% protein corn-soybean meal diet was fed. A linear increase in

litter gains was obtained as dietary protein levels increased from 10.0 to 18.0% protein, with second-litter sows nursing 9 or 10 pigs each. Total and weekly sow lactation weight losses of both first- and second-litter sows were influenced by dietary protein levels from the onset of lactation. A quadratic decrease in total lactation weight losses occurred as dietary protein increased, with a marked weight loss occurring in those sows fed either a 10.0% protein or an opaque-2 corn diet. These results confirmed the findings of Work et al. (1942), who reported a larger lactation weight loss for sows fed a 10.0% protein diet than sows fed a 14.0% protein diet. Thus indicating, that protein intake during lactation can influence sow weight changes.

Rippel et al. (1965a) reported increased litter gains at 14 days postpartum when a 16.0% protein corn-soybean meal diet was compared with a 5.0% protein corn-soybean meal-starch diet. In contrast, MacPherson, Elsley and Smart (1969) found average 42-day litter gains to increase significantly as protein levels decreased for pigs from first litter sows. This same trend continued through the second, but not the third lactation. On the other hand, there was a significantly greater loss in weight by sows fed the lower protein levels during the first lactation, although differences were not significant during either the second or third lactations. These authors concluded, that either the conversion of dietary crude protein to milk protein must be greater than the accepted 33.0%, or the sows used were utilizing body reserves. It should be pointed out, that in this study the increases in crude protein were confounded with increased concentration of essential amino acids (lysine and methionine), since white fish meal replaced barley for the desired protein levels.

From nitrogen metabolism trials, Mahan et al. (1971b) concluded that N equilibrium was necessary to obtain maximum milk production, milk nitrogen and weaning weights.

Elliott et al. (1971) fed sows incremented levels of protein, 30 days prepartum to the end of a 35-day lactation, and found a higher percentage of total solids, solids-not-fat, protein and total essential amino acids in the colostrum with 15.0% than with 5.0 or 10.0% protein levels. Pig gains were less with the 5.0% than with the 10.0 or 15.0% protein in the first 14 days of lactation, and from 15 to 34 days there was a significant improvement with each increment of dietary protein. Holden et al. (1967) had previously demonstrated a significant increase in sow milk protein with increased protein in the diet. Diets containing 8.0, 12.0, 16.0 and 20.0% protein gave 5.04, 5.37, 5.22 and 5.69% protein in sampled maternal milk, respectively.

Boomgaardt et al. (1972) concluded that the lysine need of lactating first-litter sows, does not exceed 0.60% of the diet or 20 g/day. This could be provided by a daily intake of 3.3 kg feed containing 16.0% protein. However, Ganguli et al. (1970) and O'Grady (1971) have observed acceptable lactation performance at lysine intakes as low as 18 g/day during lactation. Boomgaardt et al. (1972) did imply that with succeeding lactations, the lysine requirement could increase if the sow was control-fed during lactation. MacPherson et al. (1969) reported that, for the first three litters, lactating sows rearing nine pigs to six weeks of age did not require more than 750.0 g of protein/day, when this was associated with daily gestation protein intakes of 240.0 g. Results of recent work by O'Grady (1971), supported these observations,

and further indicated that as little as 11.7% dietary protein may be adequate, if the sow is fed to appetite.

The N.R.C. (1968), and the Agricultural Research Council (1967) have estimated the protein needs for lactation to vary in sows from 750.0 g to 1080.0 g crude protein/day, respectively. Mahan et al. (1971b) reported that 640.0 g of protein derived from a 16.0% crude protein diet, fed at the rate of 4.0 kg/day during the third week and 800.0 g of protein (16.0% crude protein, 5.0 kg/head/day) fed during the fourth week postpartum, were adequate for maintenance of nitrogen equilibrium in the lactating first-litter sow.

Gestation diets and gain, the physiological maturity of the sow, litter size and the duration of lactation, will need to be considered in establishing lactation feed intake levels for sows versus first-litter gilts. In turn, the amino acid needs during lactation are dependnet on stage of lactation, milk production, number of pigs per litter, body reserves and the feed intake of the animal.

IV. INFLUENCE OF SELECTED MINERALS AND VITAMINS ON SWINE REPRODUCTION AND THE MMA COMPLEX

A new look at the mineral and vitamin needs of gestating swine has been necessitated by confinement rearing and limited feeding regimes. Mineral and vitamin deficiencies are now becoming apparent, which previously were masked by pasture programs and over-feeding. Many of these deficiencies can be traced to the simple fact that individual nutrient level per kilogram of diet was not adjusted to the animal's daily intake needs.

Minerals

Although minerals comprise less than 4.0% of the total body mass, their dynamic functions in metabolism, and as integral parts of both body structure and function, give emphasis to their needs and importance in sow-fetus relationships. Absorbed minerals have been demonstrated to pass freely from the sow to the fetus at all stages of pregnancy, with quantity and rate increasing progressively with fetal weight and gestation age (Hansard, 1965). Mineral interrelationships with available energy, protein, vitamins and other minerals must be given consideration for maternal-fetal nourishment during gestation, for maximum postnatal performance. According to Itoh et al. (1967), and Hansard and Berry (1969), external factors depressing maternal absorption and/or retention of minerals, would limit subsequent availability to the fetus. Hansard (1969), using radiochemical procedures, reported the maternal to fetal transfer rate for zinc and iron to be much less than for calcium, and potassium suggested a possible membrane protective role for the placenta.

Mastitis-Metritis-Agalactia (MMA) Complex

During the past few years, there has appeared a condition in confinement sow operations called mastitis-metritis-agalactia (MMA). A Wisconsin survey indicated that MMA was the second most frequent disease in the herds examined (Nachreiner and Ginther, 1969). This condition has become more prevalent, since there has been a movement to reduce daily gestation feed intake. Clinical symptoms of the MMA complex are: fever, increased heart rate, loss of appetite, vaginal discharge, swollen and edematous udder sections, which are sensitive to touch, reluctance

to rise, stiff gait, disregard for litter, and failure to milk (Martin et al., 1967). Peterson et al. (1969) considered a sow to have MMA if she had any one of the following three conditions:

1. Mastitis - hard, hot, edematous udder, off-feed and high rectal temperature.
2. Metritis - vaginal discharge, loss of appetite and high rectal temperature.
3. Agalactia - no milk or partial lactation, with a hungry litter.

Evidence of bacterial infections, along with suspected endocrine imbalance, have also been implicated in the MMA situation (Martin et al., 1967). Furthermore, pen conditions may be a definite factor contributing to udder problems. Little or no bedding is used in many confinement buildings, and cold damp floors could result in conditions conducive to inflammation. The use of penicillin (oral and injected) has proven ineffective in preventing or controlling the disease (Ellis et al., 1969).

Until recently, a naturally occurring vitamin E-selenium deficiency in swine was not suspected to be a practical problem in the United States (N.R.C., 1968). The sudden deaths of feeder pigs in Michigan swine herds was blamed on edema disease. Subsequently, Michel, Whitehair and Keahey (1969) reported a vitamin E-selenium deficiency in Michigan confinement reared pigs. While clinical signs of these two conditions are similar, the acute death losses due to hepatic necrosis and muscular degeneration ceased, following supplementation of diets with vitamin E, or injection of selenium-vitamin E, or both (Trapp et al., 1970). Michigan workers (Ullrey et al., 1970, 1971) reasoned that with the increasing incidence of vitamin E-selenium deficiency in young pigs, there may be a relationship between these nutrients and MMA.

Role of Vitamin E and Selenium

It is well accepted by those in the nutrition area, that a relationship exists between vitamin E and selenium, one in which some of the deficiency symptoms can be corrected by either nutrient. In many cases vitamin E is completely effective, while in others selenium is substantially more effective. Two recent reviews detailed the inter-relationships between vitamin E and selenium and their metabolic functions (Underwood, 1971; and N.R.C., 1971).

Field cases of vitamin E-selenium deficiency in swine have been on a sharp increase during the past few years, particularly in the eastern part of the Corn Belt (Michel et al., 1969; and Trapp et al., 1970). A number of factors may be responsible for this situation: the reduced feed intakes of pregnant animals, increased movement of swine from pasture to complete confinement, increased emphasis on the development of meatiness in growing-finishing swine, the feeding of corn-soybean meal diets fortified with relatively pure vitamin and mineral sources, and the increased use of drying equipment at harvest which may interfere with or hasten the destruction of vitamin E and/or selenium.

A low level of selenium in corn grown in Michigan and other midwestern states was indicated by Kubota et al. (1967). Groce, Rossman and Ullrey (1972) have reported that as corn yields increased, the selenium content of these corns decreased ($r = -.48$). Other data would suggest that corn dried naturally may lose a great deal of its α -tocopherol during storage (Young, Lun and Forshaw, 1972), but if it is artificially dried at a low temperature, the total oxidative damage might be small (Ewan, 1971; Pond et al., 1971; and Young et al., 1972). If,

however, the drying temperatures were highly elevated and the grain was severely damaged or cracked, as can happen at harvest, substantial losses of α -tocopherol might occur (Young et al., 1972). Most of these workers (Pond et al., 1971; and Young et al., 1972) have shown no loss of selenium when corn was dried artificially. Ewan (1971) showed an 11.0% loss, when corn was dried at 93°C. These results explain why feeding grain of this type in swine diets could increase the incidence of the vitamin E-selenium syndrome.

Arsenic was used by Moxon (1941) to reduce the incidence of selenium toxicity in swine. More recently, arsenicals have been used in the swine industry to cure dysentary problems. Hitchcock, Miller and Ullrey (1972) have presented data to indicate a complementary selenium-arsenic relationship, rather than an antagonistic one. To swine fed a diet low in selenium, the addition of 99.0 ppm arsanilic acid increased the absolute retention and percentage retention of selenium.

Ku et al. (1972) demonstrated that the selenium content of the longissimus muscle, collected from swine raised in various localities, was a direct reflection of the selenium content of the diet. These workers reported a positive correlation of $r = 0.95$ between dietary and longissimus muscle selenium concentrations. No apparent relationship between dietary α -tocopherol level and tissue selenium was indicated in this study. The majority of the selenium deficiency cases seen in swine under field conditions, occur between weaning and 40.0 kg (Trapp et al., 1970).

In a reproductive study, Penhale et al. (1972) found that the addition of selenium to the diet at the rate of 0.1 ppm resulted in no

rise in glutamic-oxalacetic transaminase (SGOT), glutamicpyruvic transaminase (SGPT) or ornithine carbamoyltransferase (OCT), as indices of the vitamin E-selenium deficiency syndrome. There was a slight rise in the SGOT in the corn-soybean meal control diet in late gestation, and a significant rise in SGOT and SGPT levels at 60 and 90 days postcoitum in gilts fed a semi-purified diet. Of three sows farrowing on the latter diet, all died within one week with confirmed vitamin E-selenium deficiency symptoms. At two weeks post-weaning 17.0% of the pigs from the unsupplemented diet were lost with confirmed vitamin E-selenium deficiency symptoms.

Ullrey et al. (1970) presented evidence that was highly suggestive of a relationship between low vitamin E intake and MMA. The addition of 22 IU vitamin E/kg to a 12.0 to 13.0% protein corn-soybean meal diet, reduced the incidence of MMA by 36.0%. Increased pig survival to three weeks was attributed to the added vitamin E. Intramuscular injections of sows with 44 μ g selenium alone, or in combination with 3 IU vitamin E/kg body weight two to five weeks prepartum, increased the incidence of MMA, rather than decreased it. In an earlier report (Adamstone, Krider and James, 1949), sows fed a low vitamin E diet had poorer reproductive-lactation performance, in contrast to sows fed diets supplemented with the vitamin. These same investigators reported that pigs born of sows fed diets low in vitamin E exhibited a spraddled hind legs condition.

Michigan workers (Miller et al., 1970) continued the investigation into the influence of supplemental vitamin E or selenium during gestation-lactation by studies of hematological changes in sows and their offspring. Hematology of the sow was not influenced by treatment, nor was

the hemoglobin or packed-cell volume of the offspring, affected at two days or three weeks of age. Weights of the offspring at these ages also were not significantly influenced by the supplemental vitamin E or selenium. However, intramuscular injection of 50 IU of vitamin E to baby pigs two days post-farrowing, did improve their three week weights significantly. These results would imply that there was little or no placental transfer of vitamin E. Whiting and Loosli (1948) arrived at the same conclusion, when they reported no significant placental transfer of mixed tocopherols, as evidenced by liver storage in the newborn pig. However, prepartum diet supplementation (80.0 mg mixed tocopherols/45.4 kg body weight) caused a twofold increase in the tocopherol content of sow colostrum.

Subsequently, Ullrey et al. (1971) reported on an eight farrowing season study, to further establish the relationship between vitamin E, selenium and/or choline in the incidence of MMA and baby pig survival to three weeks. Within a single farrowing period, there were no significant differences due to treatment. However, in half the farrowings, if the sow had received supplemental vitamin E (and selenium in one gestation), there were an additional 1.1 pigs/litter surviving at three weeks. When all the farrowings were summarized together, the addition of both vitamin E and selenium resulted in a significant decrease in the incidence of MMA. The addition of choline to the diets did not improve reproduction beyond the effects of supplemental vitamin E alone. However, in none of these investigations was choline tried alone or in combination with only vitamin E.

Role of Choline

As pointed out by Ullrey et al. (1971), choline appeared to have little if any effect on the MMA complex. Yet, there has been speculation as to what caused the spraddled-hind legs syndrome in newborn pigs (Trapp et al., 1970; and Cunha, 1972). Suggested causes have varied from a hereditary factor to a virus. Increased incidence of the condition has appeared, as swine producers have lowered the total amount of feed given their sows. Where a few years ago, sows were fed 2.72 to 3.18 kg feed daily during gestation, intake now is often 1.36 to 2.04 kg daily. Since corn is used in most swine diets, along with soybean meal as the major ingredients, a choline deficiency could occur due to corn's low choline content. It is also lowest of the grains in a combined methionine and cystine level (N.R.C., 1968). The N.R.C. (1968) does not show a choline requirement for the sow, but indicates that 20.0 mg choline/kg of body weight will prevent a choline deficiency in sows fed a semi-purified diet.

Ensminger, Bowland and Cunha (1947) reported that four bred gilts fed a choline deficient, purified basal diet, supplemented with vitamin E, exhibited normal gestation periods. However, at birth, many of the newborn pigs exhibited weak leg conditions (spraddled-legged), muscular incoordination, as well as a high mortality rate and subnormal weaning weights. Post-mortem examinations showed fatty livers, congestion and petechial hemorrhages of the kidneys, and yellow granular accumulations in the kidneys. Two pigs showed an inflamed vulva. Neumann et al. (1949) reported similar pathological conditions in young pigs fed choline deficient diets. Johnson and James (1948) produced a choline deficiency

with four-day-old pigs, as evidenced by poor growth and fatty infiltration of the liver.

The lipotropic action of choline was first demonstrated by Best and Huntsman (1932). Choline plays an essential role in fat mobilization in the liver, preventing the abnormal accumulation of fat (fatty liver) by promoting its transport as lecithin, or by increasing the utilization of the fatty acids in the liver itself. The methionine and cystine level in a diet also needs consideration. A choline-methionine interrelationship exists, whereby choline is formed by the combination of the labile methyl group from methionine with ethanolamine, through transmethylation (Du Vigneaud, Ressler and Rachele, 1950). Thus, if choline is short in a diet, then methionine is used to synthesize choline. The level of cystine becomes important in such a situation as this, since this amino acid can supply or satisfy 40.0% of the pigs need for methionine (N.R.C., 1968).

Japanese researchers (Aoyama, Yasui and Ashida, 1971), working with female rats fed a choline-deficient diet, obtained results strongly indicative that the content of liver lipid was appreciably affected by the level of dietary protein. They further speculated that the level of body lipid was closely related to liver lipid, under choline-deficient conditions. Reid et al. (1968) have demonstrated that inadequate protein nutrition, accompanied by vitamin E and selenium deficiencies, may result in accumulation of lipids in the liver of rats.

Kornegay and Meacham (1973) evaluated the choline requirement of the sow, when fed 15.0% crude protein corn-soybean meal gestation-lactation diets (770.0 mg choline/kg diet) or with added choline,

providing 1650.0 mg/kg of diet. At feed intake levels of 1.82 to 2.27 kg/day during gestation, there were no significant differences after three productive cycles in reproductive efficiency and productivity of sows. However, sows fed the diet with supplemental choline, farrowed more live pigs during the fifth and sixth reproductive cycles. No abnormal conditions, such as spraddled legs, were observed in the pigs or sows. Similar findings were reported by Teague, Grifo and Christenson (1972); however, they did report that at the first farrowing, the choline supplemented gilts farrowed a lower average number of live pigs. No explanation was given, and second farrowing performance was similar to that of unsupplemented sows. It was, however, noted that more pigs, farrowed by choline supplemented sows, possessed stiff joints.

Choline was further linked to the MMA complex by a condition termed "pale pig syndrome," that has been observed in pigs at birth in the Michigan State University swine herd (Orr et al., 1970). Pigs identified by an outward pale appearance, were somewhat smaller, weaker at birth with a high mortality rate, and hematologically only if the hemoglobin concentrations were less than 7.0 g/100 ml and hematocrits were less than 25.0% at two days of age (Hitchcock et al., 1971a). Administration of 0.2 ppm selenium and 20,000 IU of vitamin E in a 13.0% corn-soybean meal gestation diet, fed at the rate of 1.81 kg/day, gave no indication of reduced incidence of pale pigs (Orr et al., 1970). However, there was an indication that additions of 800.0 g choline/ton may be helpful in ameliorating this disease (Hitchcock et al., 1971a)..

Parks and Smith (1968) found that the increased renal weight in choline-deficient weanling rats was due, in part, to increased cellular proliferation of the deficient kidneys.

V. NEONATAL PIG BODY COMPOSITION

The presence of growing fetuses progressively adds an extra physiological load to the dam, and much of the maternal response is due to this fetal growth. Pregnancy stimulates feed intake, increases nutrient absorption and utilization efficiency, and in the young female, maternal tissue growth, nutrient accretion and weight gain may exceed that accredited to the products of conception (Hansard and Berry, 1969).

The increased retention of nutrients, especially during the latter part of gestation and often in excess of that calculated to compensate for fetal growth and development, is termed pregnancy anabolism. It was recognized early by Evans (1929) and Mitchell et al. (1931), when it was observed that gilts retained as much as 69.0, 80.0 and 60.0% of the nitrogen, calcium and phosphorus, respectively, absorbed for maternal growth, allowing only 31.0, 20.0 and 40.0%, respectively, of the three nutrients for the fetus and products of conception. There are various factors, both maternal and fetal, contributing to the rate and quantity of nutrients traversing the placental membranes for deposition in the fetus: (a) maternal nutrient availability for fetal transfer, (b) placental type and subsequent membrane permeability, (c) stage of gestation and physiological age or fetal needs, and (d) size, weight, and charge of particles being transferred (Hansard and Berry, 1969).

Individual nutrients have specific functions during growth and development of the fetus. The primary feature, which determines the nutrition of the fetus, is whether the maternal absorption of essential nutrients into the blood, and their placental transfer to the fetal blood

is sufficient to allow for maternal requirements of maintenance and growth (Moustgaard, 1962; and Hansard, 1965). It is generally accepted that the fetus has first priority with regard to absorbed nutrients. Therefore, changing the chemical composition of the fetus by normal prenatal nutrition is difficult in the pig, due to this fetal privilege, when essential nutrients are considered. This was readily demonstrated by composition studies of newborn pigs (Mitchell et al., 1931; Manners and McCrea, 1963; Brooks et al., 1964; Curtis, Heidenrich and Martin, 1967; and Brooks and Davis, 1969), conducted with pigs of different genetic origin and grown under widely different environmental conditions.

According to Topel (1971), body composition values are important for providing basic data in estimating the nutritional demands of pregnancy. In the long run, maternal deprivation of absorbed nutrients could lead to shortened longevity of dam, and fetal abnormalities or resorption of the embryo.

Whole Body Chemical Composition

The chemical composition of newborn pigs from several sources is presented in Table I. Some of the variations evident in the table are due to method of analyses, while nutritional effects are slight. Mitchell et al. (1931) sacrificed pregnant gilts at different stages of pregnancy to determine the minimum nutritive requirements for reproduction in swine. The gilts used in the study were fed a 10.9% protein diet during gestation, in amounts to produce an average daily gain of 0.45 to 0.57 kg. Composition values were for prenatal pigs (whole body) taken during the last week of pregnancy (82.95% moisture, 10.1% crude protein, 0.96%

TABLE 1. SUMMARY OF BODY COMPOSITION VALUES FOR PIGS AT PARTURITION

Carcass Chemical Composition, %									
Moisture	Crude Protein		Ether Extract		Ash		Gross Energy (kcal/g)	Reference	
	Wet Tissue	Dry Matter	Wet Tissue	Dry Matter	Wet Tissue	Dry Matter			
82.95	10.1	59.2	.96	5.63	3.42	20.03	773	Mitchell <u>et al.</u> (1931)	
82.6	12.0	--	1.2	--	4.2	--	---	Manners and McCrea (1963)	
78.3	11.9	55.0	2.3	10.7	1.0	4.6	---	Brooks <u>et al.</u> (1964) Trial 1	
74.5	11.7	45.9	1.4	5.6	5.1	20.0	---	Brooks <u>et al.</u> (1964) Trial 2	
80.2	10.9	55.2	.6	3.2	4.0	20.3	---	Curtis, Heidenrich, and Martin (1967)	
76.5	--	50.5	--	5.4	--	22.2	---	Brooks and Davis (1969)	
80.45	11.3	58.1	1.52	7.76	3.46	17.67	---	Hesby <u>et al.</u> (1970b) ^a	

^aCorn-soybean meal diet providing 254 g protein intake/day for sows.

fat, 3.42% ash and 773.0 kcal/g gross energy). Manners and McCrea (1963) sacrificed three pigs at birth from sows fed 2.72 kg/day of sow-and-weaner nuts during the last third of gestation. They analyzed the entire carcass, minus gut and bladder contents. Converting those values, in grams per total carcass to percentages, found little differences, on a wet tissue basis, compared to the earlier data of Mitchell et al. (1931), except for higher protein level. Intact carcasses were analyzed in the previous two examples while, Brooks et al. (1964) in trial one used skinned, decapitated, feetless, and boned carcasses. In trial two, carcasses were only skinned before analysis, thus explaining the apparent differences between the two trials for moisture and ash percentages.

The changes in chemical composition of the perinatal pig were further investigated (Curtis et al., 1967; and Brooks and Davis, 1969), to study the relationship between body weight and the physical and chemical components. It was found that body weight was not positively associated with pig developmental maturity at birth. Pigs, from third litter sows, were used by Brooks and Davis (1969) to obtain results similar to those obtained in 1964 by the senior author and co-workers. In the latest study, weights of the stomach, kidney and spleen appeared to have plateaued before birth. Carcass and liver were found to contain higher levels of nitrogen-free extract before birth. These levels declined rapidly after birth, while percent ether extract of the carcass dry matter increased rapidly from its lowest point at birth. Carcass protein also increased rapidly after birth, from its lowest level at birth.

To this point, the studies cited were non-nutritional investigations. Hesby et al. (1970b) analyzed one neonatal male pig per litter, from sows fed normal corn, opaque-2 corn (11.2% protein and 0.49% lysine) and two normal corn-soybean meal diets (15.0% and 11.2% protein, 0.60 and 0.42% lysine, respectively), during gestation. Results of one summer's gestation revealed no significant differences due to dietary protein source on moisture, crude protein, ether extract, ash, potassium or sodium content of the newborn pig, on either fresh or dry matter basis. Likewise, Elsley, McDonald and MacPherson (1966b) found no difference in nitrogen per pig or nitrogen per litter, between progeny of sows fed either 1.6 or 2.6 kg/day of diets containing 11.0 or 18.0% protein during three successive pregnancies. However, when the first litter newborn pigs were adjusted to a constant one kilogram weight basis, those from gilts fed the higher protein diet, had a significantly higher nitrogen content than those pigs from gilts fed the lower protein diet. Over three litters, the lowest nitrogen content per one kilogram pig was found with the combination of low protein diet and low feed intake. Gimenez et al. (1972a) have reported a difference in favor of soybean protein in fetal tissue protein concentrate at 20 and 60 days of gestation, from progeny of dams fed soybean meal protein, versus fish protein during gestation. However, at 20 days post-breeding, the protein concentration (mg protein/ml) of blastocoelic and amniotic fluids favored the fish meal.

Livingston (1962) reported a significant increase in longissimus and psaos muscle fiber diameters in newborn pigs from sows fed 59.3 kg (21.2%) crude protein, when compared to pigs obtained from sows fed 29.3

kg (10.4%) crude protein during gestation. The lower protein level may have caused a nutritional stress on prenatal muscle development, and limited the genetic potential for muscle development. However, when these progeny were fed adequate diets to slaughter weights, the differences in muscle fiber diameter observed at birth did not persist.

The practical aspects of varying energy levels in fetal nutrition appeared to have little practical or economical importance, because the sow apparently buffers her offspring during pregnancy against most nutritional inadequacies (Vermedahl et al., 1969). This was supported on a cellular level by Robinson (1969). Nutritional stress, imposed by undernutrition through pregnancy alone was without effect upon changes in DNA accumulation or RNA/DNA and protein/DNA ratios during subsequent development. Pond et al. (1969) also reported no difference in DNA content of brain or skeletal muscle between offspring of gilts fed a control diet and those fed a protein-free diet throughout gestation, but the RNA content of the cerebrum and RNA/DNA ratio of the longissimus muscle were greater in pigs from the control gilts at slaughter.

Frape et al. (1969) showed that, with inadequate energy intake during pregnancy, gestation protein level influenced progeny liver weights and vitamin A storage. However, gestation protein level did not influence these measurements when gestation energy was adequate. Using a controlled feeding program during gestation, Anderson and Wahlstrom (1970) found that gilts fed to gain 0.0 to 10.0 kg during gestation produced offspring with higher blood sugar and, liver fat with lowered liver glycogen levels, compared to offspring of gilts fed to make gestation gains twice as great. The liver fat content of pigs from the low

gaining gilts was 1.00% at birth, increasing to 2.66% at 24 hours.

Liver moisture was 73.50% at birth, but increased as liver glycogen was broken down. Brooks et al. (1964) reported similar liver lipid values on a wet basis.

Fetal Mineral Concentrations

Since the fetal pig is completely dependent upon the sow for protection and nurture during prenatal growth and development, its mineral supply is directly related to the abundance of exogenous and/or endogenous maternal source. Mitchell et al. (1931) computed the total mineral content present in a litter of eight pigs, having a total fresh weight of 18,505.0 g during the last week of gestation. Of the total litter weight, 411.0 g was located in the fetuses as total ash. Calcium (Ca) and phosphorus (P) made up 101.0 and 60.0 g, respectively, of the total mineral content, while iron (Fe) totaled 581.0 mg. Later, Widdowson (1950) compared the chemical composition of other newborn mammals to the pig and Manners and McCrear (1963) studied the chemical and mineral changes in the suckled pig from birth.

More recently, the placental transfer and fetal utilization of absorbed minerals has been studied using labeled minerals. As a result of such studies, Hansard (1965) reported that a one kilogram pig fetus contained the following minerals: calcium (g), 9.9; phosphorus (g), 5.3; inorganic sulfur (g), 1.0; magnesium (g), 0.3; iron (mg), 34.8; zinc (mg), 26.8; manganese (mg), 1.0; copper (mg), 2.5; and potassium (mEq), 50.0.

Itoh et al. (1967) in a fetal-dam Ca placental transfer study, demonstrated that pigs from dams on a low-calcium diet contained only 71.0% as much total calcium as those from dams consuming a normal diet. Calcium values for total organs were, likewise, less for the prenatal pigs from the low-calcium fed sows. Results indicated that maternal needs influenced Ca movement and transfer to fetuses during the last trimester of gestation. Hansard and Itoh (1968) further investigated the effects of limited Ca intake upon zinc (Zn) absorption, and subsequent utilization by gravid gilts and their third trimester fetuses. Fetal tissue Zn levels averaged higher for fetuses from sows fed normal Ca diets. However, more total Zn was contained in the liver, heart and fetuses from sows fed limited Ca. The total fetus from sows on both treatments contained nearly 400 times more Ca than Zn. Hoekstra et al. (1967) reported the liver Zn concentration of the newborn pig to be quite sensitive to variations in the maternal Zn supply, but this was not demonstrated with kidney and muscle Zn concentrations. Gamble (1969) reported that fetal mass appeared to be a major factor affecting total manganese (Mn) transfer. Third trimester litters, standardized to eight pigs, contained 6.4 mg total Mn, while the liver, kidney and spleen were found to contain 1.7, 1.2 and 2.7 $\mu\text{g/g}$ Mn, respectively.

Blood Minerals

Swine serum (or plasma) mineral concentrations have been studied by a number of researchers, as an adjunct to investigations of mineral metabolism, or of quantitative dietary requirements. Hemoglobin levels and hematocrits have been employed as accepted criteria for assessing

blood Fe level. Craft and Moe (1933) reported hemoglobin values at birth on 117 purebred Duroc pigs to vary from 6.5 to 15.1 g/100 cubic centimeters (cc) of blood, while the average was 11.37 g/100 cc of blood. Miller et al. (1961) reported hemoglobin and hematocrit values, determined at birth, as 12.5 to 12.6 g of hemoglobin/100 cc, and 39.8 to 40.3%, respectively. Rapid decreases in hemoglobin concentration occurred shortly after birth, probably due to hemodilution, following colostrum consumption. Ramirez et al. (1963) observed that the hematocrit of the newborn pig was 36.0 ± 1.2 . During the first six hours, it decreased significantly to 30.9 ± 1.2 and was 30.7 ± 1.0 after 12 hours. The influence of protein levels (12.0 and 16.0%), protein source (soybean meal, cottonseed meal and fish meal) and dietary Fe level (0.0 or 700.0 ppm) fed to the sows during gestation was studied for the effects on Fe-related constituents of the blood (Spruill, Hays and Cromwell, 1971). Protein level and source significantly influenced ($P < .05$) hemoglobin and hematocrit levels of the newborn pig. Feeding gestation diets with high Fe levels resulted in a slight, but non-significant increase in placental transfer of Fe.

Serum Ca, magnesium (Mg), potassium (k), copper (Cu), and Zn levels were studied in clinically healthy Hampshire and Yorkshire cross-bred swine from birth to five months of age by Ullrey et al. (1967). Blood samples were obtained at birth (before nursing), and at later postpartum intervals. Mean values for the five minerals at birth and 24 hours later were, respectively: Ca 10.8, 9.3; Mg 3.4, 2.4; K 19.6, 19.4 mg/100 ml and Cu 27.0, 53.0; Zn 60.0, 56.0 $\mu\text{g}/100\text{ ml}$. Gamble (1969) reported fetal blood to contain 0.48 $\mu\text{g}/100\text{ g}$ Mn. Hansard and Itoh

(1968) reported total plasma Zn concentration of 0.9 mg/l in third trimester fetuses.

VI. SOW CONDITION EVALUATION TECHNIQUES

The use of mechanical probing and ultrasonic sound waves to estimate muscle to fat relationships in the live pig has proven to be a valuable tool for subjective carcass evaluation. However, the condition (fatness) of pregnant swine has not been studied to relate it to the composition changes of the animal as parturition approaches. Changes in backfat thickness could be an indirect method of evaluating the energy needs of pregnancy.

Mechanical Backfat Probe

The technique of using a simple metal ruler to measure the subcutaneous fat depth in live swine was first described by Hazel and Kline (1952). This procedure was said to cause comparatively little discomfort to the pig, and no ill effects were noted. The average of four live hog measurements of fatness had a correlation of 0.81, with the average of four corresponding carcass backfat measurements taken at the first, seventh and last thoracic vertebrae, and the last lumbar vertebrae (Hazel and Kline, 1952). The accuracy of probed measurements of backfat thickness, taken at various weights as indicators of eventual carcass backfat thickness, was investigated by Hetzer, Zeller and Hankins (1956). Of the variation in carcass backfat thickness among 140 pigs, 52.0% was explained by the average of three measurements taken on these animals using the probe at 102 kg.

Ultrasonic Backfat Measurement

The use of high frequency sound waves to measure the backfat thickness of pigs was first described by Dumont (1957). Hazel and Kline (1959) used an ultrasonic scanning device with a 2.5 mc/s transducer to estimate fat thickness on 56 market weight hogs. Measurements were read approximately 5.0 cm off the midline of the back over the 1. dorsi muscle at the sixth rib, twelfth rib and last lumbar vertebrae. After removing differences due to sex and carcass weights, the correlations between the average of three ultrasonic fat depths and ruler probes with carcass backfat thickness were 0.76 and 0.83, respectively. Stouffer et al. (1961) obtained a correlation of 0.92 between ultrasonic estimates of fat thickness and carcass fat thickness. They used a bleeding crate to restrain the animal, or allowed them to stand naturally. Price et al. (1960) measured ultrasonically 158 live hogs for fat thickness. Highly significant correlations of 0.91 and 0.88 were found between ultrasonic measurements with live probe and actual carcass backfat thickness, respectively.

Measurement of the inner (third) fat layer was found to be dependent on the operator's ability to detect and measure the separation between the second fasica layer and the surface of the muscle (Burgess, 1965; and Meyer et al., 1966). Hazel and Kline (1959) mentioned a similar difficulty, and they postulated that movement of the hog caused variation in fat depths and oscilloscope readings. Price et al. (1960) reported that more difficulty had been encountered in interpretation of the readings at the shoulder, than in interpretation of those taken at the loin or in the middle of the back. Burgess (1965) ultrasonically

measured fat deposition of boars, barrows, and gilts at four weights (31.3, 48.5, 67.1, and 104.3 kg). He found that the outer (first) fat layer was deposited at about the same rate in boars, barrows, and gilts from 31.3 to 104.3 kg. From 67.1 to 104.3 kg, the fat deposition in the intermediate (second) layer was less rapid in the boars and gilts, which deposited fat at about the same rate. Considerable variation in depth of the third fat layer was found among individual pigs, with deposition in this layer somewhat faster in gilts than boars but not barrows. Moody and Zobriský (1966) reported that the second fat layer increased faster, and to a greater thickness than the first or third layers in carcasses with thicker total backfat. Meyer et al. (1966) found that ultrasonic and carcass depth measurements of the first and second fat layers did not differ significantly. However, comparison of the depth measurement of the third layer of fat illustrated considerable variation between these two methods. Failure to penetrate through the trapezius muscle (false lean) in the region immediately behind the shoulders on some pigs, and penetrating this false lean on others would lower the correlation between the two procedures (Holland and Hazel, 1958). The second fat layer was more closely associated with total backfat thickness, and was considered the most reliable in the live hog for estimations of fat and lean (Meyer et al., 1966).

Results reported by Jones (1971), on 36 boars, barrows and gilts, indicated that at the first-rib, last-rib, and last-lumbar locations, there was a higher correlation between ultrasonic and carcass measurements of accumulative depth of fat layers one and two than for the first layer alone. Similar results, by Moody and Zobriský (1966), indicated

that the first and second backfat layers, as measured ultrasonically, account for an equal share of the variation in carcass merit, as does measurement of these two layers on the carcass.

CHAPTER III

EXPERIMENTAL PROCEDURE

The objective of this study was to assess the long-term effects of limit-feeding a standardized 16.0% protein diet to sows during both gestation and lactation in an effort to establish definite guidelines for evaluating and quantitating minimum nutrient requirements for maximum reproductive performance.

I. SOURCE OF DATA

Data were collected on 52 sow and litter units from the purebred Duroc and Hampshire swine herds of the Tennessee Agricultural Experiment Station, Knoxville, Tennessee. One-hundred and two neonatal pigs were used for chemical determinations.

II. ASSIGNMENT TO DIETS

Twenty-four, beginning second trimester gravid gilts averaging 9.4 months of age and weighing 128.3 kg, were started on this study in December 1970. The gilts had previously received a 16.0% protein corn-soybean oil meal diet from weaning to approximately 100.0 kg of body weight. They were fed on pasture the same diet during the pre-breeding period, and afterwards until assigned to the experiment. The 2.04 kg feed/day during the development period was increased to 4.08 kg/day one week prior to breeding, and continued for two weeks, followed by a week at 2.27 kg/day. For the remainder of the first trimester of gestation,

the bred gilts were fed 1.81 kg feed/day. Commencing the second trimester of gestation the gilts were allotted according to breed, litter and weight to the two experimental diet groups, which will be discussed under Diets and Feeding Procedure.

Two lots of six gilts from each diet group were then confined in a 6.0 x 7.3 m concrete lot, containing a 3.0 x 7.3 m concrete block house, open to the south until the 111th day of gestation. A feeding stall along one side of the pen was used for individual feeding. Water was provided by automatic waterers. Straw bedding was used during the two winter gestations as needed.

III. DIETS AND FEEDING PROCEDURE

The gravid gilts were individually fed the assigned experimental diets once daily (morning) at a level of 1.36 kg/head. The composition, amino acid content and mineral levels of the diets are shown in Tables II, III and IV, respectively.

Diet 1 was (corn-soybean control or C-SBM) the standard 16.0% protein ration used at the swine unit, while diet 2 (vitamin E-choline supplemented or Vit E-Chol Suppl'd) was formulated with added choline, vitamin E and fish meal. After farrowing, each gilt was fed the respective gestation diet at the same pre-farrowing level of intake, plus an additional 0.45 kg for each pig nursing.

The sow litter units were randomly assigned within diet groups and breed to four creep diets (3,4,5, or 6) shown in Table V. Diets 3 and 5 were 16.0% protein versions of the gestation rations (1 and 2, respectively), while diets 4 and 6 were 20.0% protein versions of the

TABLE II. COMPOSITION OF DIETS FED GILTS AND SOWS
DURING GESTATION AND LACTATION

Ingredients	Diet Group	Percent of Diet	
		1	2
Ground yellow corn, No. 2		74.10	73.48
Soybean oil meal (44%)		15.10	14.80
Dehydrated alfalfa meal (17%)		3.00	3.00
Meat and bone scrap (50%)		5.00	3.00
Menhaden fish meal (60%)		---	2.00
Dicalcium phosphate (Dynafos)		1.10	1.40
Ground limestone		.90	1.00
Salt ^a		.50	.50
Trace mineral premix ^b		.10	.10
Vitamin premix ^{c,d,e}		.10	.62
Antibiotic ^f		.10	.10
Total		100.00	100.00
Crude protein, % (calculated)		16.58	16.60
Analyzed protein, %		16.24	16.42
Fed at level of 1.36 kg/day during gestation to provide:			
Protein intake, g (calculated)		225.50	225.80
Digestible energy, kcal (calculated)		4568.60	4534.60
Energy - protein ratios		20.30	20.10

^aIodized salt used in diet 2.

^bTo provide addition of 200 mg Zn, 100.1 mg Fe, 54.9 mg Mn, 11 mg Cu, 1.5 mg I and .99 mg Co per kg diet fed.

^cTo provide addition of following vitamins per kg diet fed: riboflavin, 8.8 mg; d-pantothenic acid, 16.2 mg; niacin, 39.7 mg; choline chloride, 44.1 mg; B₁₂, 22 mcg; vitamin A, 2913 IU; and vitamin D, 437 IU.

^dCholine added as chloride to diet 2 to give additional 1200 mg choline per kg diet fed.

^eVitamin E added as dl-alpha tocopherol to diet 2 to give 120 mg/kg diet fed.

^fContains 22 g chlorotetracycline per kg.

TABLE III. ESSENTIAL AMINO ACID CONTENT OF THE EXPERIMENTAL DIETS

	N.R.C. ^a		Diets			
	Recommendations		1	2	1	2
	%		% of Diet ^b		Gram/Hd/Day	
	Diet	Gram/Hd/Day				
Amino acids						
Arginine ^c	--	--	1.04	1.03	14.1	13.9
Histidine	0.20	4.0	.36	.37	4.8	5.0
Isoleucine	0.43	8.6	.82	.85	11.1	11.6
Leucine	0.66	13.2	1.44	1.46	19.6	19.9
Lysine	0.49	9.8	.77	.80	10.5	10.8
Methionine	0.35	7.0 (4.2) ^d	.20	.22	2.7	3.0
(Cystine)		(2.8)	.23	.23	3.1	3.1
Phenylalanine	0.52	10.4 (7.3) ^e	.78	.79	10.6	10.7
(Tyrosine)		(3.1)	.27	.28	3.6	3.8
Threonine	0.42	8.4	.64	.65	8.7	8.9
Tryptophan	0.08	1.6	.18	.18	2.4	2.5
Valine	0.46	9.2	.78	.79	10.6	10.8

^aFrom Nutrient Requirements of Swine. No. 2. N.R.C. (1968).

^bCalculated from joint United States - Canadian Feed Composition tables. N.R.C. (1969).

^cNo recommended level published.

^dTotal for methionine and cystine. Values in parentheses were individual levels, as cystine can satisfy 40% of the need for methionine.

^eTotal for phenylalanine and tyrosine. Values in parentheses were individual levels, as tyrosine can satisfy 30% of the need for phenylalanine.

TABLE IV. SELECTED MINERAL LEVELS OF THE EXPERIMENTAL DIETS FED

Minerals	N.R.C. ^{a,b}		Diets			
	Recommendations		1		2	
	% Diet	Gram/Hd/Day	% of Diet ^{d,e,f}		Gram/Hd/Day	
Calcium	.75	15.0	1.230 (1.41)	1.230 (1.47)	16.70 (19.20)	16.70 (20.00)
Phosphorus	.50	10.0	.800 (0.67)	.800 (0.79)	10.90 (9.10)	10.90 (10.80)
Magnesium ^b	.04	.8	.220 (0.14)	.190 (0.14)	3.00 (1.80)	2.60 (1.90)
Potassium ^c	---	---	.690 (0.41)	.670 (0.40)	9.40 (5.50)	9.10 (5.40)
Iron ^b	.0008	.016	.018 (0.03)	.018 (0.04)	.20 (0.40)	.20 (0.50)
Copper ^b	.0006	.012	.002 (0.01)	.002 (0.01)	.03 (0.08)	.03 (0.05)
Zinc	.005	.100	.022 (0.03)	.002 (0.02)	.30 (0.37)	.30 (0.30)
Manganese ^b	.002	.040	.006 (0.01)	.006 (0.01)	.08 (0.08)	.08 (0.10)

^aFrom Nutrient Requirements of Swine. No. 2. N.R.C. (1968).^bBaby pig requirement.^cNo recommended level published.^dCalculated from joint United States - Canadian Feed Composition tables. N.R.C. (1969).^eValues in parentheses are analyzed levels, using Perkin Elmer 303 Atomic Absorption Spectrophotometer.^fInorganic phosphorus was determined by the calorimetric method.

TABLE V. DIETS FED SOW LITTER UNITS DURING LACTATION

Diets	Sow Group			
	I		II	
	3	4	5	6
Percent Protein	16	20	16	20
Ingredients, %				
Ground yellow corn, No. 2	75.20	66.45	75.06	50.58
Soybean oil meal (44%)	15.00	24.10	14.70	19.40
Dehydrated alfalfa meal (17%)	3.00	3.00	3.00	3.00
Meat and bone scrap (50%)	5.00	5.00	3.00	3.00
Menhaden fish meal (60%)	--	--	2.00	2.00
Dried skimmed milk	--	--	--	10.00
Sucrose	--	--	--	10.00
Dicalcium phosphate (Dynafofos)	1.00	.45	1.30	.60
Ground limestone	--	.20	.10	.10
Salt ^a	.50	.50	.50	.50
Trace mineral premix ^b	.10	.10	.10	.10
Vitamin premix ^{c,d,e}	.10	.10	.14	.62
Antibiotic ^f	.10	.10	.10	.10
Total	100.00	100.00	100.00	100.00
Crude protein, % (calculated)	16.63	20.02	16.69	20.02
Analyzed protein, %	16.30	20.46	16.22	19.96

^aIodized salt added to sow group II diets.

^bTo provide addition of 200 mg Zn; 100.1 mg Fe; 54.9 mg Mn; 11 mg Cu; 1.5 mg I; .99 mg Co per kg diet ration fed, respectively.

^cTo provide addition of the following vitamins per kg diet fed: 8.8 mg riboflavin; 16.2 mg d-pantothenic acid; 39.7 mg niacin; 44.1 mg choline chloride; 22 mcg B₁₂; 2913 IU vitamin A and 437 IU vitamin D.

^dCholine added as the chloride to sow group II diets during reproductive cycle I to give an additional 1200 mg choline per kg diet fed. (Diet was devoid of added choline chloride during reproductive cycles II and III.)

^eVitamin E added as dl-alpha tocopherol to group II diets to give 120 mg per kg diet fed.

^fTo contain 22 g chlorotetracycline per kg.

two experimental diets, respectively. These same creep diets were fed during the second lactation. During the third lactation, the two 16.0% protein diets also served as the creep diets.

After weaning, the respective sow diets were withheld for two days. Then the sows were fed 4.54 kg/day for a week, followed by a week at 2.27 kg/day. During the remainder of this breeding and initial trimester of second gestation, all sows were fed 1.59 kg feed/day of their respective gestation diets.

IV. SOW AND LITTER MANAGEMENT

On the 111th day post-coitum, the gilts were moved to a central farrowing house, washed, weighed and placed in farrowing crates. Each crate-stall combination measured 2.0 x 1.8 m, with slatted floor across the rear .76 m of the stall. Each farrowing crate was equipped with a feed cup and an automatic waterer. The gilts were fed their respective diets once daily while in the farrowing house.

Birth weights were obtained within the first six hours, needle teeth were clipped, and each pig was earmarked within 24 hours after birth. An injection of 100.0 mg iron as ferric hydroxide polymaltose was administered to each pig during the first week. The sow and litter units remained in the farrowing house until pigs were weaned at approximately eight weeks. The creep diets were introduced three weeks post-farrowing, during the first lactation and during the second week for the last two lactations. All male pigs except those selected as potential sires were castrated prior to weaning. The pigs were weighed at 21 days, and at weaning. Litter creep feed consumption was recorded to weaning.

The gravid gilts were weighed at the end of the first trimester of gestation corresponding to when they were confined to the concrete lots, at the end of trimester two, prior to and after farrowing, 21 days postpartum and at weaning. At each of these weigh periods, the animals were sonoscoped for backfat thickness. Subcutaneous fat layer depth was measured by the use of a Bronson Model 12 sonoray, equipped with a 2.0 megacycle, 1.27 cm zth transducer. The machine was calibrated with the first echo at 4.35 cm, so that fat depth was measured at a 1:1 ratio. Depths of the first and second fat layers (Figure 1) were measured 6.35 cm off the midline, at the point-of-shoulder, last-rib, and point-of-hip locations. These locations correspond to the first-rib, last-rib, and last-lumbar vertebra measurements on the pork carcass. All backfat measurements were obtained with the animal restrained in a weigh scale or farrowing crate. The gilts were sonorayed for fat thickness, instead of using the probe technique, to prevent soreness and possible infection. This allowed the same location to be used for subsequent backfat determinations. It was difficult, if not impossible, to probe the same site a second time within a short period.

Following weaning, the sows were hand-mated on pasture at the first estrus. They remained in pasture lots, adjacent to the confinement pens, during the first trimester of the second gestation. The sows were pasture-fed during this period according to the schedule outlined in section III, Diets and Feeding Procedure. Sows completing the first reproductive cycle, that conceived, were continued on the same feeding and management schedule for a total of three reproductive cycles.

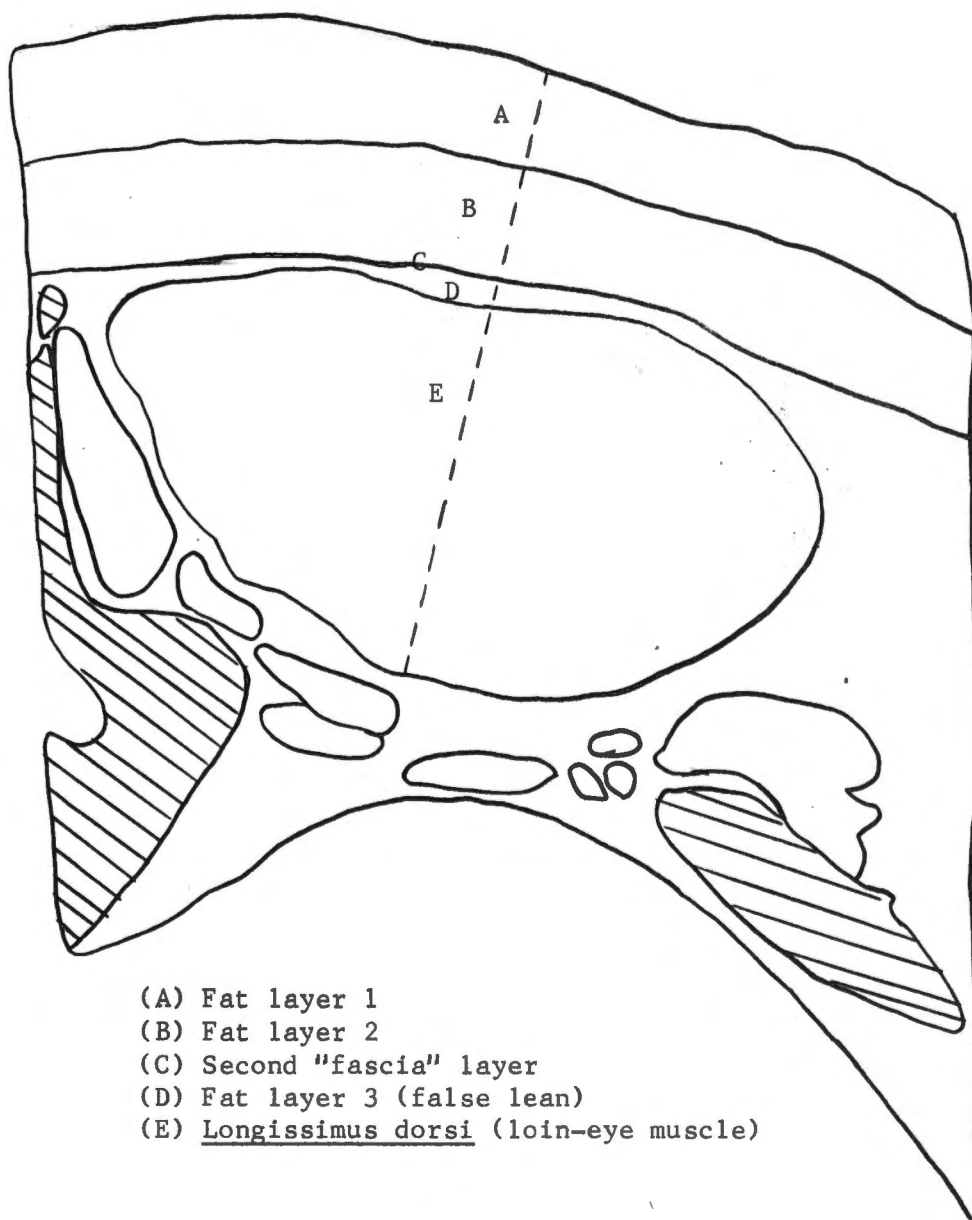


FIGURE 1. Schematic cross-sectional diagram of sow fat layers and the longissimus dorsi muscle at the last-rib location.

V. PIG CHEMICAL COMPOSITION ANALYSES

A representative female and male pig were taken from each sow after birth and before nursing, for whole body analysis. A 5.0 ml blood sample, from the anterior vena cava, was obtained from these pigs. Heparin sodium was used as the anticoagulant in the fresh blood samples. The samples were refrigerated for subsequent hemoglobin determination. The selected newborn pigs were sacrificed by an injection of 1.0 ml of Lethol.¹ A post-mortem weight (within 12 hr) was obtained in air and in water at cooler temperature (4°C), in order that specific gravity of the whole carcass could be calculated. Weight in water was taken with the carcass completely submerged in a specific-gravity tank filled with distilled water. Specific gravity (sp gr) was determined as the ratio of the carcass weight in air to the weight in water as follows:

$$\text{Whole carcass sp gr} = \frac{\text{wt in air}}{\text{wt in air} - \text{wt in water}} \times \text{density of water}$$

The spleen, one kidney, liver, digestive tract, and heart were then removed from each carcass for weighing. Whole organs were weighed and the entire spleen, tissue samples from the kidney, liver, and digestive tract were chemically analyzed, individually for Mg, Ca, K, Fe, Cu, Zn, and Mn, by atomic spectrophotometry. The heart and remaining liver tissue were then recombined with the carcass and ground in a commercial blender for subsequent chemical analysis. The blended digestive tract,

¹Pitman-Moore, Inc., highly lethol barbituate solution for euthanasia purposes.

and an aliquot of the ground whole carcass, were placed in plastic capsules and frozen for subsequent protein determination. Samples were taken for mineral analyses in tared crucibles, and ashed for 24 hr at 550°C. Percent moisture, ash, and ether extract were determined from aliquots (kidney, liver, digestive tract, and carcass) taken. Moisture, ether extract, protein, etc., were made in accordance with procedures outlined by the A.O.A.C. (Association of Official Agricultural Chemists 1965).

All ashed samples were taken into solution with 2.0 to 5.0 ml 6 N-HCL, transferred to graduated tubes, and made to definite volume with deionized water for total mineral analyses. From these, aliquots of desired concentration were made for reading on a Perkin Elmer 303 atomic absorption spectrophotometer (Perkin Elmer Manual, 1964). Individual total tissue minerals were then calculated in mg per g by the formula:

$$\frac{(\text{dilution})(\text{sample absorbance})(\text{concentration of standard})}{(\text{fresh tissue sample weight})(\text{standard absorbance})}$$

Carcass inorganic phosphorus was determined by application of the colorimetric method described by Fiske and Subba Row (1925), using a Bausch and Lomb Spectronic 20, at a wave length of 660 millimicrons. Gross energy was determined on the whole ground pig, using the Parr adiabatic oxygen bomb calorimeter (Parr Instrument Company Manual, 1960). At the second and third farrowings, the chemical analyses and mineral determinations were confined to the baby pig liver and carcass.

At the time of bleeding, a heparinized capillary tube was filled from each sample tube for subsequent hematocrit determination.

Hematocrits were determined by the micro-method described by McGovern, Jones and Steinberg (1955). Blood samples in heparinized capillary tubes were centrifuged for five minutes at 15,000 rpm, in an International MB-Micro Hematocrit Centrifuge. After centrifugation, hematocrits were read directly, as percent red cells, using the International Circular Micro-Capillary Tube Reader. Hemoglobin concentrations were determined on heparinized blood samples within three hours after collection by the cyanomethemoglobin method of Crosby, Munn and Furth (1954), using a Bausch and Lomb Spectronic 20 at a wave length of 540 millimicrons.

Plasma calcium, copper, iron, magnesium, manganese, potassium and zinc were determined by atomic absorption spectrophotometry, using the Perkin-Elmer Model 303 and air-acetylene flame.

VI. METHOD OF ANALYSES

All data were analyzed statistically to determine the effects of diet during each reproductive cycle by the least-squares analysis of variance for unequal subclass numbers (Harvey, 1960). The statistical model used to test for significant variation in the data was:

$$Y_{ijk} = \mu + D_i + B_j + DB_{ij} + \epsilon_{ijk}$$

where, Y_{ijk} is the expected or predicted performance,

and μ is μ , the overall mean,

and D_i is the effect due to diet in which $i = 1, 2$;

and B_j is the effect due to breed in which $j = 1, 2$;

and ϵ_{ijk} is the random error assumed to be independent and normally distributed. The covariate (X_{ijk}) for litter size was added to the model when analyzing the lactation data of sows, and litter units to

three weeks of age. Diet, breed and diet x breed effects were tested against the sow or litter unit/diet x breed component. From three weeks of age to weaning, the same mathematical model was used. When significant differences between diets (in this case, the four creep diets shown in Table V, page 71) were indicated by the least-squares analysis of variance, orthogonal comparisons, shown in Table VI were used to identify the source and magnitude of variation between creep diet means.

Contrast one allowed a comparison of mean data between creep diets 3 and 5. Contrast two tested the variation between creep 4 and the mean performance of litters fed creep 6. Contrast three compared the mean data from creep diets 3 and 5 to that of the mean data from creep diets 4 and 6.

Simple correlations coefficients were calculated between certain sow and litter data, and between body composition variables.

TABLE VI. ORTHOGONAL COMPARISONS USED TO
SEPARATE CREEP DIET DIFFERENCES

Diet ^a		Sow Diet			
		I	II	I	II
		3	5	4	6
Protein Level, %		16	16	20	20
Comparison	1	+ 1	- 1	0	0
Comparison	2	0	0	+ 1	- 1
Comparison	3	+ 1	+ 1	- 1	- 1

^aDiet compositions are described in Table V, page 71.

CHAPTER IV

RESULTS AND DISCUSSION

Data utilized in this study originated from 24 gilts, starting their second trimester of gestation. Through three reproductive cycles, 52 farrowings resulted from these gilts, which were used to evaluate the reproductive performance of dam, maternal influence on baby pig composition, and postnatal growth of the progeny when the maternal dam was limit-fed a standardized 16.0% protein diet during both gestation and lactation. The corn used in this study came from southern Indiana, an area known to produce corn low in selenium (Kubota et al., 1967), and two 16.0% protein diets were formulated. The corn-soybean meal control diet (C-SBM) was the standard 16.0% protein diet used at the Knoxville Swine Unit. Another corn-soybean meal vitamin E and choline supplemented diet (Vit E-Chol) was formulated with added choline (choline chloride), vitamin E (dl-alpha-tocopherol) and Menhaden fish meal. Fish meal and vitamin E were added to alleviate the possible selenium deficiency. The excellent protein quality of fish meal added another source of amino acids in this diet. Choline was added, since its daily intake would be low at the 1.36 kg/day level of diet intake (Cunha, 1972). Ullrey et al. (1971) have suggested a possible relationship between choline and the MMA complex.

Reproductive cycles 1 and 3 were conducted during the winter and reproductive cycle 2 during the summer (5.4, 7.3, and 22.7°C mean daily temperature, respectively). Since only one group of gilts started this

experiment, age of sow and season were confounded. Therefore, this functional relationship with time could not be estimated and a separate analysis of each reproductive cycle was warranted. The reproductive cycle was divided into two phases. Gestation included parturition and the lactation phase began with the postpartum sow and litter data. Only the gilts and sows completing each phase of the reproductive cycle were included in the analysis of that segment of the cycle.

The results of this study will, therefore, be presented in the following order: sow performance, progeny performance, and baby pig composition analyses.

I. GILT AND SOW DATA

Longevity

The number of gilts and sows completing each reproductive cycle and phase of the cycle are shown by diet in Table VII. Of the original 24 gilts, 12 successfully completed both phases of three reproductive cycles. During the first gestation period, two gilts fed the control (C-SBM) diet were removed from the experiment. One gilt failed to conceive and the other farrowed a litter diagnosed as having hemolytic anemia. In the subsequent lactation, one sow in each diet group failed to wean her litter and another, fed the Vit E-Chol diet, died during the second week of lactation from edema disease. It was thought that this death may have resulted from a vitamin E-selenium deficiency, because there was an extreme accumulation of pericardial fluid. Trapp et al. (1970) reported that edema was prominent in most tissues of feeder pigs that had died of a vitamin E-selenium deficiency. On necropsy, all

TABLE VII. NUMBER OF GILTS AND SOWS COMPLETING
REPRODUCTIVE CYCLES AND EXPERIMENT

	Diets		Total For Cycle
	C-SBM Control	Vit E-Chol Suppl'd	
Cycle 1			
No. animals started	12	12	24
No. animals farrowing	10	12	22
No. animals weaning pigs	9	10	19
Cycle 2			
No. animals started ^a	10	10	20
No. animals farrowing	9	8	17
No. animals weaning pigs	9	8	17
Cycle 3			
No. animals started	9	8	17
No. animals farrowing	7	6	13
No. animals weaning pigs	6	6	12

^aIncludes sows which did not complete their first lactation.

organs of the sow were found to be grossly normal with the following exception: an extreme accumulation of pericardial fluid, an area of suspected thickening of the stomach wall and edema. Since there was no evidence of hepatic necrosis or muscular degeneration and this animal was fed a diet supplemented with vitamin E, the diagnosis appeared to be correct.

Two sows fed the Vit E-Chol diet failed to rebreed at the first post-weaning estrus. Another sow was removed for non-nutritional reasons. Midway through the second gestation, one sow on the C-SBM diet became noticeably lame in her hind legs. This lameness continued to the extent that one week before her scheduled farrowing date, she was too crippled to get to her feet. Three days later, she farrowed a litter of 11 pigs averaging 1.15 kg each. All the pigs died due to agalactia and the sow was euthanased.

After weaning their second litter, two sows fed the Vit E-Chol diet, again failed to rebreed at the first estrus. One sow on the C-SBM diet, failed to conceive after weaning her second litter and another aborted her litter during the final week of the winter gestation. It was thought that this sow aborted her litter in self-defense against her extremely emaciated condition. Another sow on this dietary treatment, farrowed a litter of nine pigs averaging 1.08 kg each, but the litter was lost due to malnutrition from agalactia.

The low survival percentage (50.0%) at the end of the third reproductive cycle, for both diets, was in close agreement with the findings of Frobish et al. (1973). They had a survival rate of 46.0 and 52.5%, after three complete cycles, among sows fed 3.0 and 4.5 Mcal

ME/day, respectively. At those low energy intake levels, failure to conceive was the predominant cause. However, in that study, all sows were carried through a short two-week lactation and then rebred on the second post-weaning estrus. In the present study, sows were carried through a strenuous eight-week lactation and then rebred at the first estrus following weaning. Lidvall and Griffin (1962) and Hardy and Lodge (1969) reported higher conception rates following increased lactation feed intakes. Hitchcock et al. (1971b) reported no significant difference in the percentage of sows that conceived at the first estrus following weaning. Yet, only 79.3 and 86.7% of the sows fed to scale and fed ad libitum during lactation, respectfully, conceived for a second litter. Hawton and Meade (1971) observed higher incidences of conception failure on daily gestation protein intakes of 154.0 and 250.0 g than on 341.0 g for the second reproductive cycle. Thus suggesting, that the productive life of the sow was sensitive to dietary protein quantity and quality when low levels of protein were fed during gestation. However, Holden et al. (1968) had previously reported that a protein intake of 218.0 g/day during gestation had no effect on breeding performance through four successive gestations.

Weight and Weight Changes

The weights and weight changes for the five weight periods by diets and reproductive cycles, are shown in Table VIII. Gestation weights through the first two reproductive cycles were similar for both diets, although the sows fed the Vit E-Chol diet gained significantly ($P < .10$) more weight during the limited-feeding period of the second gestation (18.3 vs. 23.9 kg). Following weaning of the second litters, a weight

TABLE VIII. LEAST-SQUARES MEANS FOR GILT AND SOW WEIGHTS
AND WEIGHT CHANGES DURING THE REPRODUCTIVE CYCLE

Period	Diets		Avg For Cycle
	C-SBM Control	Vit E-Chol Suppl'd	
Weights, kg			
At end of trimester I			
1 ^a	127.6	129.0	128.3
2	149.7	146.1	147.9
3	165.8	159.2	162.5
At end of trimester II			
1	135.1	136.6	135.8
2	159.3	157.4	158.3
3	163.7	156.1	159.9
At end of trimester III			
1	142.9	143.0	142.9
2	168.0	170.2	169.1
3	169.2	158.9	164.0
Three weeks post-farrowing			
1	133.4	133.2	133.3
2	155.0	156.8	155.9
3	153.9 ^d	140.6 ^e	147.3
Weaning			
1	139.3	140.8	140.1
2	138.5	143.5	141.0
3	140.9 ^d	130.2 ^e	135.5
Gestation gain, kg			
Last two trimesters			
1	15.3 ^b	13.9	14.6
2	18.3 ^b	23.9 ^c	21.1
3	3.4	- 0.1	1.6
Total			
1	--	--	--
2	28.6 ^b	28.9	28.8
3	24.9 ^b	14.3 ^c	19.6

TABLE VIII (continued)

Period	Diets		Avg For Cycle
	C-SEM Control	Vit E-Chol Suppl'd	
Lactation weight change, kg			
Pre-partum to 3 weeks postpartum			
1	- 7.3 ^b	-12.7 ^c	-10.0
2	-14.7	-11.9	-13.3
3	-16.8	-18.3	-17.6
Pre-partum to weaning			
1	- 1.3	- 4.9	- 3.1
2	-29.5	-26.6	-28.6
3	-29.9	-28.7	-29.3
Reproductive cycle weight change, kg			
Last two-thirds gestation to weaning			
1	13.6	9.7	11.7
2	-11.2 ^d	- 2.7 ^e	- 7.0
3	-23.6	-28.9	-26.2
Total cycle			
1	--	--	--
2	- 0.8 ^d	2.2	0.7
3	- 3.2 ^d	-14.5 ^e	- 8.8

^aRefers to reproductive cycle one, two, and three, respectively.

^{b,c}Means within the same row, having different superscripts were significantly different ($P < .10$).

^{d,e}Means within the same row, having different superscripts were significantly different ($P < .05$).

differential developed between the two sow groups. The Vit E-Chol fed sows, rebred for their third litter, made smaller gains during the first trimester of the third gestation (21.5 vs. 14.5 kg). This weight difference persisted and increased slightly (3.5 kg), due to the greater weight gain of the C-SBM sows during the remainder of that pregnancy. The resulting total body weight gain during the last gestation was significantly ($P < .10$) greater for the sows on the C-SBM diet (24.9 vs. 14.3 kg). However, both of these gestation gains were less than those made in the previous summer gestation. Average cycle sow weights, at the end of second and third trimesters of the last winter gestation, were equal to or less than corresponding weights of the previous summer gestation. This was due to gravid sows failing to gain weight during the period of limited-feeding.

Gestation weights and gains reported in this study were generally lower than those reported by other investigators (Clawson et al., 1963; Frobish et al., 1966; Lodge et al., 1966b; Meade et al., 1966; Baker et al., 1969; and Frobish et al., 1973). For the entire gestation period, Vermedahl et al. (1969) reported an average daily gain of 0.25 kg in first litter gilts fed 1.36 kg/day, while in the present study daily gain was 0.19 kg. Over two reproductive cycles, Hawton and Meade (1971) found that daily protein intakes of 250.0 g or less did not cause significant cycle weight differences, but their gestation gains were larger. Season was not mentioned in that study and daily energy intake was approximately 1100.0 kcal ME higher.

Effect of season (temperature) on weight gain during gestation (influenced by maintenance requirements), in the present study, follow

closely the trend reported by Clawson (1968) for a similar gestation feed intake. In that study, sow gestation weight gains were 28.1, 33.6 and 5.9 kg for successive winter, summer and winter gestations, respectively. Those total gestation gains are larger than reported in the current study for a shorter period of limited-feed intake. However, the same trend was noted for greater body weight gain during the summer gestation, followed by a small winter gestation gain. Frape et al. (1971) also reported season (temperature) to have an effect on sow gestation empty live weight gain. Winter weight gain was only about half that observed in summer. The low rate of gestation feeding (1.8 kg/day) was also associated with low or negative gestation weight increases after the third to fourth litters.

Sow lactation weights, at three weeks and at weaning within each cycle were similar for the first two lactations, although the sows fed the Vit E-Chol diet did weigh more at weaning for the second litters (138.5 vs. 143.5 kg). During the third lactation, sows fed the C-SBM diet weighed significantly ($P < .05$) more three weeks postpartum and at weaning. This was apparently a continuation of the weight difference initiated during the gestation period, since total lactation weight loss (including products of conception) by each diet group was similar (-29.9 vs. -28.7 kg) for the C-SBM and Vit E-Chol fed sows, respectively. The first lactation weight loss was the smallest of the three lactations. Lodge et al. (1966b), Clawson (1968), and Baker et al. (1969) found that high gestation weight gains were followed by lower lactation weight increases. A breed difference, in lactation performance, was evidenced during the second lactation as Hampshire sows lost significantly

($P < .01$) more weight than Durocs.

Weight changes during the periods of controlled feeding (last two trimesters of gestation and lactation) indicate that the level of feed intake employed in this study was not adequate to maintain maternal body weight. Some maternal growth occurred during the first reproductive cycle, but weight losses were experienced during the last two cycles. Significantly ($P < .05$) less weight was lost by sows fed the Vit E-Chol diet (-11.2 vs. -2.7 kg) during the second reproductive cycle. In the third cycle, the opposite occurred, but the difference was non-significant. Average third cycle weight loss, for the periods of limited-feeding, was nearly four times that lost during the preceding summer reproductive cycle (-26.2 vs. -7.0 kg, respectively).

When weight change for the entire reproductive cycle is considered, the first trimester of gestation interval had a significant influence on sow body weight change. This information was not available for the first reproductive cycle since the gilts were not weighed at breeding. For the second reproductive cycle, sows fed the C-SBM diet gained significantly ($P < .05$) more weight during the initial trimester (10.4 vs. 4.8 kg). During the third gestation, corresponding trimester sow weight gains were twice as large as those in the previous gestation for both diet groups. The smaller gain (21.5 vs. 14.5 kg) by the sows fed the Vit E-Chol diet was reflected in their significantly ($P < .05$) greater total cycle weight loss (-3.2 vs. -14.5 kg), compared to those fed the C-SBM diet. Consequently, in this last winter cycle, a negative weight balance occurred for both diet groups; whereas, the total weight change for the second reproductive cycle was slightly positive in favor of the

Vit E-Chol fed sows. The low sow weights at the end of the third lactation were further evidence that level of daily feed intake used in this study was inadequate to allow for maternal growth through three successive reproductive cycles. While these weaning weights are slightly larger than initial gestation first trimester weights, only the C-SBM fed sows made a substantial total body weight gain through three reproductive cycles. Yet, this net gain (13.3 kg) is less than half the 32.0 kg suggested by Lodge et al. (1966b) to be needed from first service to the third weaning. Clawson (1968) observed a 45.6 kg increase in body weight at the end of the third reproductive cycle, but his sows were liberally fed during lactation.

During the second reproductive cycle, Hampshire sows lost significantly ($P < .05$) more weight than Duroc sows, for the periods of limited-feeding and for the total cycle.

Condition (Backfat) Changes During the Reproductive Cycle

Condition of the gravid and lactating sows (gilts), as evaluated by ultrasonic estimates of backfat thickness, is presented in Tables IX and X. Measurements of backfat depth, shown in Table IX, were the average of three measurements taken at the first-rib, last-rib, and last-lumbar vertebrae for the first and second fat layers. Only the first and second layers were measured, since a high correlation has been observed between ultrasonic and carcass measurements for these two fat layers and for estimates of carcass composition (Meyer et al., 1966; Moody and Zobrisky, 1966; and Jones, 1971). A third fat layer was detected in only a few of the sows during lactation and during the third

TABLE IX. LEAST-SQUARES MEANS FOR ULTRASONIC ESTIMATES OF GILT AND SOW BACKFAT DEPTH DURING REPRODUCTIVE CYCLES

Period	Diets		Avg For Cycle
	C-SBM Control	Vit E-Chol Suppl'd	
At the end of trimester I			
1 ^a	20.7 ^b	22.7	21.7
2	17.2	17.2	17.2
3	21.6	20.8	21.2
At the end of trimester II			
1	23.0 ^c	25.2 ^d	24.1
2	18.7	18.7	18.7
3	20.0	18.6	19.3
At the end of trimester III			
1	18.1	19.5	18.8
2	20.6	22.0	21.3
3	17.0	15.2	16.1
Three weeks post-farrowing			
1	16.2	16.6	16.4
2	20.0	20.2	20.1
3	16.1	13.7	14.9
Weaning			
1	15.4	15.6	15.5
2	18.0	18.4	18.2
3	14.8	12.4	13.6

^aRefers to reproductive cycle one, two, three, respectively.

^bMeans were the average of three measurements taken at the first rib, last rib and last lumbar vertebrae for the first and second fat layers.

^{c,d}Means within the same row, having different superscripts were significantly different ($P < .05$).

TABLE X. LEAST-SQUARES MEANS FOR OVERALL ULTRASONIC ESTIMATES OF BACKFAT LAYER DEPTHS DURING REPRODUCTIVE CYCLES

Site of Measurement	Trimester of Gestation			Lactation	
	1	2	3	Three Wks	Weaning
First Reproductive Cycle					
First rib, layer 1 ^a	14.5	17.6	12.9	11.9	11.4
First rib, layer 2	10.5	9.8	9.0	7.5	7.2
Last rib, layer 1	12.2	15.5	11.1	10.0	9.5
Last rib, layer 2	6.4	5.4	5.2	3.6	3.2
Last lumbar, layer 1	13.8	17.5	12.5	11.6	11.0
Last lumbar, layer 2	7.6	6.4	5.6	4.7	4.4
Average total (layers 1+2) for three sites	21.7	24.1	18.8	16.4	15.5
Second Reproductive Cycle					
First rib, layer 1	11.8	13.0	15.7	15.8	15.1
First rib, layer 2	8.4	9.4	10.8	9.0	6.8
Last rib, layer 1	10.3	11.2	12.2	12.2	11.9
Last rib, layer 2	3.9	4.2	4.6	4.3	2.9
Last lumbar, layer 1	12.2	13.1	15.1	14.5	13.8
Last lumbar, layer 2	5.1	5.4	5.6	4.4	4.1
Average total (layers 1+2) for three sites	17.2	18.7	21.3	20.1	18.2
Third Reproductive Cycle					
First rib, layer 1	17.4	16.1	13.8	12.9	11.6
First rib, layer 2	7.8	7.0	5.5	4.6	4.8
Last rib, layer 1	13.2	12.3	10.9	10.4	9.3
Last rib, layer 2	4.6	3.6	2.5	2.2	2.2
Last lumbar, layer 1	15.2	14.0	12.3	11.2	10.2
Last lumbar, layer 2	5.4	4.8	3.2	3.5	2.8
Average total (layers 1+2) for three sites	21.2	19.3	16.1	14.9	13.6

^aBackfat layer depths are expressed in millimeters.

gestation as indicated by the extremely thin second fat layers (Table X).

During the first two reproductive cycles, there was an increase in backfat thickness through part or all of the gestation period, followed by a steady decline during lactation. The largest increase for the limited-feeding period occurred during the summer gestation, being 3.4 and 4.8 mm increases for the C-SBM and Vit E-Chol diets, respectively. The increases in backfat depth during the first gestation (winter) ceased, going into the third trimester. During this trimester, the cycle average backfat thickness decreased by 5.2 mm. Therefore, for the period of limited-feed intake (last 2/3 gestation), there was actually a net loss in backfat thickness. Average mean temperature for the last trimester was 4.1°C, which could explain the decline in backfat. Increased maintenance requirements, due to low ambient temperature, may have caused adipose tissue to be utilized as a source of energy. This was essentially the hypothesis put forth by Elsley et al. (1968) when they found only 10.3 mm of carcass backfat in sows slaughtered on the 100th day of their fourth pregnancy. Their sows had been fed 1.36 kg feed/day during the preceding gestations.

During the third gestation of the current study, there was a progressive reduction in backfat thickness after the 1.36 kg/day level of feed intake was imposed. Sows fed the Vit E-Chol diet experienced a more rapid rate of backfat depletion. Elsley et al. (1968) stated that continued mobilization of adipose tissue could eventually lead to reduced reproductive performance. This was manifested in the current study by the reduced birth weights, which will be discussed later. Failure of

both sow diet groups to increase or maintain their condition during the last gestation was found to be significantly correlated ($r = 0.83$, $P < .01$), with low gestation gains for the period of limited-feed intake. Other investigations (Dean *et al.*, 1958; Waldorf *et al.*, 1958; Dean and Tribble, 1961; and Frape *et al.*, 1971) have reported similar decreased backfat thickness with low gestation gains. At each of the first gestation measurement periods, the Duroc gilts had significantly ($P < .05$) more backfat than did Hampshire gilts. However, no further significant differences were measured between the two breeds for the last two gestations.

Figure 2 shows a third litter Duroc sow, two weeks pre-partum, that had been fed the C-SBM diet during gestation at the 1.36 kg/day level of feed intake.

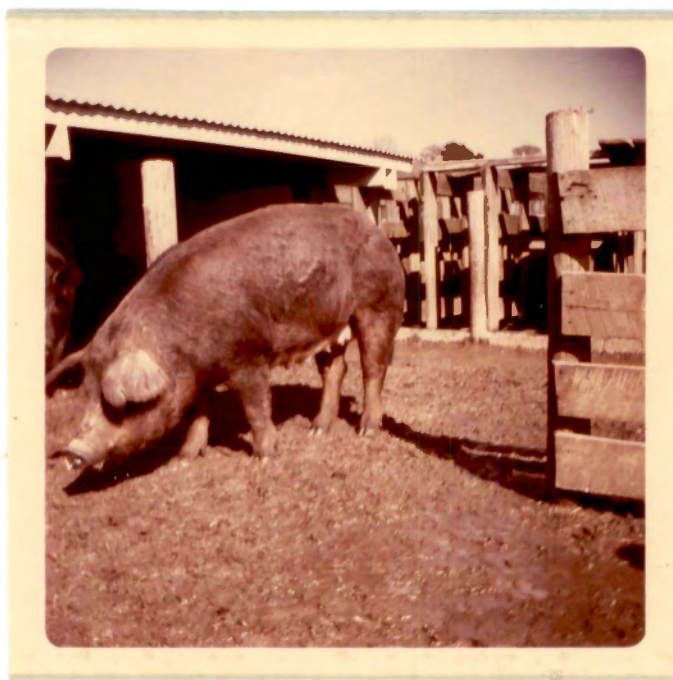


FIGURE 2. Third litter Duroc sow, two weeks pre-partum, fed 1.36 kg/day of the 16.0% corn-soybean meal diet.

Typical of the sows in this study, signs of pregnancy were not readily observed. This animal shows only slight bulging of the sides, some lowering and filling of the abdominal cavity from products of conception and some indication of udder development for the forthcoming lactation. However, these indications of pregnancy were not easily recognizable, especially prior to the first farrowing.

Towards the end of the last gestation period, apparent low energy intake caused the sows to have a listless and dull appearance and there was a noticeable grinding of the teeth. These conditions, plus the low gestation gains, were in agreement with the description for "thin sow syndrome," reported by Maclean (1968). During this gestation, there was observed an excessive amount of urination by the sows, which contributed to keeping the bedding and floors damp. Craving thirst resulting in excess urination was another symptom of the "thin sow syndrome" (Maclean, 1968).

After farrowing, backfat depths declined during each of the three lactations with the reduction least noticeable in the second (summer) lactation. During the first three weeks of the initial lactation, sows fed the Vit E-Chol diet lost significantly more backfat than those fed the C-SBM diet. Sows fed this diet during the last lactation became extremely thin, possessing little backfat as evident in Figure 3. This third litter sow, in foreground, is shown at the end of a three-week lactation period. She had less than 10.0 mm of backfat at this time, was nursing nine pigs and was receiving 5.40 kg feed/day.

Significant breed differences in backfat thickness were measured during the lactation periods. Duroc sows lost significantly ($P < .10$)



FIGURE 3. Top view of third litter Hampshire sow shown in foreground at the end of a three-week lactation when fed 1.36 kg/day + 0.45 kg/pig nursing of the Vit E-Chol diet.

more backfat than Hampshire sows during the first and third lactations, with the largest loss occurring during the first three weeks of lactation ($P < .05$). Hampshire sows had 4.0 mm less backfat ($P < .05$) than the Duroc sows at each of the second lactation measurement periods. Table X, page 92, shows the overall means for ultrasonic estimates of individual backfat layer depths measured periodically during the reproductive cycle. From these measurements, it was noted that backfat layer two decreased throughout the first and third reproductive cycles. This decline was made regardless of whether the first layer increased or decreased in depth. It was only during the second cycle that any increase

in the second layer was measured. This reproductive cycle had the highest average daily temperature during gestation. The thicker first fat layer depths in this study were in agreement with the findings of Jones (1971). However, rate of increase by the second fat layer in the present study was not faster than the first layer as reported, by Moody and Zobrisky (1966). The current thin layers of backfat, measured at the third farrowing, were not as extreme as those reported by Elsley et al. (1968) in fourth litter sows slaughtered shortly before farrowing.

Elsley et al. (1966a) and Kline et al. (1972) have observed reduced backfat thickness in pregnant gilts compared to nonpregnant ones at daily feed intakes of 1.82 to 2.20 kg. Thus, it would seem that pregnant swine utilize exogenous dietary energy intake, first, for products of conception and, secondly, for maternal energy store (backfat). Baker et al. (1969) proposed an increased maternal fat synthesis at gestation feed intakes above 1.9 kg/day. Therefore, if it is accepted that the second fat layer is closely associated with total backfat thickness and the most reliable layer in the live hog for estimation of fat and lean (Meyer et al., 1966), then changes in the depth of the second fat layer could indicate a change in the composition of the sow. In the pregnant sow, discontinued adipose tissue deposition in the second fat layer could connote an inadequate energy intake for continued maternal growth subsequent to fetal needs.

II. PARTURITION DATA

Parturition data in terms of pigs farrowed per litter, average birth weights, and average litter weights are shown in Table XI. During

TABLE XI. LEAST-SQUARES MEANS FOR LITTER PARTURITION DATA

Parameter	Diets		Avg For Cycle
	C-SBM Control	Vit E-Chol Suppl'd	
Total pig/litter			
1 ^a	8.3	8.5	8.4
2	8.8	8.6	8.7
3	10.1	11.3	10.7
Live pigs/litter			
1	7.4	7.6	7.5
2	8.6	8.6	8.6
3	9.8	10.2	10.0
Avg birth weight of all pigs, kg			
1	1.16	1.16	1.16
2	1.36 _d	1.40 _e	1.38
3	1.25 ^d	1.08 ^e	1.17
Avg birth weight of live pigs, kg			
1	1.17	1.18	1.17
2	1.38 _b	1.40 _c	1.39
3	1.25 ^b	1.10 ^c	1.17
Litter weight of all pigs, kg			
1	9.56	9.64	9.60
2	11.81	12.07	11.94
3	12.57	12.16	12.37
Litter weight of live pigs, kg			
1	8.60	8.81	8.70
2	11.68	12.07	11.87
3	12.27	11.30	11.78

^aRefers to reproductive cycles one, two, and three, respectively.

^{b,c}Means within the same row, having superscripts were significantly different ($P < .10$).

^{d,e}Means within the same row, having superscripts were significantly different ($P < .05$).

the first two reproductive cycles, neither of the two gestation diets had a significant effect on total (8.3, 8.8 vs. 8.5, 8.6) or live pigs (7.4, 8.6 vs. 7.6, 8.6 kg) farrowed per litter, nor on average birth weights of total (1.16, 1.36 vs. 1.16, 1.40 kg) and live pigs (1.17, 1.38 vs. 1.18, 1.40 kg) farrowed per litter for sows fed C-SBM and Vit E-Chol diets, respectively. However, more stillborn pigs were farrowed at the first farrowing compared to the second. Hampshire pigs, born at these two farrowings were significantly ($P < .05$) heavier than the Duroc pigs.

Over the three reproductive cycles, there were continued increases in total and live pigs farrowed. The number of total pigs farrowed per litter by third litter sows fed the Vit E-Chol diet, while larger by 1.2 pigs/litter was not statistically different from the 10.1 average litter size for the C-SBM sows. However, the number of pigs stillborn per litter was significantly ($P < .10$) higher among litters from sows fed the Vit E-Chol diet. Davidson (1930) reported the proportion of ova accounted for by live pigs at birth, was not reduced by low protein intake during gestation. More recently, the amount of protein in the gestation diet has been shown to have little effect on litter size (Clawson et al., 1963; Rippel et al., 1965b; Holden et al., 1968; Pond et al., 1968b, 1969; Baker et al., 1970b; Hesby et al., 1970b; and Hawton and Meade, 1971). This was not in agreement with Vermedahl et al. (1969) who reported that feeding gilts 1.36 kg feed/day (4,400.0 kcal ME) resulted in a significant reduction in total pigs farrowed per litter, but not in number of live pigs per litter. A significant reproductive cycle effect for total and live pigs farrowed was observed by Frobish et al. (1973) with

increasing daily energy intakes (3.0 to 7.5 Mcal ME). After a marked increase in litter size between the first and second reproductive cycles, there was a decrease between the second and third cycles, except for an energy intake of 4.5 Mcal ME/day. At this level, both total and live pigs farrowed per litter increased through the three cycles.

At the third farrowing, there were statistically significant differences between the two diets for average birth weight of total pigs per litter (1.25 vs. 1.08 kg, $P < .05$) and live pigs per litter (1.25 vs. 1.10 kg, $P < .10$) in favor of the heavier pigs from sows fed the C-SBM diet. The sow was apparently unable to buffer her litter against continued low energy intake into this gestation, as indicated by lighter offspring birth weights of both diet groups, compared to previous summer birth weights. It has been shown in this study, that maternal weight gain and backfat thickness were severely affected by the limited-feed intake of the last gestation (Tables VIII, IX and X, pages 85, 91 and 92, respectively). Hanson et al. (1953); Clawson and Barrick (1962); Hensen et al. (1964); Lodge et al. (1966a); O'Grady (1967); Baker et al. (1969); and Elsley et al. (1969) have reported that the sow is less able to protect the litter against an energy deficiency than a protein deficiency. Lodge et al. (1966a) and Frobish et al. (1973) did not report a significant decrease in birth weights of third litter pigs from sows fed similar energy intake levels as used in the present study.

The observed lighter birth weights, at the third farrowing, could be a partial reflection of the increased litter size rather than an energy effect per se. Lodge et al. (1966a) reported a significant linear increase in number of pigs born with successive parities, but no parity

effect for birth weight. The lower third litter average birth weight of the Vit E-Chol pigs agreed with the three litter average birth weight (1.09 kg) reported by Lodge et al (1966a) for pigs from sows fed the same level of dietary intake. Frape et al (1971) reported, however, that birth weight per pig increased with increasing gestation weight gain, independent of litter size at birth ($P < .001$), but declined with increasing litter size at birth ($P < .001$). Other reports (Salmon-Legagneur and Rerat, 1962; Clawson et al., 1963; Frobish et al., 1966; Mayrose et al., 1966; Meade et al., 1966; O'Grady, 1967; and Baker et al., 1969) have demonstrated gestation weight gain to have little effect on litter size at birth, but birth weight was influenced in some investigations. Lodge (1969) found that it was the stage of pregnancy when gestation gains were made rather than the total amount that affected birth weights. Yet, Mayrose et al. (1966) and Anderson and Wahlstrom (1970) did not obtain increased pig birth weights from elevated energy intakes during last third of gestation.

Through the three current reproductive cycles, birth weights were significantly correlated with maternal gestation weight gains ($r = 0.42$, $P < .01$). Failure of the sows to increase or maintain their condition during the last two-thirds of gestation, as measured by backfat depths, was also significantly correlated with pig birth weights ($r = 0.50$, $P < .01$). Therefore, as backfat and gestation weight gains increased, a corresponding increase in birth weights could be expected to occur under the conditions of this study.

For birth weights to be responding to a low protein intake during the last gestation, a protein deficiency would apparently need to have

occurred during the first trimester, at the time of implantation (Strachan et al., 1968; and Pond et al., 1969). These researchers reported that birth weights and postnatal growth of progeny, from gilts given transitory protein levels at implantation of blastocyst, were greater than those of gilts deprived of protein during this period or throughout gestation. Over four successive gestations, Holden et al. (1968) have shown that protein levels of 218.0 and 291.0 g/day had no significant ($P < .05$) effect on birth weights, compared to lower and higher protein levels with adequate energy intake (5915.0 kcal ME/day). If there was a protein deficiency during the last gestation, then it could have been expected to manifest itself during the first few weeks of lactation, when a negative nitrogen balance would have been more likely to occur (Mahan et al., 1971b). At such times, maternal protein sources would be utilized for milk production. Serum-protein data and nitrogen balance trials have been used to determine the protein status of the sow during gestation, in response to quantity and quality of dietary protein (Mitchell et al., 1931; Rippel et al., 1965a; Miller et al., 1969a; Hesby et al., 1970a; and Kline et al., 1972). Since such determinations were not conducted in the present study, maternal nitrogen stores at farrowing were unknown.

Average litter weights of both total and live pigs tended to be heavier in litters from sows fed the Vit E-Chol diet, except at the last farrowing. Palmer et al. (1970) reported significantly heavier litters at birth due to the inclusion of fish meal in the gestation diet.

III. INCIDENCES OF THE MMA COMPLEX AND SPRADDLED-LEGS

Before discussing the sow lactation performance, as measured by progeny survival and growth, it seems appropriate to look at the incidences of the MMA Complex and the spraddled-leg condition (Table XII). Cases of MMA were identified by the clinical symptoms proposed by Peterson et al. (1969).

From the table, it is evident that MMA was equally associated with both diets during each reproductive cycle. However, a smaller percentage of the sows had the complex at the first farrowing than at the last two (31.8, 94.1 and 92.3%, respectively). Ullrey et al. (1970, 1971) reported a lower incidence of MMA in vitamin E supplemented sows. The low occurrence of MMA at the first farrowing could be reflecting a failure of the new herdsman to recognize the condition. Another possible explanation is that at the initial farrowing, each animal was intramuscularly injected with 10 cc Terramycin² for three consecutive days before farrowing, and sow rectal temperatures were not taken post-partum. These two practices could conceivably have lowered the incidence of MMA since metritis, as diagnosed by vaginal discharge and high rectal temperature, was evident in 70.6 and 38.5% of the sows at the last two farrowings, respectively. However, Martin et al. (1967) have reported that vaginal discharge does not necessarily denote histological evidence of metritis. Of 18 MMA affected sows, 94.5% had a vaginal discharge, but only 11.0% were histologically positive for metritis. Mastitis

²Pfizer oxytetracycline HCl product.

TABLE XII. RELATION BETWEEN DIETARY TREATMENT AND OBSERVED INCIDENCE OF MASTITIS -
METRITIS - AGALACTIA (MMA) AND THE SPRADDLED-LEGS CONDITION

Repro- ductive Cycle	Diets	No. of Litters	Number of Observations of						Myoclonia _b Congenita	Spraddled Legs
			Mastitis	Metritis	Agalactia ^a	Hypogalactia	MMA			
1	C-SBM control	10	2	2	0	3	4	1	2	
	Vit E-Chol suppl'd	12	1	0	0	3	3	4	1	
	Total for cycle	22	3	2	0	6	7	5	3	
2	C-SBM control	9	2	5	0	6	8	0	0	
	Vit E-Chol suppl'd	8	1	7	0	4	8	0	0	
	Total for cycle	17	3	12	0	10	16	0	0	
3	C-SBM control	7	4	3	1	4	6	0	1	
	Vit E-Chol suppl'd	6	5	2	0	2	6	0	0	
	Total for cycle	13	9	5	1	6	12	0	1	
Overall Total		52	15	19	1	22	35	0	4	

^aDoes not include those with hypogalactia.

^bCommonly referred to as shaker pigs.

occurred more frequently during the third reproductive cycle, and the frequency of metritis tended to be less.

Varying levels of hypogalactia were evident at each farrowing. The smallest number of sows were affected in the initial farrowing, as compared to the second and third parturitions 27.3, 58.8 and 46.2%, respectively. Sows fed the C-SBM diet during gestation and lactation tended to have a higher incidence of this condition. Results were in agreement with the finding of Ullrey et al. (1971), although in their study, vitamin E, selenium and choline supplemented diets were compared to the controls.

One case of complete agalactia occurred at the last farrowing in a sow fed the C-SBM diet. This sow farrowed a litter of nine small pigs averaging 1.08 kg each, but could not be induced to give milk to nourish the litter.

During the duration of the experiment, there were four cases of the spraddled-leg condition. Three litters at the first farrowing and one at the last had one or more pigs affected. Additional choline in the Vit E-Chol diet may have helped lower the incidence of this condition, because only one case was observed among litters from sows fed diets containing added choline. Daily choline intake by these sows was over 3000.0 mg, while that of sows fed the C-SBM diet was 1370.0 mg/day. The higher daily choline intake was the level suggested by Cunha (1972) to prevent spraddled legs. Slightly higher daily choline intake levels (1400.0 to 1500.0 mg) than fed in the current C-SBM diet have failed to result in the spraddled-leg condition (Teague et al., 1972; and Kornegay and Meacham, 1973). However, choline itself may not be entirely

responsible for preventing spraddled legs. Adamstone et al. (1949) and Trapp et al. (1970) have both reported that supplemental vitamin E may have a role in preventing this condition.

At the first farrowing, several of the litters had pigs exhibiting myoclonia congenita. This is a condition of the newborn pig where they shake, bounce, tremble or shiver to such an extent that they can have difficulty in nursing. It is believed that the condition may be heritable, although Stromberg and Kitchell (1958) were more inclined to believe that the sire plays a role in transmission of this disease by contact rather than genetically. In this study, the litters showing this condition were all sired by the same boar. However, in subsequent farrowings where the same boar was used at breeding, there was no recurring evidence of the disease. Since more pigs from the Vit E-Chol fed sows had the conditions, a nutritional link could exist. However, Stromberg and Kitchell (1958), in their investigation could find no support for the theory that the disease was associated with inadequate nutrition.

IV. LACTATION DATA

Litter performance data, to three weeks of age and from three weeks to weaning, are shown in Tables XIII, XIV, and XV, respectively. In this study, the effects of limited maternal dietary intake on the growth of the progeny cannot be completely separated from the sow lactation treatment. This is due to the continued limited-feeding schedule practiced during lactation. Instead, offspring lactation response must be viewed in terms of a continued diet and management program,

TABLE XIII. LEAST-SQUARES MEANS FOR LITTER-LACTATION
PERFORMANCE TO THREE WEEKS OF AGE

Parameter	Diets		Avg For Cycle
	C-SBM Control	Vit E-Chol Suppl'd	
Average litter size ^a			
1 ^b	4.7	4.3	4.5
2	5.1	6.0	5.5
3	6.9	7.3	7.1
Litter weight, avg, kg			
1	19.57	20.08	19.83
2	27.47	29.27	28.37
3	37.03 ^d	32.91 ^e	34.97
Average pig weight, kg			
1	4.61	4.84	4.73
2	5.19	5.29	5.24
3	5.34	4.71	5.03
Litter gain, avg, kg			
1	10.89	11.43	11.16
2	15.04	18.10	16.57
3	24.07	22.02	23.04
Pig gain, avg, kg			
1	3.42	3.59	3.50
2	3.81	3.90	3.86
3	4.09	3.60	3.84
Percent mortality, birth to 3 weeks ^c			
1	40.47	40.61	40.54
2	39.02	34.16	36.59
3	30.57	29.45	30.01

^aTwo pigs per litter were sacrificed at birth for chemical analyses.

^bRefers to reproductive cycle one, two, and three, respectively.

^cIncludes the two sacrificed pigs per litter.

^{d,e}Means within the same row, having different superscripts were significantly different ($P < .10$).

TABLE XIV. LEAST-SQUARES MEANS FOR LITTER RESPONSE
THREE WEEKS TO WEANING

Parameter	Creep Diets ^a				Avg For Cycle
	(3) 16% C-SBM Control	(5) 16% Vit E-Chol Suppl'd	(4) 20% C-SBM Control	(6) 20% Vit E-Chol Suppl'd	
Number weaned/litter ^b					
1 ^c	3.5	4.6	3.8	3.7	3.9
2	3.7	5.7	5.5	7.1	5.5
3	6.8	7.0	--	--	7.9
Avg weaning weight, kg					
1	15.54	17.23	8.10	13.01	13.47
2	16.92	14.39	14.36	14.62	15.07
3	17.06	16.36	--	--	16.71
Avg pig gain, 3 wks to weaning, kg					
1	10.63	11.82	4.62	8.42	8.87
2	11.07	9.16	9.55	9.33	9.78
3	11.74	11.62	--	--	11.68
Avg pig gain, birth to weaning, kg					
1	14.37	16.02	6.93	11.78	12.27
2	15.52	13.07	12.99	13.15	13.68
3	15.79	15.24	--	--	15.51
Creep consumption/pig, kg					
1	11.46	18.47	1.71	6.71	9.58
2	8.58	6.40	6.37	8.57	7.48
3	20.86	19.23	--	--	20.04
Creep consumption/kg pig gain					
1	0.39	0.54	0.20	0.28	0.35
2	0.26	0.24	0.24	0.31	0.26
3	0.60	0.59	--	--	0.60
Sow feed/pig weaned, kg					
1	63.67	69.86	52.38	56.96	60.72
2	41.98	42.91	39.79	43.74	42.10
3	46.25	45.98	--	--	46.12

TABLE XIV (continued)

Parameter	Creep Diets ^a				Avg For Cycle
	(3) 16%	(5) 16%	(4) 20%	(6) 20%	
	C-SEM Control	Vit E-Chol Suppl'd	C-SEM Control	Vit E-Chol Suppl'd	
Sow feed/kg pig weaned					
1	1.47	1.46	3.43	1.88	2.06
2	1.21	1.37	1.32	1.29	1.30
3	1.03	1.08	--	--	1.05

^aCreep diets are described in Table V, page 71.

^bTwo pigs per litter were sacrificed at birth for chemical analyses.

^cRefers to reproductive cycle, one, two, and three, respectively.

TABLE XV. ANALYSIS OF VARIANCE FOR LITTER RESPONSE THREE WEEKS TO WEANING

Source ^a	d.f.	Mean Squares							
		Pig Gains		Creep Feed Consumption		Sow Feed Consumption			
		3 Wks to Weaning	Birth to Weaning	Avg Per Pig	Per Kg Pig Gain	Avg Per Pig	Per Kg Pig Weaned		
First Reproductive Cycle									
Creep	3	52.595***	33.52***	52.550***	189.49***	0.0850***	221.41**	2.718***	
Comparison 1	1	6.544	3.79	6.501	114.62**	0.0525*	83.55	0.002	
Comparison 2	1	42.340***	26.53***	40.189***	59.48*	0.0261	31.96	3.497***	
Comparison 3	1	129.978***	82.92***	129.752***	587.32***	0.3151***	795.56***	4.453***	
Breed	1	39.984***	28.22***	45.612***	167.30**	0.0494*	47.90	1.443**	
Creep X Breed	3	4.626	3.74	4.538	10.89	0.0290	62.88	0.673*	
Litter Size	1	44.975***	17.95***	46.433***	100.60**	0.0142	3741.22***	1.213**	
Residual	10	3.850	1.67	3.696	17.34	0.0126	53.83	0.224	
R ²		0.85***	0.89***	0.86***	0.83***	0.80**	0.90***	0.84**	
Second Reproductive Cycle									
Creep	3	2.227	0.77	1.973	6.01	0.0043	11.12	0.012	
Comparison 1	1	1.605	1.04	1.619	4.58	0.0012	2.80	0.026	
Comparison 2	1	5.890	1.78	4.728	16.52	0.0103	7.80	0.033	
Comparison 3	1	0.124	0.47	0.005	0.72	0.0010	4.30	0.004	
Breed	1	13.542*	2.24	9.873*	0.05	0.0016	55.63**	0.004	
Creep X Breed	3	1.187	0.66	0.884	0.30	0.0008	17.60	0.019	
Litter Size	1	4.777	3.92	5.192	4.42	0.0014	471.54***	0.201**	
Residual	8	2.901	1.54	2.781	7.39	0.0056	8.78	0.021	
R ²		.68	0.66	0.66	0.32	0.29	0.94***	0.68	

TABLE XV (continued)

Source ^a	d.f.	Mean Squares							
		Pig Gains		Creep Feed Consumption		Sow Feed Consumption			
		3 Wks to Weaning	Birth to Weaning	Avg Per Pig	Per Kg Pig Gain	Avg Per Pig	Per Kg Pig Weaned		
		Third Reproductive Cycle ^b							
Creep	1	1.308	0.04	0.797	7.00	0.0002	0.195	0.006	
Breed	1	2.736*	1.75**	2.132	0.07	0.0016	0.069	0.005	
Creep X Breed	1	0.006	0.83	0.045	1.89	0.0060	4.246	0.004	
Litter Size	1	34.914***	26.34***	34.235***	82.76***	0.0012	89.549***	0.035**	
Residual	7	0.674	0.26	0.670	3.20	0.0033	4.807	0.006	
R ²		0.89***	0.94***	0.89***	0.83***	0.33	0.76**	0.53	

^aOrthogonal comparisons are described in Table VI, page 79.

^bOrthogonal comparisons were not used since there were only two creep diets.

*P < .10.

**P < .05.

***P < .01.

subsequent to the gestation treatment. Furthermore, Frape et al. (1971) suggested the possibility that greater milk production, following winter pregnancies, may occur as a consequence of low temperature stimulation of the thyroid gland.

Litter Performance to Three Weeks of Age

During the first two lactations, small litter sizes at three weeks postpartum were due, in part, to the two pigs per litter, sacrificed, at birth for whole body composition analyses. There were also lower pig survival rates during these two lactations, compared to the last (59.5, 63.4, 70.0%, respectively). No statistically significant differences between the two diets were indicated for average litter size. Yet, during the last two reproductive cycles, size of an average litter was larger by 0.9 and 0.4 pigs, respectively, for litters nursing sows fed supplemental vitamin E. This is in agreement with reports of Ullrey et al. (1970, 1971) who attributed higher pig survival, at three weeks, to supplemental vitamin E in the gestation diet. Kornegay and Meacham (1973) however, found no significant difference in the number and weight of pigs weaned per litter from choline addition to the gestation diet. Hitchcock et al. (1971b) reported that a limited vs. ad libitum lactation feeding treatment for the sow did not affect number of pigs at 21 or 49 days of age. A non-significant increase in litter size at two and six weeks of age was reported by Palmer et al. (1970) among litters from sows fed fish meal compared to soybean meal supplemented diets.

Average pig weights at three weeks did not differ significantly ($P > .10$) during any of the three lactations, even though pigs nursing sows fed the Vit E-Chol diet were slightly heavier in the first two reproductive cycles. However, at the third lactation, pigs nursing sows fed the C-SBM diet were 0.63 kg heavier ($P > .10$) due to the Vit E-Chol pigs not maintaining their higher lactation gains seen in the first two cycles. Miller et al. (1970) found that supplemental maternal vitamin E did not significantly influence weight of the offspring at three weeks. The average three week weights were less than those reported by Vermedahl et al. (1969), and Hitchcock et al. (1971b), but agree with weights reported by Baker et al. (1969, 1970a). Average litter weights at the end of the three week lactation period followed the same trend set by the pig weights. However, litters nursed by sows fed the C-SBM diet were significantly ($P < .10$) heavier in the third reproductive cycle, despite the larger size of the Vit E-Chol litters. This could be an indication that sacrifice of maternal tissue for fetal growth may have impaired the use of maternal labile protein for lactation as reported by Rippel et al. (1965a,b); Pond et al. (1968b, 1969); Strachan et al. (1968); and Baker et al. (1970b). Sows fed the Vit E-Chol diet did not increase their body weight, including the products of conception, during the period of limited-feeding in the last gestation. Furthermore, they experienced a weight loss during the second trimester (-3.06 kg), but regained most of this during the last trimester (2.84 kg), when the greatest increase in fetal growth occurs (Moustgaard, 1962; and Hansard, 1965). Since average birth weight of the Vit C-Chol litters was 12.16 kg, it would seem that maternal protein sources may have been used for

fetal growth during the last pregnancy. If this did occur, a negative nitrogen balance during the first three weeks of lactation may have resulted in reduced milk production. Mahan et al. (1971a,b) concluded nitrogen equilibrium to be necessary to obtain maximum milk production, milk nitrogen and weaning weights. With a negative nitrogen balance, sows compensate by catabolizing body protein tissue, but are unable to compensate indefinitely. Furthermore, Mahan et al. (1971b) calculated that 640.0 g protein daily was required for second-litter sows fed 4.0 kg/day to maintain nitrogen equilibrium from day 14 to 19 postpartum. In the current study, third litter sows fed the Vit E-Chol diet, received approximately 775.0 g crude protein/day. This protein level was slightly less than the 750.0 g protein/day recommended by MacPherson et al. (1969) for lactating third litter sows fed 240.0 g protein/day during gestation.

Hesby et al. (1970a) have shown that the loss in weight during lactation was inversely proportional to the sow weight gain during gestation. However, when dietary protein was lacking in quantity and quality during lactation, as well as gestation, increased sow weight loss during lactation indicated a greater demand for protein during lactation (De Geeter et al., 1972). If this protein was not stored in maternal labile reserve, it must come from the diet.

Average reproductive cycle pig weights and pig gains to three weeks of age increased through the first two cycles, but failed to increase during the third lactation because of poor performance of baby pigs nursing Vit E-Chol fed sows. Duroc pigs gained significantly ($P < .05$) more weight during the first lactation; while in the second

lactation, Hampshire pigs gained more and were heavier ($P < .05$) at three weeks. No statistically significant breed differences for three week pig weight and gain were found during the third lactation.

Smith (1959), Lidvall and Griffin (1962), Parker and Clawson (1967), Elsley et al. (1969), Vermedahl et al. (1969) and Hitchcock et al. (1971b) concluded that level of feeding imposed during lactation had no significant effect on progeny, lactation gain or pig weaning weight. However, Baker et al. (1969) and Frobish et al. (1973) indicated progeny growth to be significantly influenced by level of diet intake during gestation. Frape et al. (1971) have suggested milk production to be equally affected by extra feed intake during pregnancy or lactation, as measured by three week litter size and pig weights.

Litter Performance Three Weeks to Weaning

Table XIV, page 108, shows progeny response to four different creep diets for the period from three weeks of age to weaning. For this phase of lactation, progeny growth was evaluated by orthogonal comparisons to assess differences due to creep diets fed. The creep comparisons were:

1. A 16.0% protein creep (3) version of the C-SBM gestation diet compared to a 16.0% protein creep (5) version of the Vit E-Chol gestation diet.
2. A 20.0% protein creep (4) version of creep 3 compared to a 20.0% protein creep (6) version of creep 5 containing 10.0% dried skim milk and 10.0% sucrose.
3. Creep diets 3 and 5 (16.0%) compared to mean of creep diets 4 and 6 (20.0%).

Orthogonal comparisons were not used during the last reproductive cycle, since only two creep diets (3 and 5) were fed. Creep feed was introduced to the litters during the second week of lactation, except during the first cycle, when it was introduced three weeks postpartum.

The figures shown in Table XIV, page 108, for average litter size at weaning, do not include the two pigs per litter that were sacrificed for whole body composition analyses. Statistical analyses by orthogonal comparisons indicated no significant differences in litter size among the different creep diets for any of the reproductive cycles. However, more pigs were weaned per litter when the creep diet was supplemented with vitamin E within the protein level. This could be a continuation of the higher survival rate of these same pigs evident at three weeks of age, and as reported by Ullrey et al. (1970, 1971), due to the response to vitamin E added to the gestation diet. Choline was not added to the creep diets during the last two lactations.

At weaning of the first litters, pigs fed creep 6 were significantly ($P < .01$) heavier than those fed creep 4, and pigs fed the 16.0% protein diets (3 and 5) were significantly ($P < .01$) heavier than those fed the 20.0% protein creeps (4 and 6). The same trends in weaning weights were evident in the second reproductive cycle, but values were not significantly different. At the last weaning, pigs fed creep 3 were non-significantly heavier than those fed creep 5 (17.06 vs. 16.36 kg, respectively). Average pig gains from three weeks to weaning and from birth to weaning, showed the same differences ($P < .01$) due to creep diets, as seen with weaning weights. Average pig gains from three weeks to weaning were not significantly increased by the higher protein

levels of creeps 4 and 6. Instead, pigs fed the 16.0% diets showed significantly ($P < .01$) greater gains during the first lactation, but not the second, although the same trend was evident. Within each protein level, pigs fed diets with supplemental vitamin E and choline had higher gains during the first lactation. However, during subsequent lactations, this same response was not shown. This may have been due to the deletion of supplemental choline from the creep diets. In a starter protein level study for pigs, Wyllie et al. (1968) reported a significant quadratic gain and feed per gain response to protein levels of 10.0, 17.0, 24.0, and 30.0%. The 17.0 and 24.0% levels produced greatest gains, and were the most efficient. A part of the difference during the first lactation may have been related to litter size, and the confounding of breed with litter age distribution among the creep diets. Late litters tended to be assigned to the high protein creeps, while earlier born litters were assigned to 16.0% protein creeps within breeds. Duroc pigs during the first lactation gained significantly ($P < .01$) more weight; while in the second lactation, the Hampshire pigs gained more weight to weaning ($P < .10$), and were heavier ($P < .10$) at weaning than the Duroc pigs. Hampshire pigs were also heavier ($P < .10$) at the third weaning and gained more weight from three weeks to weaning ($P < .10$).

Average creep feed consumption per pig was significantly affected by protein level and diet composition during the first lactation. Pigs fed creeps 5 and 6 consumed significantly ($P < .05$, $.10$, respectively) more feed per pig than those fed creeps 3 and 4, which contained no additional vitamin E, choline or fish meal. This higher creep feed consumption per pig corresponded to the greater gains by pigs fed these

two creep diets during the period subsequent to three weeks. However, when the creep consumption was compared by protein level, pigs fed the 16.0% protein diets consumed more feed ($P < .01$). More of the complex creep 6 was consumed at the 20.0% protein level than of the simpler creep 4 during the first two lactations. But, the pig gains, subsequent to three weeks, were significantly ($P < .01$) greater for creep 6 pigs at only the first reproductive cycle. Meade et al. (1969) observed that pigs weaned at three weeks usually did not consume larger amounts of diets containing sucrose, fish meal and dried skim milk. It was mentioned, however, that the 5.0% level of sucrose and dried skim milk may have been too small to cause increased diet acceptability. More creep feed was consumed during the first and third lactations, indicating more efficient gains during the second lactation, suggesting possibly greater milk production by the sow. The lower average cycle creep consumption per kilogram pig gain, during the second lactation, would support this conclusion. Also, the total gains from three weeks to weaning were higher during the second cycle compared to the first; but less than at the third lactation, when nearly three times as much creep feed per pig was consumed. Frape et al. (1971), in a five year study, could find no significant difference between dietary protein levels during gestation and lactation and the amount of creep feed consumed per litter up to eight weeks of age. Limiting daily feed intake of the sow during lactation has been shown (Hitchcock et al., 1971b) to result in a significant increase in total creep feed consumption per litter and average creep feed consumption per pig weaned.

Sows consumed more feed per pig weaned during the first lactation, because of the smaller litters weaned and they were less efficient in the conversion of feed to kilograms of pig weaned. Sows were most efficient in this latter performance trait during the last lactation, when it took approximately 50.0% less feed. This was made possible by the heaviest litter weaning weights and highest average creep consumption per pig of the three lactations. Consuming significantly ($P < .01$) more feed per pig weaned during the first lactation, sows whose pigs were fed the 16.0% protein creeps were more efficient in producing heavier pigs to weaning ($P < .01$). The second lactation required the least amount of sow lactation feed per pig weaned. Sow feed consumptions per pig weaned at the last two lactations were less than the 49.0 kg of feed/pig weaned, reported by Hitchcock et al. (1971b), for sows fed ad libitum during a 49-day lactation.

V. BODY COMPOSITION DATA FOR NEWBORN PIGS

Whole Body Chemical Composition

The whole body chemical analyses on both a fresh and dry matter basis are shown in Table XVI, as a function of reproductive cycle and diet. Pigs were sacrificed before nursing, reflecting gestation sow diets. Values obtained are in good agreement with the range in values reported by other investigators (Mitchell et al., 1931; Manners and McCrea, 1963; Brooks et al., 1964; Curtis et al., 1967; and Brooks and Davis, 1969), for non-nutritional studies of chemical composition of the young pig carcass. The table also provides some insight into the long-term effects resulting from limited maternal intake of

TABLE XVI. LEAST-SQUARES MEANS FOR WHOLE BODY CHEMICAL COMPOSITION OF NEONATAL PIGS^a

Diets	Reproductive Cycles											
	I				II				III			
	C-SEM		Vit E-Chol		C-SEM		Vit E-Chol		C-SEM		Vit E-Chol	
	Control	Suppl'd	Avg	Cycle	Control	Suppl'd	Avg	Cycle	Control	Suppl'd	Avg	Cycle
No. pigs ^b	19	24	43		17	16	33		14	12		26
Specific gravity	1.030	1.034	1.032		1.029 ^f	1.037 ^g	1.033		1.034	1.034		1.034
Moisture, %	81.25	81.59	81.42		80.84	81.34	81.11		80.52 ^d	81.32 ^e		80.92
Fat, %	1.07	1.05	1.06		0.72	0.80	0.76		0.84	0.80		0.82
D.M. basis ^c	5.70	5.68	5.69		3.79	4.32	4.05		4.34	4.22		4.28
Ash, %	4.11	4.03	4.07		3.84	3.70	3.77		3.84	3.72		3.78
D.M. basis	21.93	21.93	21.93		20.06	19.88	19.97		19.76	19.98		19.87
Protein, %	11.18	11.16	11.17		11.13 ^d	10.71 ^e	10.93		10.97 ^h	10.21 ⁱ		10.59
D.M. basis	59.82	60.73	60.28		58.21	57.57	57.89		56.39	54.82		55.61
Gross energy, cal/g	881.5	900.3	890.9		855.5	869.9	862.7		856.0 ^h	802.8 ⁱ		829.4
D.M. basis, kcal/g	4.713	4.906	4.810		4.468 ^f	4.674 ^g	4.571		4.402	4.308		4.355

TABLE XVI (continued)

- ^aPigs were sacrificed after birth and before nursing.
- ^bRepresents one female and one male pig per litter.
- ^cOn dry matter basis.
- ^{d,e}Means within same row, having different superscripts were significantly different ($P < .10$).
- ^{f,g}Means within same row, having different superscripts were significantly different ($P < .05$).
- ^{h,i}Means within same row, having different superscripts were significantly different ($P < .01$).

nutrients on subsequent fetal composition.

Percent moisture in the carcass was lower in every case for pigs from C-SBM fed sows, and a significant ($P < .10$) difference was observed between diet groups at the third farrowing. Neither the fat, as measured by ether extract determination, nor ash percentages of the whole carcass, showed any statistically significant differences due to gestation dietary treatment. Average fat and ash levels for both reproductive cycles and diets were highest at the first farrowing.

It is known that pigs are born with a high carbohydrate, low fat content in both the carcass and liver, and that during the first two weeks after birth, changes occur which result in a decreased carbohydrate and relatively increased fat content in both the carcass and liver (Manners and McCrea, 1963; Brooks et al., 1964; Brooks and Davis, 1969; and Anderson and Wahlstrom, 1970). While the whole carcass nitrogen free extract (NFE) content was not determined chemically in the present study, Brooks et al. (1964) have shown that the calculated carcass NFE agree quite closely with chemically deduced NFE. Furthermore, it was determined that the NFE was primarily glycogen. The NFE content of the carcasses calculated in the present study was less than that reported by Mitchell et al. (1931); Brooks et al. (1964) and Brooks and Davis (1969). At the last two farrowings, however, there were higher NFE levels. It has been suggested (Brooks and Davis, 1969) that differences in age at slaughter (up to three hours postpartum) could account for differences in NFE level. This could explain the lower NFE levels for the present study, since the pigs were not always sacrificed immediately after birth. Furthermore, it has been reported, as liver glycogen is

broken down, water content of the liver increases by a similar, but opposite amount (Anderson and Wahlstrom, 1970). Such a change would explain the higher moisture content of the pig carcasses from the Vit E-Chol fed sows, provided there was a more rapid tissue glycogen breakdown in these pigs. Anderson and Wahlstrom (1970) illustrated this possibility with muscle tissue. Glycogen level in the muscle decreased steadily from birth (8.54%) to 2.77% after 72 hours. Unfortunately, there was no mention of muscle moisture in conjunction with this change.

Whole body carcass protein was significantly lower, in the baby pigs sacrificed at both the second ($P < .10$) and third ($P < .01$) farrowings, for those pigs from sows fed the Vit E-Chol diet. Average protein levels also declined with successive reproductive cycles, primarily because of the lower protein level in the Vit E-Chol pig carcasses ($P < .10$). Through the three reproductive cycles, percent carcass protein was significantly and negatively correlated with percent carcass moisture ($r = -.37$, $P < .01$) for the Vit E-Chol pigs. Brooks and Davis (1969) suggested that the protein concentration of the carcass was related to the change in glycogen content. On a dry matter basis, percent carcass protein was lower ($P > .10$) in the Vit E-Chol carcasses at the last two farrowings. Hesby et al. (1970a) found no differences in the protein levels, on either a fresh or dry matter basis, for newborn pigs from sows fed different dietary levels and sources of protein in a one summer gestation study. In a longer study, Elsley et al. (1966b), using regression procedures, found a lower nitrogen content per one-kilogram pig in first litter pigs from gilts fed an 11.0% protein diet, regardless of gestation feed intake. In the second and third

farrowings, a higher protein level (18.0%) did not help maintain this difference. In all three litters, limited protein and feed intake (1.6 vs. 2.6 kg/day) resulted in the lowest nitrogen content per one-kilogram pig. Zeman and Stanbrough (1969) and Zeman (1970) concluded that the reduction in total liver and whole carcass protein of rat fetuses at days 16, 18, and 20 of gestation was due to a decrease in cell number the last four days of gestation, caused by maternal protein deficiency (6.0 vs. 30.0% casein diets).

Gross energy content of the total carcass was non-significantly higher for pigs from Vit E-Chol fed sows during the first and second farrowing. At the last farrowing, there was a significant reversal of energy levels between diets. The gross energy content of pigs from sows fed the C-SBM diet was 53.2 cal/g higher ($P < .01$) than that of the Vit E-Chol pig carcasses. Through the three reproductive cycles, average cycle carcass gross energy content declined with successive farrowings. Expressed on a dry matter basis, the gross energy level during the second reproductive cycle, was the only carcass component showing any significant difference between the two diets. Vit E-Chol pig carcasses were significantly ($P < .05$) higher in gross energy content. Mitchell et al. (1931) reported a lower gross energy level for the developing pig fetus than values reported in this study. However, their determinations were made on 16 week old pig fetuses taken from full-fed gilts.

Specific gravity determinations were not consistently correlated with any of the different chemical components of the whole body composition.

Liver Chemical Composition

The liver chemical composition is shown in Table XVII, except for percent liver protein. On a fresh tissue basis there were no significant differences among the liver chemical components, due to the dietary intake of the sow during gestation. Percent liver moisture was higher in the present study than that reported by Mitchell et al. (1931); Brooks et al. (1964); Brooks and Davis (1969); and Anderson and Wahlstrom (1970). This could reflect liver glycogen breakdown. Anderson and Wahlstrom (1970) have shown liver glycogen levels to decrease rapidly from 11.5% at birth to 2.83% at 18 hours. Swiatek et al. (1968) reported a similar decrease in pig liver glycogen content from birth. The previous researchers, Anderson and Wahlstrom (1970), also observed that as liver glycogen was broken down, water content of the liver increased. This explained the increased pig liver moisture in their study from birth (73.3%) to 18 hours of age (78.4%). The observed lower moisture percentages in pig livers during the last farrowing of the current study might be related to less glycogen available for breakdown. Fetal glycogen stores normally build up during late gestation, but poor maternal nutrition during late gestation would cause a reduction in the glycogen content of the fetal liver (Hafez, 1969).

Liver fat levels, in the current study, were generally higher than those reported by Mitchell et al. (1931); Brooks et al. (1964); Brooks and Davis (1969); and Anderson and Wahlstrom (1970) for the first two reproductive cycles. At the last farrowing, however, the liver fat content was equal to or less than levels reported by these researchers. Percent liver fat in pigs from sows fed C-SBM diet was higher,

TABLE XVII. LEAST-SQUARES MEANS FOR LIVER CHEMICAL COMPOSITION OF NEONATAL PIGS^a

Diets	Reproductive Cycles											
	I			II			III					
	C-SEM Control	Vit E-Chol Suppl'd	Cycle Avg	C-SEM Control	Vit E-Chol Suppl'd	Cycle Avg	C-SEM Control	Vit E-Chol Suppl'd	Cycle Avg	C-SEM Control	Vit E-Chol Suppl'd	Cycle Avg
Liver samples ^b	19	24	43	17	16	33	14	12	26			
Moisture, %	80.11	79.51	79.81	79.91	79.95	79.93	77.00	76.82	76.91			
Ash, %	1.18	1.14	1.16	1.12	1.08	1.10	1.09	1.05	1.07			
D.M. basis ^c	5.94	5.65	5.80	5.60	5.42	5.51	4.78	4.56	4.67			
Fat, %	2.47	2.13	2.30	1.72	1.42	1.57	1.13	0.95	1.04			
D.M. basis	12.50 ^d	10.54 ^e	11.52	8.66	7.12	7.89	4.94	4.11	4.53			
Liver wt. of body wt., %	2.01	1.99	2.00	2.12	2.14	2.13	3.50	3.82	3.66			
D.M. basis	0.40	0.41	0.41	0.43	0.43	0.43	0.81	0.89	0.85			

^aPigs were sacrificed after birth, before nursing.^bRepresents one female and one male pig per litter.^cOn dry matter basis.^{d,e}Means within same row, having different superscripts were significantly different ($P < .10$).

approaching a significant difference ($P > .10$) during the first reproductive cycle. On a dry matter basis, fat difference between the two diets was significant ($P < .10$) for this cycle. Over the three cycles, there was a dramatic decline in average reproductive cycle liver fat percent, with levels at successive farrowings going from 2.30 to 1.04%.

There are several complex mechanisms apparently involved in the control of liver fat content in the baby pig. Anderson and Wahlstrom (1970) demonstrated a highly significant ($P < .005$) difference in liver fat content, due to time treatment following birth. Liver fat content increased from 1.00% at birth to 2.66% at 24 hours. These same investigators noted a significant difference ($P < .005$) in liver fat, at birth, due to gilt gestation weight gains. Lower gains (0.0 - 10.0 kg) resulted in higher liver fat levels. Nutritionally, choline deficient diets have been associated with fatty livers in young pigs (Ensminger et al., 1947; Johnson and James, 1948; and Neumann et al., 1949), and in the weanling rat (Kroening and Pond, 1967). Results from feeding female rats choline deficient diets, containing different protein levels, have also indicated that the liver lipid content of rats was appreciably affected by the level of dietary protein (Aoyama et al., 1971).

In the baby pig, as in the chicken, the ability of methionine to supply methyl groups for the synthesis of choline from aminoethanol may be limited (Neumann et al., 1949). The sows fed the C-SBM diet consumed less than the recommended N.R.C. (1968) daily allowances of methionine and cystine, and they also received less choline per day than the Vit E-Chol fed sows. These combined conditions could explain the higher

liver fat levels in pigs from these sows. The rat work of Kroening and Pond (1967) further supports this study. A lower liver ether extract percentage was found in weanling rats fed soybean meal or isolated soybean meal diets, supplemented with 1646.0 mg of choline/kg diet, but containing no added methionine. Response was less evident in the soybean meal diets due to the inherent choline. It was also reported that incremented methionine additions to the diets, resulted in lipotropic action similar to that produced by choline, and that 0.11% additional methionine could be replaced by 1646.0 mg of choline/kg diet in the rat. Neither hepatic choline content nor histological liver sections for fat infiltration were made in the current investigation to further elucidate the liver fat differences. Choline deficiency in the baby pig has resulted in fatty infiltration of the liver, severe renal damage characterized by renal glomerular occlusion and some tubular epithelial necrosis (Neumann et al., 1949).

Liver weight, expressed as a percent of body weight, increased slightly at the second farrowing, with the largest increase (more than 1.5 times) occurring at the third farrowing. At this farrowing, liver weights were heavier on both a fresh and dry matter basis from pigs gestated by the Vit E-Chol fed sows.

Chemical Constituents of Other Selected Organs

Table XVIII shows the comparative chemical composition for the spleen, kidney and alimentary tract for pigs from sows in the first farrowing only. Between diets, there were no significant differences due to maternal dietary intake other than the differences in kidney

TABLE XVIII. LEAST-SQUARES MEANS OF THE CHEMICAL COMPOSITION VALUES FOR SPLEEN, KIDNEY AND ALIMENTARY TRACT OF NEONATAL PIGS^a

Organs	Diets		Avg For Cycle ^b
	C-SBM Control	Vit E-Chol Suppl'd	
Spleen			
Ash, %	1.32	1.26	1.29
Percent body weight	.11	.11	.11
Kidney			
Ash, %	1.24	1.24	1.24
Water, %	82.61	82.59	82.60
Fat, %	1.37 ^d	1.55 ^e	1.46
Percent body weight	.34 ^d	.30 ^e	.32
Alimentary tract ^c			
Ash, %	1.09	1.07	1.08
Water, %	84.39	84.17	84.28
Fat, %	.95	.95	.95
Protein, %	10.13	10.15	10.14
Percent body weight	4.53	4.63	4.58

^aTissues were taken from first litter pigs that had not nursed.

^bCycle average of 43 pigs, a female and male pig from each litter where available.

^cIncludes stomach, intestines and contents.

^{d,e}Means in same row, having different superscripts were significantly different ($P < .10$).

weight, expressed as a percent of body weight. Kidneys from C-SBM pigs were significantly heavier ($P < .10$) compared to Vit E-Chol pigs. Heavier kidney weights were observed (Parks and Smith, 1968) in choline-deficient weanling rats due to increased renal cellular proliferation.

Spleen, kidney, liver and heart weights, in the present study, were well within the range of similar organ weights taken from newborn pigs of comparable birth weights (Mitchell et al., 1931; Ullrey et al., 1965; and Brooks and Davis, 1969). At the last farrowing, weights of these organs were lower for the Vit E-Chol pigs, as were birth weights.

Hematology and Plasma Mineral Concentrations

In Table XIX are shown the hematocrit, hemoglobin level and plasma mineral concentrations determined on blood samples taken from the pigs, sacrificed at birth, for whole body analyses. Hemoglobin levels were not determined at the first farrowing and plasma manganese (Mn) levels were not determined in the subsequent farrowings.

No diet differences were noted for either of the whole blood parameters, within reproductive cycles. Hematocrit levels were lowest in the second reproductive cycle and highest at the first. Hemoglobin levels were higher at the last farrowing. These iron-related blood constituent values are in close agreement with other hematological levels reported in swine blood pattern studies (Craft and Moe, 1933; Miller et al., 1961; and Ramirez et al., 1963), although the hematocrit percents at the first parturition are slightly higher than levels reported by Miller et al. (1961). Spruill et al. (1971) reported markedly higher baby pig hemoglobin levels, due to the higher protein intake (16 vs.

TABLE XIX. LEAST-SQUARES MEANS FOR HEMOGLOBIN, HEMATOCRIT AND SELECTED PLASMA
ELECTROLYTES OF NEONATAL PIGS^a

Repro- ductive Cycle	Diet	Ht ^b (%)	Hb ^c (mg/ 100ml)	Iron (mg/ 100ml)	Zinc (mg/ 100ml)	Copper (mg/ 100ml)	Potassium (mg/ 100 ml)	Calcium (mg/ 100 ml)	Magnesium (mg/ 100 ml)	Manganese (ppm)
1	C-SBM control	44.5	--	0.76	0.19 ^e	0.15	38.6	10.51 ^g	2.57	1.4
	Vit E-Chol suppl'd	43.5	--	0.66	0.23 ^f	0.13	42.3	9.68 ^h	2.49	1.4
	Avg for cycle	44.0 (43)	--	0.71 (43)	0.21 (43)	0.14 (42)	40.5 (42)	10.10 (42)	2.53 (43)	1.4 (43)
2	C-SBM control	34.5	10.35	0.68	0.23	0.52	22.3	10.11	1.88	--
	Vit E-Chol suppl'd	35.8	10.65	0.68	0.24	0.52	24.1	9.75	1.78	--
	Avg for cycle	35.2 (33)	10.50 (33)	0.68 (31)	0.23 (29)	0.52 (29)	23.2 (28)	9.93 (31)	1.83 (29)	--
3	C-SBM control	38.1	11.40	0.33	0.13	0.40	14.9	10.13	1.75 ^g	--
	Vit E-Chol suppl'd	39.8	11.56	0.30	0.15	0.39	14.6	9.97	2.01 ^h	--
	Avg for cycle	39.0 (26)	11.48 (26)	0.31 (24)	0.14 (25)	0.40 (25)	14.7 (23)	10.05 (25)	1.88 (24)	--

^aBlood samples were taken before pigs nursed.

^bHt = Hematocrit.

^cHb = Hemoglobin.

^dObservations in cycle average.

^{e,f}Means within same column, having different superscripts were significantly different ($P < .10$).

^{g,h}Means within same column, having different superscripts were significantly different ($P < .05$).

12.0%) and protein source (fish meal) fed the sow during gestation; while the higher hematocrit response ($P < .05$) for the pigs came from the fish meal rather than the soybean diet.

The low hemoglobin and hematocrit values, reported by Orr et al. (1970), and Hitchcock et al. (1971a), for two-day-old pigs having the "pale pig syndrome," were not detected in the present study at birth. Nor did the pale appearance manifest itself later, in any way that is clinically characteristic for this syndrome. Results of the current study tend to confirm the findings of Miller et al. (1970), that maternal treatment with dietary vitamin E does not appear to affect either hemoglobin or hematocrit levels of the very young pig. Instead, higher hematological levels of the Vit E-Chol pigs could be a result of the fish meal in the maternal diet as observed by Spruill et al. (1971).

Plasma mineral concentrations showed considerable variation through the three reproductive cycles, but reflected existing trends. During the first reproductive cycle, there was a significant inverse relationship between neonatal pig plasma zinc (Zn) and calcium (Ca) concentrations, when analyzed for gestation diet source. Plasma Zn level of pigs, from gilts fed the Vit E-Chol diet, was higher ($P < .10$) than level found in pigs from gilts fed the C-SBM diet. Plasma Ca concentration was higher ($P < .05$) in the pigs from C-SBM fed gilts. In subsequent reproductive cycles, dietary differences of the same magnitude were not evident for these two minerals, but their relationship remained the same. Average Zn concentration at the last farrowing was one-third less than the level at the first farrowing. The Ca levels of plasma were in agreement with those reported by Ullrey et al. (1967).

In a long term study (five reproductive cycles), Kornegay, Thomas and Meacham (1973) found no significant differences between baby pig serum Ca levels, when the sow was fed diets containing either 10.3 g Ca and 11.0 g total phosphorus (P) or 15.5 g Ca and 15.0 g/day total P. However, in the last cycle, baby pig serum calcium values were less (8.8 mg/100 ml) than in the current study (10.05 mg/100 ml) after three reproductive cycles.

The plasma Zn concentrations were considerably higher at the first two farrowings than reported by Hoekstra et al. (1967); and Hansard and Itoh (1968). At the last reproductive cycle, plasma Zn levels corresponded to levels found in pigs one week old (Ullrey et al., 1967).

Both plasma iron (Fe) and potassium (K) concentrations decreased with successive reproductive cycles. Iron made the greatest drop at the last farrowing, where it declined to an average of 0.31 mg Fe/100 ml plasma. This represented a decline of well over 50.0% from the levels in the two previous farrowings. Still, the plasma Fe levels at each of these farrowings were higher than values reported by Miller et al. (1969b); Spruill et al. (1971); and Furugouri (1972) for the newborn pig. The higher plasma Fe levels for the first two farrowings can be partially explained by a higher incidence of hemolysis.

Potassium plasma levels decreased by an average of 17.3 mg/100 ml to the second farrowing average of 23.2 mg/100 ml and decreased still further to an average 14.7 mg/100 ml at the last farrowing. Ullrey et al. (1967) reported K concentrations to range from 15.6 to 25.6 mg/100 ml with the mean average at birth being 19.6 mg/100 ml of serum.

Stable copper (Cu) was the only mineral to show a trend toward an increase through the three reproductive cycles, being nearly four times its initial concentration at the second farrowing. From a low of 27 mcg/100 ml, Ullrey et al. (1967) reported that baby pig serum Cu concentrations rose from 53 mcg/100 ml 24 hours post-farrowing to a high of 198 mcg/100 ml at three weeks of age. Thus, the first litter plasma Cu concentrations in the current study reflect the level of an older pig rather than a newborn pig. Although, Gamble (1969) reported a whole blood Cu level of 180 mcg/100 ml in the third trimester fetus (105 days post-breeding), suggesting change during early growth.

The average magnesium (Mg) levels remained relatively uniform for the last two farrowings, following the decline from the initial parturition. At the last farrowing, there was a significant ($P < .05$) difference in plasma Mg levels between the two gestation diets. Ullrey et al. (1967) reported a Mg level of 3.4 mg/100 ml at birth, followed by a drop to 2.4 mg at 24 hours and then a peak, at two weeks, with subsequent mean value of 3.5 mg/100 ml Mg.

Whole Body Mineral Concentrations

The maternal-fetal relationships in terms of mineral transfer to the whole carcass and selected organs are shown in the following tables. Eight mineral levels for the neonatal pig carcass are presented in Table XX, as a function of reproductive cycle and gestation diet. In Table XXI, are shown the liver mineral concentrations for these same pigs. Selected mineral levels found in the spleen, kidney and alimentary tract, for the baby pigs sacrificed at the first farrowing, are shown in Table XXII.

TABLE XX. LEAST-SQUARES MEANS FOR WHOLE BODY MINERAL CONCENTRATIONS OF NEONATAL PIGS^a

Reproductive Cycle	Diet	Minerals							
		Iron (mg%)	Manganese (ppm)	Zinc (mg%)	Copper (mg%)	Potassium (mg/g)	Calcium (mg/g)	Magnesium (mg/g)	Phosphorus (g%)
1	C-SBM control	1.96±.09 ^b	0.8±0.0	1.32±.04	0.22±.01 ^d	1.164±.036 ^f	13.293±.373	0.247±.007	0.78±.06
	Vit E-Chol suppl'd	1.88±.08	0.8±0.0	1.26±.03	0.19±.01 ^e	1.028±.030 ^g	13.279±.316	0.235±.006	0.81±.05
	Avg for cycle	1.92±.06 (41) ^c	0.8±0.0 (43)	1.29±.03 (42)	0.21±.01 (42)	1.096±.024 (42)	13.286±.245 (40)	0.241±.004 (41)	0.79±.04 (41)
2	C-SBM control	2.32±.15	0.6±0.0	2.09±.18 ^d	0.11±.00	0.705±.046	12.178±.413	0.245±.012	0.65±.03
	Vit E-Chol suppl'd	2.10±.16	0.6±0.0	1.60±.16 ^e	0.12±.01	0.714±.044	11.548±.338	0.226±.011	0.61±.03
	Avg for cycle	2.21±.11 (30)	0.6±0.0 (33)	1.84±.12 (31)	0.11±.01 (30)	0.710±.032 (33)	11.863±.267 (30)	0.235±.008 (33)	0.63±.02 (31)
3	C-SBM control	0.98±.04	0.6±0.0	1.23±.06	0.08±.01	0.909±.031 ^d	12.008±.320	0.246±.010 ^d	0.54±.02
	Vit E-Chol suppl'd	1.02±.04	0.5±0.0	1.24±.06	0.08±.01	0.807±.032 ^e	11.601±.326	0.215±.011 ^e	0.57±.02
	Avg for cycle	1.00±.03 (23)	0.5±0.0 (25)	1.23±.04 (24)	0.08±.00 (25)	0.858±.022 (25)	11.804±.229 (25)	0.230±.007 (26)	0.56±.02 (25)

TABLE XX (continued)

^aPigs were sacrificed before nursing.

^bMean $\pm$ SEM on wet tissue basis.

^cObservations in cycle average.

^{d,e}Means within same column, having different superscripts were significantly different ($P < .05$).

^{f,g}Means within same column, having different superscripts were significantly different ($P < .01$).

TABLE XXI. LEAST-SQUARES MEANS FOR LIVER TISSUE MINERAL CONCENTRATIONS OF NEONATAL PIGS^a

Reproductive Cycle	Diet	Minerals						
		Iron (mg%)	Manganese (ppm)	Zinc (mg%)	Copper (mg%)	Potassium (mg/g)	Calcium (mg/g)	Magnesium (mg/g)
1	C-SBM control	11.52±0.91 ^b	1.3±0.1 ^d	2.61±.29	4.13±.26	1.310±.067	0.281±.028	0.124±.004
	Vit E-Chol suppl'd	11.44±0.78	1.1±0.1 ^e	3.21±.25	4.24±.22	1.224±.057	0.247±.024	0.119±.003
	Avg for cycle	11.48±0.60 (43) ^c	1.2±0.1 (43)	2.91±.19 (43)	4.18±.17 (42)	1.267±.044 (42)	0.264±.018 (42)	0.122±.003 (42)
2	C-SBM control	15.39±1.23	1.0±0.0 ^d	5.49±.84	4.13±.41	1.114±.035	0.213±.019	0.146±.005 ^f
	Vit E-Chol suppl'd	14.46±1.16	0.8±0.0 ^e	6.63±.82	3.94±.39	1.056±.036	0.178±.019	0.122±.005 ^g
	Avg for cycle	14.92±0.85 (31)	0.9±0.0 (31)	6.06±.59 (31)	4.03±.28 (30)	1.085±.025 (31)	0.196±.014 (31)	0.134±.003 (31)
3	C-SBM control	17.98±1.22	1.0±0.0	1.62±.21	3.00±.31	1.406±.048	0.075±.005	0.124±.004 ^d
	Vit E-Chol suppl'd	15.39±1.24	0.9±0.0	2.00±.22	3.28±.31	1.344±.049	0.077±.005	0.113±.004 ^e
	Avg for cycle	16.69±0.87 (25)	0.9±0.0 (26)	1.81±.15 (24)	3.14±.22 (24)	1.375±.034 (25)	0.076±.004 (26)	0.119±.003 (25)

TABLE XXI (continued)

- ^aTissue was taken from pigs that had not nursed.
- ^bMean $\pm$ SEM on wet tissue basis.
- ^cObservations in cycle average.
- ^{d,e}Means within same column, having different superscripts were significantly different ($P < .10$).
- ^{f,g}Means within same column, having different superscripts were significantly different ($P < .01$).

TABLE XXII. LEAST-SQUARES MEANS FOR SPLEEN, KIDNEY AND ALIMENTARY TRACT
MINERAL CONCENTRATIONS OF NEONATAL PIGS^a

Diet	Minerals						
	Iron (mg%)	Manganese (ppm)	Zinc (mg%)	Copper (mg%)	Potassium (mg/g)	Calcium (mg/g)	Magnesium (mg/g)

^aTissue was taken from first litter pigs that had not nursed.

^bMean ± SEM on wet tissue basis.

^cObservations in cycle average.

No significant differences were found between the two diets for carcass iron, manganese, calcium or phosphorus concentrations. This was to be expected, since the two gestation diets were formulated to meet pregnant swine daily nutrient intakes (N.R.C., 1968). Except for Fe, the above mentioned minerals plus Cu, all showed some degree of decreasing concentrations with each successive farrowing. In contrast, carcass Fe and Zn levels were higher at the second farrowing and carcasses of pigs from the C-SBM fed sows contained significantly ($P < .05$) more Zn per gram of tissue. Carcass K concentrations exhibited a slight increase at the last reproductive cycle, following the lowest level at the second farrowing. Where other significant differences were indicated by the analyses of the carcass minerals, the lower mineral levels were found in carcasses of pigs gestated by the Vit E-Chol fed sows. This same pattern of mineral differences was also present for most of the other mineral concentrations ($P > .10$). Carcass Mg concentrations for the C-SBM pigs remained constant during the three reproductive cycles, while levels for the Vit E-Chol nurtured pig carcasses declined with successive farrowings.

In general, the whole body mineral component values in the present study, other than Ca and P, were lower than levels reported by Hansard (1965) for the swine fetus. Some of this difference may be due to the age of the fetus sampled, since most of the fetuses in that report were sacrificed around the 110th day of gestation. Furthermore, mineral concentrations were corrected to a one-kilogram weight basis by direct proportion, rather than integrated with time for mineral accretion. Levels of the micro-elements, Fe and Cu, were also lower than levels

(fat-free basis) reported by Widdowson (1950) and (fresh weight) Manners and McCrea (1963) for the newborn pig, as were the concentrations of the two macro-elements Mg and K. The lower, whole body P levels of third litter pigs were less than Widdowson (1950) observed, but were higher than the levels reported by Mitchell et al. (1931); Manners and McCrea (1963); and Hansard (1965). Kornegay et al. (1973) found that it took four successive gestation periods to produce a lowered Ca level in the turbinate, rib, tibia and kidney of the newborn pig when the gestating sow was fed controlled intakes of Ca and P. Neonatal pig femur breaking strength, in that study, was reduced after the third farrowing. Itoh et al. (1967) had previously demonstrated a reduced total placental transfer of calcium to the fetal pig at much lower Ca and P levels than used in the current study.

Total placental transfer of Mn to the baby pig agreed with the levels found in the perinatal pig (Newland and Davis, 1961; Manners and McCrea, 1963; and Gamble, 1969), with the lowest level in the third farrowing associated with the postnatal concentration (0.48 ppm) reported by Manners and McCrea (1963).

Carcass Zn concentrations were higher than the levels reported by Widdowson (1950) and Manners and McCrea (1963) for newborn pigs, but less than the levels reported by Hansard (1965) and Hansard and Itoh (1968) for the prenatal fetus.

Liver Mineral Concentrations

As with the carcass minerals, most of the liver elements except for Zn and Cu, were lower in baby pigs from sows fed the Vit E-Chol

gestation diet. Liver Zn concentrations were higher at each reproductive cycle for the Vit E-Chol pigs, while Cu was higher at only the first and third farrowings. Spray and Widdowson (1950) reported a liver Zn concentration of 30.0 mg/kg in the newborn pig. This level was slightly higher than the average level for the first litter pig livers, less than that found at the second farrowing and nearly double the level found in the third litter pig livers. The higher hepatic Zn concentration of the second litter C-SBM pigs was less than that reported by Hansard and Itoh (1968), but the level found in the Vit E-Chol pig livers was in agreement. In a Zn deficiency study of reproducing gilts, Hoekstra et al. (1967) obtained liver Zn values of 40.0 - 60.0 mg/kg of dry tissue in pigs, at birth, from sows that had received a high calcium (1.6%), low Zn (30 - 40 ppm) corn-soybean meal diet during gestation. Pigs from sows fed the same diet, but supplemented with 100.0 ppm Zn, were found to have a four to ten fold higher liver Zn concentration.

Liver Fe concentrations did not follow the pattern of carcass Fe, in that they showed an increase at each of the three farrowings, going from a cycle average of 11.48 to 16.69 mg/100 g at the last parturition. Thus, it would seem that with progressive farrowings, Fe storage in the liver increased, while there was a corresponding decrease in plasma and carcass Fe levels. Mitchell et al. (1931) reported a first litter fetal liver Fe level of .018% on the fresh basis which was somewhat higher than the average cycle concentration found in the last farrowing of the present study, but equivalent to the level of the C-SBM pig livers. From a pig anemia study, Miller et al. (1969b) obtained liver Fe levels,

at birth, ranging from 143 to 189 ppm; while Spruill et al. (1971) reported higher levels (0.89 to 1.25 mg/g) depending on gestation protein level and source. The values reported by the latter authors appear to be quite high and may be due to the levels being expressed on a dry basis, although this was not indicated.

While the Fe level increased, hepatic Mn, Cu and Ca concentrations declined, as was observed in the whole carcass, with successive farrowings. Liver Mn levels were significantly ($P < .10$) higher for pigs from C-SBM fed sows at the first two farrowings. Widdowson and Dickerson (1964), in their treatise of the chemical composition of the body, reported the Mn in the liver to be about 8.0 mg/kg of dry matter, varying very little from one age and one species to another. Gamble (1969) reported a higher liver Mn concentration (1.73 $\mu\text{g/g}$) in late third-trimester pig fetuses than observed for newborn pigs of the current study. Since reserve stores of Mn do not occur in the livers of the newborn, Mn is unlike Fe and Cu, but similar to Zn (Underwood, 1971).

At birth, it has been noted that Cu concentration in the pig was considerably higher than in adult life (Widdowson, 1950). Cunningham (1931) reported Cu concentration in the pig at birth to be 230.0 mg/kg and 20.0 mg/kg dry liver in adult life. It was also evident that during fetal life, there appeared to be an increase in Cu concentration in the calf, guinea pig and rabbit (Cunningham, 1931). Gamble (1969) obtained lower hepatic Cu concentration (29.5 mg/kg) in third trimester pig livers than observed in the newborn pigs of the current study.

Mitchell et al. (1931) found the liver of the 15-week-old pig fetus to contain .0091% calcium, which was less than levels found in the

first and second litter pig livers, but more than that observed in the third. Widdowson and Dickerson (1960) reported a lower liver Ca level (.0441 mg/g) than found in the prevailing investigation for the newborn pig. The high Ca values, found in fetal skeletal muscle and heart tissue, have not been observed in the fetal liver (Widdowson and Dickerson, 1964).

At the last two farrowings, there were significant ($P < .10$) differences in liver Mg concentrations due to gestation diet source. At the second reproductive cycle, liver Mg level of the C-SBM gestated pigs was significantly higher ($P < .01$) than that of the Vit E-Chol pig livers. Liver Mg levels in the present study were less than concentration reported in the liver of the newborn pig (0.204 mg/g) by Widdowson and Dickerson (1960).

Liver K levels followed the distribution pattern of whole carcasses K through the three successive farrowings except highest hepatic K values were observed at the last parturition. Widdowson and Dickerson (1960) reported a liver K concentration of 3.33 mg/g for the newborn pig.

Spleen, Kidney and Alimentary Tract Mineral Concentrations

The mineral levels of the spleen, kidney and alimentary tract for the sacrificed first litter pigs, are shown in Table XXII, page 139. There were no significant differences among the organ minerals, due to maternal intake for the two gestation diets.

Mitchell et al. (1931) reported a fetal spleen iron content of 0.015%, which was nearly double the levels obtained in the prevailing

study for the newborn pig. These levels were slightly less than concentration (87 ppm) reported by Miller et al. (1969b). In the current study, the liver contained a higher level of Fe than the spleen, which was in agreement with Mitchell et al. (1931), and Miller et al. (1969b). The Mn levels of the spleen were less than that reported by Gamble (1969), but kidney Mn concentrations were higher. Both kidney and spleen Cu levels were higher than corresponding organ Cu levels of the third-trimester fetus (Gamble, 1969). In agreement, also, was the higher level of Cu in the spleen, than the kidney.

Hoekstra et al. (1967) reported duodenum and kidney Zn concentrations of 76 to 79 and 83 to 98 mcg/g dry sample, respectively, in the baby pig dead at birth. Thus, perhaps explaining the lack of any difference between these two organs in their Zn concentration, regardless of maternal dietary Zn intake during gestation. Kidney Zn levels were higher than reported by Hansard and Itoh (1968), who found no difference in the Zn levels (12.0 mg/kg), even when some gilts were fed a low Ca diet from 70 days post-breeding to sacrifice prior to farrowing. Fetal spleens in that study, from gilts fed a normal Ca level, did contain slightly less Zn than those of fetuses from the gilts fed the low Ca diet (16.0 vs 22.0 mg/kg, respectively).

Kornegay et al. (1973) reported a kidney Ca level of 0.09% (dry matter) at the first reproductive cycle, compared to a level of 0.05% in the fourth and fifth cycles in the baby pig ($P < .05$).

Total Litter Chemical Composition and Mineral Content

In Tables XXIII and XXIV, is presented the maternal contribution to a litter (standardized to eight pigs), based on the litter weights recorded in this study and the averaged chemical and mineral values for the two sacrificed pigs within the litter. Table XXIII shows the chemical constituents that the dam transferred across the placental membranes to the litter and Table XXIV gives the mineral analyses, but does not include placenta or fluids.

During the first two reproductive cycles, there were small differences in the litter chemical compositions due to the gestation diets consumed by the maternal dam. The Vit E-Chol litters contained more of the individual chemical constituents except for fat content of the first litter. The litter fat content was the only component that did not increase through the second farrowing. At the last farrowing, pigs from the C-SBM litters had significantly ($P < .05$) more of the individual chemical components. These litters had moisture, protein and gross energy contents equal to or slightly less than that found in the first litters. The combination of heavier litters at birth and higher carcass composition levels for the C-SBM pigs accounted for most of the differences between diets in the last reproductive cycle. Also, in standardizing each litter unit to eight pigs per litter, the Vit E-Chol litters, being larger at birth, may have been corrected to a greater extent than the C-SBM litters.

Mitchell et al. (1931) reported higher uterine nutrient levels in pregnant gilts, compared to nonpregnant gilts, than were accounted for by fetal pigs themselves. In their study, dry matter, ether extract,

TABLE XXIII. MEAN LITTER CHEMICAL CONSTITUENTS
CORRECTED TO LITTER OF EIGHT PIGS^a

Repro- ductive Cycle	Diets	Moisture (g)	Fat (g)	Ash (g)	Protein (g)	Gross Energy (kcal)
1	C-SBM control	7451.3	99.9	374.1	1027.7	8125.9
	Vit E-Chol suppl'd	7574.4	97.7	375.2	1040.1	8380.8
	Avg for cycle	7518.5	98.7	374.7	1034.5	8265.0
2	C-SBM control	8397.3	79.0	393.0	1164.3	8892.8
	Vit E-Chol suppl'd	9020.6	89.5	406.3	1191.4	9635.2
	Avg for cycle	8690.6	83.9	399.3	1177.1	9242.2
3	C-SBM control	7595.5	78.0	359.1	1032.4	8112.0
	Vit E-Chol suppl'd	7133.8	70.5	321.2	906.0	7165.9
	Avg for cycle	7382.4	74.6	341.6	974.1	7675.4
Overall average		7867.6	87.8	374.5	1066.0	8437.0

^aCalculated arithmetic means: Litter weight x averaged chemical composition values of sacrificed pigs within litter x (8/litter size).

TABLE XXIV. MEAN LITTER MINERAL CONCENTRATIONS CORRECTED TO LITTER OF EIGHT PIGS^a

Reproductive Cycle	Diet	Minerals							
		Iron (mg)	Manganese (mg)	Zinc (mg)	Copper (mg)	Potassium (g)	Calcium (g)	Magnesium (g)	Phosphorus (g)
1	C-SBM Control	180.27	7.73	121.26	20.29	10.55	120.67	2.25	69.04
	Vit E-Chol Suppl'd	174.27	7.57	117.85	17.51	9.59	123.96	2.18	74.88
	Avg for Cycle	177.00	7.64	119.40	18.77	10.03	122.46	2.22	72.23
2	C-SBM Control	245.68	6.57	214.88	12.01	7.32	125.58	2.53	67.16
	Vit E-Chol Suppl'd	230.18	6.64	174.32	12.35	7.84	127.46	2.49	66.49
	Avg for Cycle	238.39	6.60	195.79	12.17	7.57	126.47	2.52	66.85
3	C-SBM Control	92.48	5.48	114.23	7.80	8.59	111.48	2.34	52.28
	Vit E-Chol Suppl'd	89.77	4.50	110.25	7.94	7.23	100.38	1.90	50.02
	Avg for Cycle	91.23	5.03	112.39	7.87	7.97	106.36	2.14	51.24
Overall Average		175.62	6.65	142.62	13.89	8.71	119.75	2.29	65.22

^aCalculated arithmetic means: Litter weight x averaged mineral concentration of sacrificed pigs within litter x (8/litter size).

and gross energy of the fetuses accounted for 70.0% or more of the total, at parturition, and for more than 85.0% of the ash, Ca and P. Current chemical constituent levels are less than those reported by Mitchell et al. (1931) for a litter of eight pigs, as were average litter weights.

Mean litter mineral concentrations did not appear to maintain their levels as well as the chemical components through the three reproductive cycles. Mean litter Mn, Cu and P showed a progressive decline through the three cycles, while Fe, Zn, Ca and Mg increased to the second farrowing, then declined to levels lower than found for first litters. Generally, C-SBM litters contained more of the individual minerals, with there being significantly ($P < .05$) more K, Mg and Ca in these litters at last farrowing. Zinc content of these litters was higher ($P < .05$) in the second reproductive cycle. Litter Fe levels for first and second litters were higher than levels obtained by Hoskins and Hansard (1964) for litters standardized to 8 - 1 kg fetuses (105 days old). After 105 days gestation, total fetal Fe (119.0 mg) comprised 42.5% of that present in the fetal complex (Hoskins and Hansard, 1964). Litter Ca levels also exceeded Ca contents reported by Mitchell et al. (1931), and Itoh et al. (1967). Phosphorus levels in the first two litters exceeded the level reported by Mitchell et al. (1931). Gamble (1969) found the third-trimester litter to contain 6.4 mg Mn, which is equal to or less than levels of the first two litters. Copper concentrations at each of the farrowings were less than those found in standardized third-trimester litters (Gamble, 1969).

CHAPTER V

SUMMARY

Over-estimated nutritional needs, ecological awareness and confinement operations, have placed added emphasis on establishing minimum maternal dietary intake requirements for gravid swine. Yet, few investigations have been of long duration into the effects of limited-feeding for both gestation and lactation. The objectives of this study were to evaluate the reproductive performance of dam, maternal influence on baby pig composition, and postnatal growth of the progeny, when the maternal dam was limit-fed a standardized 16.0% protein diet during three successive reproductive cycles.

Twenty-four gilts, starting their second trimester of gestation, were maintained on concrete in open-fronted houses during the gestation period and individually fed 1.36 kg daily of a corn-soybean meal diet (C-SBM) formulated to provide 225.0 g protein and 4.6 Mcal digestible energy intake. Fish meal replaced 2.0% of the meat and bone scrap in a second corn-soybean meal diet supplemented with 120.0 mg dl-alpha-tocopherol and 1200.0 mg choline chloride/kg diet (Vit E-Chol). Sow lactation feed intake was limited to 1.36 kg plus 0.45 kg/pig nursing of the respective gestation diets. Chemical composition of two newborn pigs per litter was used to assess maternal dietary influence throughout successive gestations.

Confinement limited-feeding during the last two-thirds of gestation, supported increased maternal weight gains for the first two

pregnancies (14.6 and 21.1 kg), but an extremely low gain (1.6 kg) was made during the last gestation (winter). Sows were in a negative weight balance for the controlled feeding periods of the last two reproductive cycles. Vit E-Chol sows gained significantly ($P < .10$) more weight during the second gestation (summer), which combined with their smaller lactation weight loss nearly maintained body weight for the reproductive cycle ($P < .05$).

Reduced maternal backfat thickness during third trimester of winter gestation one, and last two-thirds of the third gestation, accompanied by weight gains (first farrowing), suggest daily feed intake level was not sufficient to maintain maternal condition and products of conception, simultaneously. The increased adipose tissue deposition in the second fat layer, during the summer gestation, could indicate adequate energy for continued maternal growth. Lactation caused a further decrease in condition. Low sow weights at the end of the third lactation, were further evidence that daily feed intake was inadequate for maternal growth through three successive reproductive cycles.

Fifty percent of the gilts started on each diet remained after three reproductive cycles (52 total farrowings). Failure to conceive at the first post-weaning estrus caused removal of more Vit E-Chol sows. A higher incidence of hypogalactia was evident in the C-SBM sows and apparent malnutrition during the last gestation caused abortion.

Increased number of total and live pigs farrowed per litter at successive gestations, indicated that ovulation and embryo survival were apparently not affected by feeding regime. Third farrowing birth weights were reduced. Vit E-Chol sows farrowed 1.2 more pigs per litter at the

third farrowing, but average birth weight was significantly ($P < .05$) less. Through the three reproductive cycles, birth weights were significantly correlated with the limited-feeding gestation gains ($r = 0.42$, $P < .01$) and condition changes ($r = 0.40$, $P < .01$).

Three week litter performance increased in favor of the Vit E-Chol pigs with successive lactations, except for average pig weight and gain, which were lower ($P > .05$) at the third lactation. Fetal priority over extrauterine maternal anabolism may have limited the labile protein store of Vit E-Chol sows for subsequent milk production. Pre-weaning pig growth increased through the three lactations and more pigs were weaned per litter when the creep diets also contained vitamin E. Increased creep feed consumption, per kilogram pig gain, indicated reduced milking ability of third lactation sows.

Whole body composition analyses revealed gross energy and protein levels declined slightly in succeeding farrowings with significantly ($P < .01$) lower levels in the Vit E-Chol pigs at the last farrowing. Over the three farrowings, Vit E-Chol carcass protein and moisture were significantly and negatively correlated ($r = -.37$, $P < .01$). There were no significant differences among the neonatal pig liver chemical components, but percent hepatic fat in C-SBM pigs was higher. It was significantly ($P < .10$) higher on the dry matter basis at first farrowing. Average liver fat declined from 2.30 to 1.04% over the three farrowings.

Gestation mineral levels fed appeared to meet needs for fetal growth as there were no clinical symptoms of mineral deficiency at birth. In general, neonatal pig plasma mineral concentrations, in this study,

did not reflect trends for liver and whole carcass mineral concentrations. For most of the minerals studied, Vit E-Chol pig tissue levels tended to be lower than in the C-SBM pigs and tissue concentrations were lowest at the last reproductive cycle.

Season and diet were associated with suboptimum sow reproductive performance and the dietary intake levels proved inadequate to maintain the sow through three successive reproductive cycles. The 225.0 g protein/day during gestation appeared to be sufficient for fetal development and growth, but pigs gestated by sows fed the Vit E-Chol diet were less responsive, for some undetermined reason, in terms of their chemical and mineral composition levels. However, progeny growth did not appear to be permanently curtailed by gestation diets or level of lactation feeding.

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VITA

Steven Philip Bertsch, the oldest of four children born to his parents, Bertha Emma (Bauer) Bertsch and Ralph Lowell Bertsch, was born May 27, 1941, in Indianapolis, Indiana. Following the death of his father, he farmed his mother's farm, raising a herd of purebred Hampshire hogs, while attending Whiteland High School. He was active in sports and other school activities, a 4-H member for ten years and a four year member of the Future Farmers of America.

Following graduation in 1959, he entered the Purdue University Indianapolis Regional Campus. After working at Allison, Division of General Motors, he completed the last two years at the Purdue Campus, graduating in 1965 with a Bachelor of Science degree in Agriculture. In September 1965, he entered graduate school at Purdue University and received the Master of Science degree in Animal Science in June of 1967.

He was employed for two years in Gibson County, Indiana, as an Area Extension Agent-Youth prior to his resignation in September 1968 to pursue graduate study at The University of Tennessee. He served as an Assistant in Animal Science and worked on Strong Stock Farm, Knoxville, during his graduate study and received his Doctor of Philosophy degree in Animal Science, under Dr. Sam L. Hansard, in June 1974. His minor area of study was Agriculture Economics. Mr. Bertsch is a member of the American Society of Animal Science, Gamma Sigma Delta and Phi Sigma.

He was married to the former Janet Irene Dingeldein of Franklin, Indiana, on September 1, 1963. They have two children, Laura, age eight, and Curtis, age five.