AN ABSTRACT OF THE THESIS OF

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Title: Evaluation of Responses of Sows and Their Litters to Feeding Patterns

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Preweaning mortality of piglets continues to be a problem in the swine industry, and improvement in either the fat content of colostrum and milk or the energy reserves of the porcine neonate may improve piglet survival. Two studies were conducted to assess the responses of Landrace x Yorkshire crossbred sows and their offspring to (a) same total but different patterns of gestational feeding (Study 1) and (b) dietary energy restriction in late gestation and early lactation (Study 2).

In Study 1, Trial 1, 20 controls and 20 treated sows were utilized. Total gestational feed intake was equal but pattern of feeding differed. Feed intake in 1st trimester was equal for control and treated sows (2.0 $kg \cdot sow^{-1} \cdot day^{-1}$). Treated sows were fed more than control sows in the 2nd trimester (3.0 versus 2.0 $kg \cdot sow^{-1} \cdot day^{-1}$), but less in the 3rd trimester (1.5 versus 2.5 $kg \cdot sow^{-1} \cdot day^{-1}$). High feed intake during the 2nd trimester increased treated sow weight gain ($P<.001$) and backfat thickness ($P<.05$), while

low feed intake in the 3rd trimester reduced treated sow weight gain and backfat thickness ($P<.001$ and $P.10$, respectively). Low level of feeding in the 3rd trimester elevated levels of serum glycerol and plasma fatty acids in treated sows ($P<.10$ and $P<.05$, respectively). Sow lactational weight gain, backfat thickness, and milk composition were similar for control and treated sows. The experimental pattern of feeding had no significant effect on piglet birthweight, survival, growth rate, or milk consumption. Percent small piglets from treated sows was positively correlated with piglet mortality on days 3 and 7 ($P<.10$ and $P<.01$, respectively). A partial repeat of the experiment (Study 1, Trial 2), using 7 controls and 8 treated sows, indicated results similar to those of Trial 1.

Study 2 utilized 20 controls and 20 treated sows: controls received the standard dietary energy intake; treated sows recieved 85% of the standard dietary energy intake. The 15% dietary energy reduction 7 days before and 3 days after parturition had no significant effect on sow weight gain, blood metabolites, or milk composition except for a higher day 3 milk fat level in treated sows ($P<.10$). Birthweight, survival, growth rate, and plasma free fatty acids concentration were similar for piglets of control and treated groups.

Results indicate that the pregnant sow is able to perform reproductive functions adequately with different patterns of gestational feeding, provided that nutrient intake is sufficient (Study 1), and with moderate dietary energy restriction in late gestation and early lactation (Study 2).

Evaluation of Responses of Sows and Their Litters to Feeding Patterns

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DEDICATION

In memory of my late mother,

Victoria Charlotte Akosua Adobea Addow

(1915-1985)

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDIX TABLES

EVALUATION OF RESPONSES OF SOWS AND THEIR LITTERS TO FEEDING PATTERNS

INTRODUCTION

The importance of piglet survival at birth and through the preweaning period to sow productivity has been repeatedly emphasized (Pomeroy, 1960; Sharpe, 1966; English and Smith, 1975). Poor preweaning survival of pigs continues to be a major problem in the swine industry. About 20% (range 10-30%) of piglets die before weaning (Fraser, 1966; English et al., 1982). Preweaning mortality in the United States is 30 million per annum with financial losses of 450 million dollars to swine producers (University of Georgia, 1981).

The majority of losses occur in the first week of life, notably the first 72 hours (Pomeroy, 1960). Newborn pigs encounter several challenges to their survival during the first few hours after birth (Mersmann, 1974). These challenges include ability to stay warm in an environment which is about 42 degrees below that of the uterus ($60^{o}F$ vs $102^{o}F$), ability to get sufficient nutrition at regular intervals, and ability to escape being crushed by the dam (McCance and Widdowson, 1959; Mount, 1963; England, 1974; English and Smith, 1975).

Inadequate prenatal development of energy stores and inefficient metabolic pathways may contribute to the high mortality among newborn piglets (Mersmann, 1974; Pettigrew, 1981). Glycogen is the major energy reserve for neonatal pigs. There is a rapid rate of liver glycogen utilization within the first 12-18 hours after birth (Stephens, 1971; Okai et al., 1978). Until it obtains some energy

from its first feed of colostrum, the piglet depends on its glycogen reserve to survive and establish itself (Curtis, 1970).

The newborn piglet has only 1-2% body fat (Seerley et al., 1978b), but most of it is structural and, therefore, unavailable for use as energy by the porcine neonate (Pettigrew, 1981). The rapid depletion of carbohydrate reserves even in the piglet obtaining all its energy from colostrum suggests a life-threatening condition with respect to the lack of energy supplies (Pettigrew, 1981).

Factors that increase either the fat content of sow colostrum and milk or the energy reserves of newborn pigs may improve the survival rate of neonatal pigs. Potential means of improving the energy stores of the porcine fetus may be to increase maternal substrates transferred across the placenta and also to alter hormone status of the gravid sow (Kasser et al., 1982).

One of the factors contributing to poor survival of pigs from birth to weaning is low birthweight (English and Wilkinson, 1982). Several attempts have been made to improve the preweaning survival of piglets without much success. These include: (a) increasing the plane of nutrition of the sow, (b) supplementing dietary energy of the dam with carbohydrate or fat, (c) use of diabetogenic agents (Streptozotocin and Alloxan), (d) use of synthetic energy source (1,3-butanediol), (e) use of exogenous glucocorticoid (triamcinolone), and (f) use of dichlorvos (DDVP).

Unborn pigs grow fastest during the last 3 weeks of gestation; therefore, nutrients needed for their growth are greater in late pregnancy. One of the ways this need is met traditionally is by

increasing feed intake of the sow during the last 3 to 5 weeks of gestation. Another way may be to stimulate mobilization of stored fat in the gravid sow to increase fatty acid concentration in the dam's blood circulation and presumably increase the availability of fatty acids to the developing fetus.

The traditional method of feeding sows moderately in early and mid gestation and increased level in late gestation is suitable for areas of the world where supply of feed ingredients is always abundant. However, in parts of the world where annual temporary feed shortages are experienced, there is need for a different pattern of feeding, one that allows for flexibility in the level of gestational feeding without adversely affecting the reproductive performance of the sow. To date, most reported studies on nutritional manipulation have measured only physical characteristics of sow and her offspring. Very few studies have reported on the effects of nutritional manipulation on concentrations of blood energy substrates. Most of the studies have been conducted during gestation, very few during lactation, but almost none during gestation and lactation. With these points in mind, two studies were conducted. The aim of Study 1 was to evaluate the effect of increased level of feeding in mid gestation and decreased level of feeding in late gestation on the performance of the sow and her litter. The purpose of Study 2 was to determine whether reduction in availablity of dietary energy 7 days before and 3 days after parturition would affect the sow and her litter.

LITERATURE REVIEW

Nutritional Manipulation Throughout Gestation

Much research work has been undertaken on the relation between nutrition and reproductive performance in pigs; however, it is not easy to make a comparison between the different studies because conditions, such as the age of breeding females and the energy system (e.g., gross or net) in which the requirement of the pigs was expressed, were different. Another problem is that most trials are small and variation may be wide, especially in studies on fertility.

Level of Feeding

Effect of level of feeding on sow fertility. Some studies have indicated that the gilt and sow can tolerate mild nutritional insult for several parities with no marked effect on sow prolificacy. Increasing the level of feeding in gilts (flushing) prior to breeding resulted in higher ovulation rates (one or two more ova) in the first or second estrus (Self et al., 1955; Brooks and Cole, 1972a). Conception rates were improved in primiparous sows when plane of nutrition was increased from weaning to estrus (Brooks and Cole, 1972b). Other reports indicated that multiparous sows were not affected by high levels of feeding prior to breeding (Dyck, 1972; Fahmy and Dufuour, 1976; Tribble and Orr, 1982). The only instance when a positive effect of feeding was observed in multiparous sows was when the sows were in very poor condition and/or in herds where the litter size was below average (Lodge and Hardy, 1968). Thus, the level of feeding in the weaning-to-breeding interval is not likely to

improve reproductive performance of mature sows unless it is to reverse a reduction in performance due to poor management in the preceding lactation (Aherne and Kirkwood, 1985).

Severe restriction of protein/energy intake for several parities resulted in reduction in number of sows exhibiting estrus and an increase in rebreeding interval (Pike and Boaz, 1972; Hovell and MacPherson, 1977). In another study, restriction of non-protein energy or feed intake during the first two-thirds of pregnancy had no adverse effect on sow productivity (Pond and Yen, 1987). Pregnancy was maintained in 79% of primiparous sows when a 37-day starvation was imposed on them (Anderson, 1975), indicating the ability of the sow to effectively buffer the developing fetus against nutritional inadequacy (Elliot and Lodge, 1977, 1978). In the multiparous sow, a high plane of nutrition during the first 30 days of pregnancy had no effect on embryonic survival or development (Toplis et al., 1983). Other reports indicated that high levels of feed intake, especially energy-rich diets, may lead to increased embryo mortality (Robertson et al., 1951; Frobish and Steele, 1970; Dyck and Strain, 1980). In one study, overfeeding of sows in gestation (8.84 Mcal DE$\cdot$sow$^{-1}\cdot$day^{-1}) for three parities caused an increase in the culling rate due to lameness and failure to exhibit estrus (Aherne et al., 1990).

It is obvious that timing of the level of feeding is essential, particularly in younger sows and gilts, if the full benefits of nutrition on fertility of the dam is to be achieved.

Effect of level of feeding on sow liveweight and weight change. Sows are commonly fed so that a considerable weight gain during

pregnancy is followed by an almost equal weight loss during the subsequent lactation (Lodge et al., 1961). Elsley (1973) reported that feed intake in pregnancy was highly correlated with liveweight gain of the sow ($r = .7$).

That weight gain during pregnancy may be reduced considerably below that accepted as normal without adverse effect on reproductive performance was indicated by several researchers (Eyles, 1959; Dean and Tribble, 1961; Clawson et al., 1963; O'Grady, 1967). Reports from other studies suggested that overall efficiency of energy utilization by the sow would be greater if weight gain during pregnancy and weight loss during lactation were reduced so that the sow remained at a more constant body weight (Smith, 1960; Bowland, 1967).

The literature revealed that even though sows can withstand mild nutritional insults without any apparent adverse effect on their reproductive performance, extremes in plane of nutrition is not a sound management practice.

Effect of level of sow gestational feed intake on piglet performance. One of the factors observed to contribute to poor survival of piglets from birth to weaning was low birthweight (English and Wilkinson, 1982). In one study (Elsley, 1973), sow feed intake was moderately correlated to piglet birthweight ($r = .46$), suggesting there may be a progressive increase in piglet birthweight as level of sow gestational feed intake is increased. In another study (Clawson et al., 1963), sows on higher feed intake tended to produce large piglets. This linear relationship was not observed when sow daily

feed intake exceeded 25 MJ DE (Libal and Wahlstrom, 1977; Henry and Ettiene, 1978).

In general, the argument for feeding higher than recommended levels throughout pregnancy, in an attempt to improve piglet birthweight, was not well established. Even if higher feed intake in pregnancy results in higher birthweights, it may not be economical to put gravid sows on high plane of nutrition throughout gestation (Elsley et al., 1969). Apart from the risk of agalactia in early lactation, the increase in birthweight of piglets is modest compared to the extra amount of feed given to the sow (Elsley et al., 1969). It has been reported that for each additional kilogram of feed per day, piglet birthweight increased by 20 grams and 30-50 grams for gilt and sow litters, respectively (Aherne et al., 1990).

Other studies indicated that low gestational feed intake had negative effect on birthweight (Dean and Tribble, 1961; Close et al., 1984; Pond et al., 1987). Reducing the feeding level of pregnant sows by 40-50% resulted in 7-13% reduction in average piglet birthweight (O'Grady, 1962; Clawson et al., 1963; Lodge et al., 1966a). It is possible that the 40-50% reduction in feed intake caused a reduction in mean piglet birthweight as a result of nutrient deficiencies. However, Lodge et al. (1966b) observed no symptoms of specific deficiency peculiar to the group fed low. When mineral and vitamin intakes by sows were equalized and the effects of energy and protein on piglet birthweight were studied (Clawson et al., 1963), low protein intake had no effect on piglet birthweight but low energy intake caused a 10% reduction in the weight of newborn pigs.

In general, the literature indicated that putting sows on a high plane of nutrition throughout pregnancy in an attempt to improve piglet birthweight and, hence, preweaning survival rate, is apparently not an answer to the problem because (a) it is uneconomical and (b) the sows are at risk for agalactia in early lactation, when regular and adequate nutrition for the piglet is crucial.

Patterns of Feeding

Effect of patterns of feeding on sow and litter performance.

While there have been several studies on overall levels of feeding for pregnant sows, few have studied the effects of change in level of feeding (Elliot and Lodge, 1978). Among these studies changes were imposed during the first month (Elsley et al., 1971; Anderson, 1976), the last trimester (Lodge et al., 1966a), and both first and last months of pregnancy (O'Grady, 1967; Elsley et al., 1971). Apart from the total starvation imposed by Anderson (1975), the magnitude of change did not exceed an increase of 100% (O'Grady, 1967; Lodge et al., 1966a) or a decrease of 56% (Anderson, 1976). Some reports indicated that pattern of feeding was less important than the total amount of feed (Salmon-Legagneur, 1962; O'Grady, 1967; Elsley et al., 1971). Different patterns of feeding had no effect on number born, birthweight, or subsequent growth rate of the offspring (Salmon-Legagneur, 1962). There was no adverse effect on reproductive performance of second parity sows fed once every third day (Michel et al., 1980), but gilts subjected to the same feeding pattern gained less weight during gestation and produced smaller litters with lower birthweights. In another study, average daily feed intake for

primiparous sows and second parity sows fed every 3 days was higher (0.4 kg and 1.2 kg, respectively) than average daily feed intake for those fed daily (Michel and Easter, 1985). In that experiment, it was observed that when sows were allowed to eat ad libitum every third day, consumption was greatest at the end of the first trimester and again at the beginning of the third term, but average voluntary feed intake declined during mid gestation.

More research is required to fully understand the effect of change in patterns of feeding throughout gestation on sow productivity.

Nutritional Manipulation in Late Gestation

Effect of Increased Feed Intake in Late Gestation on Sow and Litter Performance

Over the past two decades, several studies have been conducted to provide estimates of effects of varying the energy intake of sows on their reproductive performance (Elsley, 1973). Since energy requirements increase as offspring grow in utero, it has been suggested that daily feed intake should reflect growth of the fetus, rather than remain constant throughout gestation (Commonwealth Agricultural Bureaux, 1981).

The greatest growth rate of the porcine fetus occurs during the last 2 to 3 weeks of pregnancy. It follows, theoretically, that nutrient requirement of the sow increases as pregnancy advances (Aherne and Kirkwood, 1985). Fetal weight has been reported to double in the last 10 to 30 days and such reports have generated interest in

the effect of change in the level of sow feeding, particularly in the last term of pregnancy, on piglet birthweight and subsequent performance. Piglet birthweight increased by 81.82 g when feed intake of dam was doubled in the last 5 weeks of gestation (Lodge et al., 1966a). The beneficial effects of increased feed intake in late gestation was confirmed by other researchers (Hillyer and Phillips, 1980; Cromwell et al., 1982). Ad libitum feeding of sows in late gestation significantly improved survival of piglets that weighed less than 1.0 kg at birth (Okai and Aherne, 1976). Such piglets contribute greatly to the mortality rate in a litter, especially in the first 3 days after birth (English and Wilkinson, 1982).

Additional feeding during the last 3 to 4 weeks of pregnancy may be a practical method for improving reproductive performance of thin gilts and sows. Cromwell et al. (1989) reported that increasing the daily feed intake of sows by 1.36 kg during the last 23 days of gestation resulted in .3 pigs more per litter and 172.73 g higher piglet weaning weight. They indicated that the additional feed cost of about $4 per sow was offset by the additional .3 pig/litter (worth about $4-$8) plus the additional net weight gain by the sow from breeding to weaning (5.0 kg, worth $3.50 to $4.) However, not all studies on higher plane of nutrition in late gestation reported beneficial effects. Increasing the feed intake by 200% during the last 21 days before parturition resulted in no improvement in sow productivity (Eyles, 1959; Lima and Cline, 1987).

It appears that increasing the feed intake of sows at the time of maximum piglet growth *in utero* may be sound management practice to attempt to improve birthweight of the porcine neonate and subsequent piglet performance.

Effect of Restricted Feed Intake in Late Gestation on the Sow and Litter Performance

At the time of this study, there was little information on the effects of reduction in nutritional status for short, possible critical periods during gestation, such as the final 2 to 4 weeks, when fetal growth is maximum. Imposition of severe feed restriction (.45 $kg \cdot sow^{-1} \cdot day^{-1}$) during the last 15 days of pregnancy did not affect either birthweight or litter size (Elliot and Lodge, 1978). Fasting gilts for 1 or 2 weeks prior to farrowing caused no adverse effects on reproductive performance of dams or subsequent performance of offspring (Aherne and Kirkwood, 1985).

It appears that severe restriction in feed intake for a short period during late gestation has relatively little influence on sow productivity, confirming the ability of the sow to buffer the developing fetus against nutritional insults.

Effect of Supplemental Energy in Late Gestation on Sow and Litter Performance

Inadequate energy storage by the porcine fetus may be responsible for the high mortality rate of the neonatal piglet. One way to improve the energy store prior to parturition may be to manipulate the nutrition of the dam in the latter part of pregnancy (Ruwe et al., 1991). An example of such manipulation is the use of carbohydrate or fat to increase the energy content of the diet. Feeding of 24%

galactose during gestation promoted lipid synthesis in the adipose tissue of porcine fetus, increasing energy storage for use postnatally and, therefore, improving survivability of the neonate (Olivieri et al., 1989). However, dietary galactose did not appear to partition glucose for use in glycogen synthesis and deposition (Olivieri et al., 1989).

The pioneer research in short-term fat supplementation was conducted by Seerley et al. (1974). Addition of corn oil (CO) was superior to corn starch (CS) fed in the sow diet from day 109 of gestation to parturition, at the rate of 24 kcal ME $kg \cdot BW^{-1} \cdot day^{-1}$, and resulted in improved survival rate of piglets from birth to weaning. This was especially true for small piglets (less than 1.0 kg birthweight) in the CO group. These findings were confirmed by other researchers (Okai and Aherne, 1976; Cast et al., 1977; Holness and Mandisodza, 1985). The probable reasons for the improved piglet survival were: (a) increased average piglet birthweight (Seerley et al., 1974; Boyd et al., 1978); (b) increase in carcass fat (Seerley et al., 1974; Boyd et al., 1978); (c) slower disappearance of liver glycogen (Boyd et al., 1978; Okai et al., 1978), or an increase in the blood glucose level of the piglet (Seerley et al., 1974; Cast et al., 1977). One study observed no beneficial effect of energy supplementation on piglet survival rate (Friend, 1974).

The beneficial effect of energy supplementation on piglet survival has been controversial. The area generating the least controversy has been the observation that supplemental fat improved colostral and milk fat content (Seerley, 1981; Moser, 1983) and milk

yield (Kruse et al., 1977; Coffey et al., 1981; Boyd et al., 1982a, 1982b). In general, there was little or no effect on the number born, but survival rate on the average improved by 2.6%, which translated into .3 more pigs weaned per litter. The .3 pigs more than offset the cost of supplemental fat (Moser and Lewis, 1980). Energy supplementation in late gestation appears to be a promising method for improving sow productivity.

Other Methods Used to Improve Piglet Survival

Use of 1,3-butanediol (BD)

1,3-butanediol is a synthetic energy source with ketogenic properties. It is nutritionally palatable, calorie dense (6 kcal ME/g), and readily absorbed in monogastrics.

Studies indicated that BD could be used as a feed additive to improve reproductive performance of the sow. Substitution of 15% of the caloric content of gestation diet by BD 24 days prior to farrowing increased fetal glycogen storage but not fetal lipid content (Boyd et al., 1982a, 1982b). Replacement of 20% of the daily energy intake of sows from day 105 of pregnancy improved preweaning piglet survival by 5.7%, which translated into .51 pigs weaned per treated litter at 28 days postpartum (Stahly et al., 1985).

Use of Dichlorvos (DDVP)

During an investigation by a commercial company on the efficacy and safety of 2,2-dicholorovinyl dimethyl phosphate (Dichlorvos or DDVP) as an anthelmintic for gravid sows, it was observed that sow reproductive performance improved. This generated interest in the

effect of DDVP on sow productivity. Several studies (Foster, 1968; Singh et al., 1968; England, 1969, 1974) reported that addition of 800 mg of DDVP in the daily ration for 3 to 6 weeks prior to farrowing improved piglet birthweight and preweaning survival. Findings of another study (Anderson and Wahlstrom, 1970) did not confirm the positive influence of DDVP on piglet birthweight, but did observe an increase in the liver glycogen content of piglets. In general, the reports indicated that feeding DDVP in late gestation has beneficial effects on sow productivity.

Use of Triamcionolone, a Synthetic Glucocorticoid

Triamcionolone supplementation in gestation diets in late pregnancy resulted in a 21% increase in sow colostral fat (Bishop et al., 1985). The elevated colostral fat level was probably due to the stimulatory effects of glucocorticoid on fatty acid mobilization from the sow's fat stores (Jeanrehaud and Renold, 1960) and the apparent readiness of incorporation of the fatty acids into milk fat (Salmon-Legagneur, 1965). Oral ingestion of triamcinolone in late pregnancy increased average piglet birthweight and survival rate (Bishop et al., 1985). The improvement in piglet performance may have been due to an increase in total amount of energy substrates available to the porcine fetus (Felig, 1975).

Use of Porcine Somatotropin (PST)

There are indications that piglet survival can be improved by manipulating circulating maternal hormones. Administration of 10 $mg \cdot sow^{-1} \cdot day^{-1}$ of highly purified porcine growth hormone for 21 days prior to farrowing elevated serum glucose level in gravid dams,

leading to a corresponding increase in neonatal piglet blood glucose level and body lipids and a tendency toward increased piglet liver glycogen (Kveragas et al., 1986).

In general, the use of feed additives and growth promotants such as 1,3-butanediol, dichlorvos, triamcinolone, and porcine somatotropin in gestation diet in late pregnancy appeared to have beneficial effects on sow and litter performance.

Manipulation of Maternal Blood Metabolites

Inadequate prenatal development of energy stores and inactive metabolic pathways contribute to high rates of preweaning mortality of pigs (Mersmann, 1974). Two potential means of altering energy stores in fetal pigs are: (a) increasing maternal energy substrates transferred across the placenta and (b) altering hormone status to favor energy storage in the developing fetus (Kasser et al., 1982).

Effect of Diabetogenic Agents

Studies have shown that Streptozotocin- or Alloxan-induced maternal diabetes increased body fat content of the porcine fetus (Ezekwe et al., 1984) and the neonatal piglet (Ezekwe and Martin, 1978, 1980; Kasser et al., 1981a, 1981b). Although human maternal diabetes has been reported to result in heavier babies (Farquhar, 1966), Ezekwe et al. (1984) did not observe such a relationship between maternal diabetes in sow and piglet size. Pigs from alloxan-diabetic dams survived a 60-hour fast better than controls (Kasser et al., 1982), implying that energy status of piglets from diabetic dams improved.

Higher levels of lipids in piglets from treated sows may be due to placental transfer of maternal glucose and fatty acids (Romsos et al., 1971; Ezekwe et al., 1984). An increase in maternal free fatty acids (FFA) may raise the rate of transport to the fetus (Sabata et al., 1968) and improve synthesis and storage of lipids (Ezekwe et al., 1984). Higher energy status in pigs at birth may improve their chances of survival (Ezekwe et al., 1984).

Effect of Fasting

In one study (Kasser et al., 1982), fasting raised free fatty acids (FFA) and beta-hydroxybutyrate (BOHB) concentrations nearly twofold in the blood of pregnant gilts, but there was no corresponding increase in the circulation of the offspring. Failure to sustain higher serum FFA and BOHB in fetuses may be due to: (a) greater placental utilization of these substrates or (b) higher utilization of these substrates by fetal tissues (Kasser et al., 1982).

In another study (Ruwe et al., 1991), a 10-day fast in late gestation (day 100 to 110) elevated nonesterified fatty acids (NEFA) by 907% but there was only a slight trend toward increased NEFA concentration in fetal blood from treated groups (42.83 vs 34.46 μEq/L). No change was observed in metabolic rates of fetal adipose tissue or placenta, indicating that neither the placental tissue nor the fetus had access to the elevated maternal fatty acids (Ruwe et al., 1991). This implied that the actual uptake of these substrates may be the parameter responsible for the ineffectiveness of dietary manipulation during gestation to improve fetal energy storage (Ruwe et al., 1991).

It is clear that nutritional manipulation can be beneficial to the improvement of sow and piglet performance. Prior to the present study, there have been several studies on plane of nutrition throughout pregnancy on pre- and post-natal performance of the sow and her offspring but few on the effects of different patterns of feeding during gestation on sow productivity. The present study was designed to evaluate the effect of change in level of feeding during different stages of pregnancy on physical and physiological conditions of the sow and the relationship of these to piglet survival and growth rate.

MATERIALS AND METHODS

Experimental Design

The studies were conducted at the Oregon State University Swine Center from summer 1988 to summer 1990.

Study 1

The purpose of this study was to evaluate the effect of increased feed intake in mid-pregnancy and decreased level of feeding in late gestation on: (1) piglet birthweight, survival, and growth rates; (2) sow blood glycerol, glucose, and free fatty acids and their relationships with piglet performance for piglet birthweight, growth, and survival rates; and (3) the lactation and subsequent breeding performance of sows.

The theoretical basis of the study is that a large amount of energy will be accumulated in the sow as fat during the middle portion of gestation. The fat will be mobilized in late gestation, thereby increasing the level of fatty acids in the dam's blood. This might result in a corresponding increased availability of fatty acids to: (a) the developing fetus and (b) the sow for lactation.

Forty Landrace x Yorkshire (L x Y) crossbred sows were randomly allocated to one of two patterns of feeding within 24 hours of breeding (Study 1, Trial 1). Fifteen of the 40 sows (7 controls and 8 treated) were used to determine whether the treatment regimen at next pregnancy had discernible cumulative effect different from the initial parity (Study 1, Trial 2).

Study 2

The objective of this study was to evaluate the effect of reduction in dietary energy in late gestation and early lactation on sow and piglet performance. The hypothesis being tested was whether reduction of the energy content of the diet from day 105 of gestation to day 3 of lactation would influence the level of energy substrates, especially plasma fatty acids, in the sow's blood and presumably influence the energy status of soon-to-be-born piglets and performance of the sow in early lactation.

Forty L x Y crossbred females were allocated to control (C) and treated (T) groups at random.

Methodology

Animal Management

Housing. In Study 1, the breeding sows were housed in a barn with individual stalls from day of breeding (day 0) to day 110 of pregnancy. Sows were then moved into farrowing crates until day 21 postpartum. Heat lamps over two creep areas along sides of farrowing crates ensured maintenance of temperatures of about 90^{o}F for newborn piglets.

In Study 2, similar procedures were followed, except sows were moved into farrowing crates on day 105 of pregnancy.

Feeding. In Study 1, the gestation period was divided into three trimesters: days 0 to 36 = 1st trimester; days 37 to 72 = 2nd trimester; days 73 to 110 = 3rd trimester (Fig. 1). Total feed intake throughout gestation was equal for both groups (Table 1). Control (C) sows were fed 2.0 kg·sow^{-1}·day^{-1} in the 1st and 2nd trimesters and 2.5 kg·sow^{-1}·day^{-1} in the 3rd trimester. Daily feed intake per treated

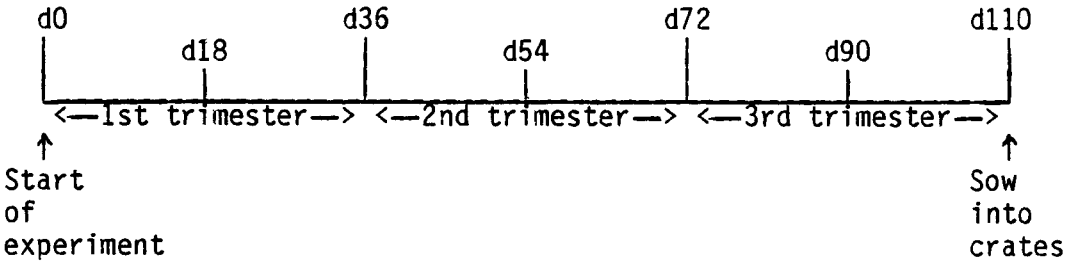


Fig. 1. The gestation period divided into three trimesters

Table 1. Feeding program in Study 1

	Gestation Diet (kg/sow/day)	
	Control[a]	Treated[b]
1st trimester	2.0	2.0
2nd trimester	2.0	3.0
3rd trimester	2.5	1.5
	Lactation Diet (kg/sow/day)	
d. 111-112	3.75	3.75
Postpartum	ad lib	ad lib

[a] Traditional feeding pattern

[b] Experimental feeding pattern

sow was 2.0, 3.0, and 1.5 kg of the same diet in the 1st, 2nd, and 3rd trimesters, respectively (Table 2). Sows were hand fed daily in individual closed stalls to ensure accuracy of feed per animal; stalls were opened after 30-minute feeding time. From day 111 to 112, sows were fed 3.75 $kg \cdot sow^{-1} \cdot day^{-1}$ of lactation diet (Table 2). Feeders were filled twice daily from day of farrowing to day 21 of lactation and the quantity of feed recorded at each feeding time. Any remaining feed was weighed back at the end of each week.

The feeding program and composition of diets in Study 2 are shown in Tables 3 and 4, respectively. Control (C) sows were fed 2.5 $kg \cdot sow^{-1} \cdot day^{-1}$ of wheat-soy lactation diet from day 105 of pregnancy to parturition. Treated (T) sows were fed an equal amount but half of the daily ration (1.25 kg) was wheat bran-based diet (high fiber diet), which reduced their dietary energy by 15%. All sows were fed ad libitum from day 0 to day 3 of lactation and amount of feed recorded. From day 4 to day 7 of lactation, both groups were fed the control diet ad libitum.

Liveweight and backfat measurement. Ultrasonic measurements of backfat were taken as average of three determinations (shoulder, midback, and rump). In Study 1, gestational sow weights and backfat measurements were recorded on days 0, 18, 36, 54, 72, 90, and 110. Sow weights and backfat for lactation were measured within a day of farrowing and once weekly for 3 weeks. Piglets were weighed at birth and on days 3, 7, 14, and 21.

In Study 2, sow liveweight and backfat measurements were recorded on days 105 and 112 of gestation and day 7 of lactation. Piglets were weighed at birth and on day 7.

Table 2. Composition of gestation and lactation diets

Ingredient	Gestation (%)	Lactation (%)
Wheat	69.40	70.80
Soybean oil meal (47%)	12.65	15.20
Molasses (sugar beet)	--	5.00
Suncured alfalfa meal (17% CP)	15.00	5.00
Dicalcium phosphate	0.70	1.50
Ground limestone	1.50	1.00
Potassium chloride	--	0.75
Shamrock vitamin mix	0.25	0.25
Trace mineralized salt	0.50	0.50
	100.00	100.00
Zinc sulfate	340 g/ton feed	340 g/ton feed
Energy (kcal/kg DE)*	2974.15	3055.17
Crude protein (%)	14.77	18.29
Acid detergent fiber (%)	8.09	6.40

* Calculated

Table 3. Feeding program in Study 2

	Lactation Diet (kg/sow/day)	
	Control[a]	Treated[b]
Gestation (d. 105-112)	2.5	1.25 CD + 1.25 ED
Lactation		
d. 0-3	Ad lib CD	Ad lib CD + ED
d. 4-7	Ad lib CD	Ad lib CD

Note: d. 105 = start of experiment
CD = control diet
ED = experimental diet

[a] Standard dietary energy

[b] 85% of standard energy

Table 4. Composition of diets in Study 2

Ingredient	Control (%)	Experimental (%)
Wheat	70.80	--
Wheat bran	--	91.48
Soybean oil meal (47%)	15.20	3.51
Molasses (sugar beet)	5.00	5.00
Suncured alfalfa meal (17% CP)	5.00	5.00
Dicalcium phosphate	1.50	--
Ground limestone	1.00	2.76
Potassium chloride	.75	.75
Shamrock vitamin mix	0.25	0.50
Trace mineralized salt	0.50	0.75
Zinc sulfate	trace[a]	.25
	100.00	100.00
Energy (kcal/kg DE)[b]	3055.17	2078.96
Crude protein (%)	16.86	18.29
Acid detergent fiber (%)	6.40	13.08

[a] 340 g/ton feed

[b] Calculated

Health. The following procedures were followed in both studies.

1. Prepartum: 2 ml of Escherichia coli bacterin (litter-guard) was administered intramuscularly on days 70 and 110 of pregnancy to protect newborn pigs from piglet scour (diarrhea).

2. Postpartum: Two boluses of tetracycline (antibiotic) were inserted as close as possible to the cervix, using a bolus gun. Sows were also given 5 ml procaine penicillin (intramuscular injection) for the first 3 days postpartum. The antibiotics were to protect the dams from infections that might have had adverse effects on lactational performance.

Parturition.

1. Induction: 2 ml of lutalyse (Dinoprost tromethamine), an exogenous prostaglandin ($PGF_{2\alpha}$), was administered intramuscularly in the rump of all sows on day 112 of gestation to induce farrowing within 18-30 hours. In Study 2, gilts were not induced to farrow due to adverse reaction to the drug.

2. Farrowing: Farrowing was supervised as much as possible to prevent such perinatal losses as piglets born in the sac and dying of asphyxiation, or prolonged farrowing, resulting in weak piglets prone to starvation, hypothermia, and overlying by the dam. Each sow was allowed to farrow the first piglet on her own, after which 2 ml oxytocin (20 USP/ml) were administered intramuscularly in the rump at 45-minute intervals until farrowing was completed with the delivery of the afterbirth. Each piglet was wiped dry and gently placed under a heat lamp after the umbilical cord became detached from the dam.

Sows having difficulty farrowing (dystocia), as indicated by strong and prolonged straining for over 2 hours between consecutive

deliveries of piglets, were given assistance. The vulva was washed with warm water containing disinfectant. An arm covered with a shoulder-length polyethylene glove lubricated with sterile gel was gently inserted as far as possible into the birth canal. Any piglet blocking the passage due to large size or wrong position (across rather than linearly) was gently pulled out. Sows needing farrowing assistance were given antibiotics and closely watched during the first 3 days of lactation for any signs of infection.

In Study 2, sows were also attended at farrowing so that blood samples could be obtained from neonatal piglets before their first nursing in order to assess more accurately plasma fatty acid status immediately prior to farrowing.

In both studies, the number of piglets born dead was recorded while live ones were weighed, ear-notched, and teeth-clipped within 24 hours of birth. At 3 days of age, 2 ml of iron dextran were administered into the neck muscle to prevent piglet anemia. Tails of piglets were docked to leave about 2 cm of tail.

Fostering. As far as possible, piglets were allowed to suckle their own dams. Number of piglets nursed by each sow was standardized to 11, so supranumerary piglets were fostered onto other sows in the same experimental group.

Milk.

1. Collection and analysis: In Study 1, a total of 35 ml of colostrum or milk was collected from all functional glands of the dam within 6 hours of farrowing and on days 3, 7, 14, and 21 of lactation. In Study 2, milk samplings were on days 0, 3, and 7 of lactation.

After the first day, 2 ml of oxytocin was administered intramuscularly to induce sows to let down milk for sampling. Milk samples were strained through a metal strainer and poured into special plastic sample bottles with snap caps. A preservative tablet was added to each sample to prevent spoilage during shipment to the Dairy Herd Improvement Agency (DHIA) at Tillamook, Oregon, for analysis of milk fat, lactose, protein, and solids-not-fat (SNF) in an automatic milk analyzer.

2. Estimation of milk yield: Average milk intake per piglet was measured using the weigh-suckle-weigh method (Lewis et al., 1978). Piglets were removed from warm creep area and put in an unheated wooden box for 30-40 minutes. The colder environment induced them to urinate and defecate before the initial weighing, rather than between the two weighings. Milk intake of six average-size piglets per litter were used to determine the milk intake and, hence, estimate the milk yield of each dam. Piglets were weighed individually, allowed to suckle, and weighed immediately after nursing. The difference between the two weights was an estimation of the milk intake and, hence, milking capacity of the sow.

Blood.

1. Collection: Sows were restrained in a chute and a total of 20 ml of blood was collected from the ear vein on days 0 (day of breeding), 36, 72, and 110 of gestation in Study 1 and on days 105 and 112 of gestation and day 7 of lactation in Study 2. Ten ml of the blood was collected over heparin (anticoagulant) in a vacutainer and later used for collecting plasma. The remaining 10 ml of whole blood

was collected into nonheparinized vacutainers and 10 mg of powdered sodium fluoride (NaF) added per ml of whole blood to inhibit glycolysis. Serum was prepared from this sample.

In Study 2, blood was collected from piglets. Piglets were removed from farrowing crates as soon as umbilical cords became detached from the dam. The neonates were dried and placed in a heated wooden box for 30 minutes to allow the body temperature to rise. At the end of the waiting period, about 3/4 of the piglet's tail was cut off, using a new sterile surgical blade, and discarded (a new blade was required for each litter to ensure clean cuts and prevent cross contamination between litters). The cut end of the remaining tail was quickly stuck into the open end of a heparinized tube. A total of 3 ml of blood was collected from 4 to 6 piglets per litter. After blood collection from each piglet, the tail end was pinched between the index finger and thumb for about 60 seconds to stop the blood flow and disinfectant applied to the wound.

2. Plasma and serum preparation: Whole blood samples (heparinized and nonheparinized) were held on ice for 4 hours to allow plasma in heparinized blood samples to separate and blood in nonheparinized samples to clot. Blood samples were centrifuged at 2900 x g for 15 minutes. Aliquots of 2 ml of plasma or serum were put in 12 x 75 mm snap cap borosilicate glass tubes, labelled with date of collection, sow's identity, and contents (plasma or serum). Tightly capped tubes were stored at -20^{o}C until analyzed for plasma nonesterified fatty acids (NEFA), serum glucose, and serum glycerol.

Laboratory Analysis of Serum and Plasma

Serum glucose. Glucose in perchloric acid deproteinized serum was determined (Sigma, 1984) based on the following coupled enzymatic reactions:

$$\text{Glucose} + 2H_2O + O_2 \xrightarrow{\text{Glucose oxidase}} \text{Gluconic acid} + 2H_2O_2$$

$$H_2O_2 + \underset{\text{(colorless)}}{\text{o-Dianisidine}} \xrightarrow{\text{Peroxidase}} \underset{\text{(brown)}}{\text{oxidized o-Dianisidine}}$$

The intensity of the brown color measured at 450 nm was proportional to the original glucose concentration (see Appendix A for details of this procedure).

Serum glycerol. Concentration of glycerol in the serum sample was determined by fluorometric method (Wieland, 1974). The principle of the method is as follows:

1. $\text{Glycerol} + \text{ATP} \underset{\longrightarrow}{\overset{\text{GK}}{\longleftarrow}} \text{L - (-) Glycerol - 3 - P} + \text{ADP}$

2. $$\text{L - (-) Glycerol - 3 - P} + NAD^+ \quad \uparrow\downarrow \text{GPDH}$$
$$\text{Dihydroacetone phosphate} + \text{NADH} + H^+$$

The formation of NADH as measured by an increase in absorbance at 340 nm was proportional to the amount of glycerol (see Appendix A for details) (GK = glycerokinase; GPDH = glycerophosphate dehydrogenase).

Plasma nonesterified fatty acid (NEFA). Concentration of plasma NEFA was determined by extraction and microtitration of the fatty acids (Dole and Meinertz, 1960; Kelly, 1965) (see Appendix A for details).

Statistical Analysis

Data were analyzed using General Linear Models procedure (SAS, 1988). Associations between variables were explored using the Pearson correlation coefficient. Correlations were calculated within treatment.

RESULTS AND DISCUSSION

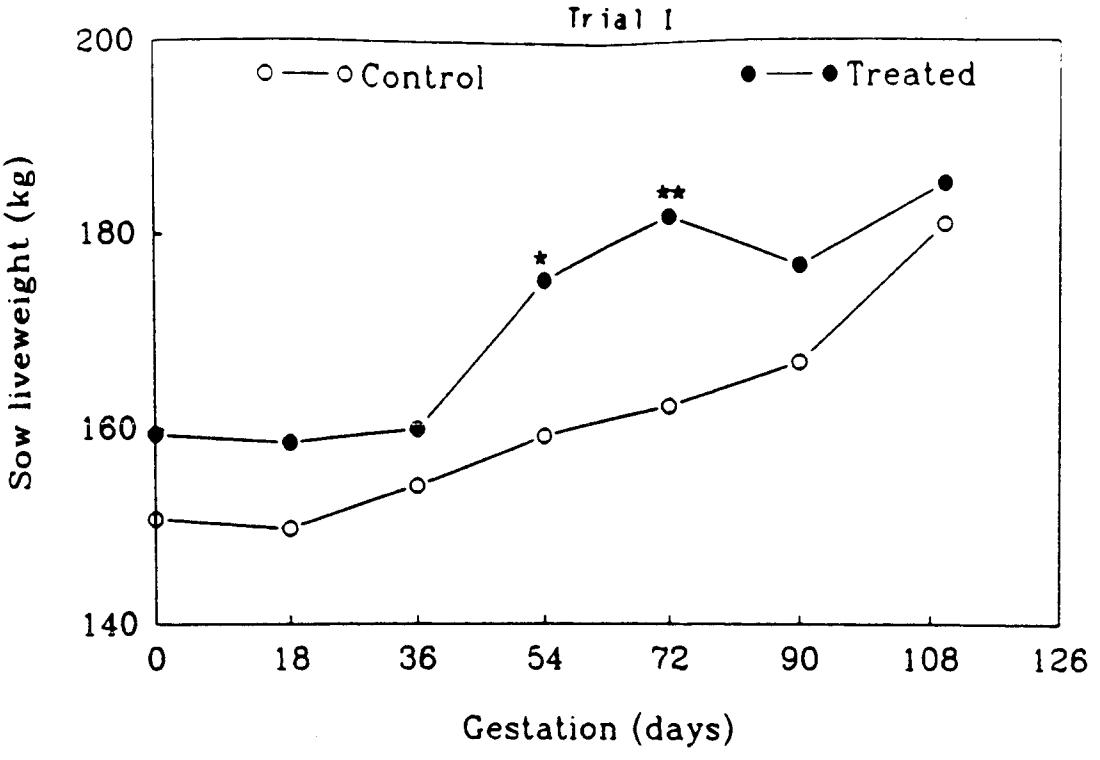
Study 1

Physical and Physiological Characteristics in Gestation

Sow liveweight and weight changes. The effect of feeding pattern during gestation on sow liveweight (LW) is shown in Fig. 2 and Table B1 (Appendix B). In Trial 1, sow liveweights for the two groups were similar during the 1st trimester, when feed intake was equal. During the 2nd trimester, when treated (T) sows were fed 1.0 kg more per day than control (C) sows, liveweights for T sows were significantly higher at midway (175.41 kg vs 159.23 kg, $P<.05$) and end of the 2nd trimester (181.93 kg vs 162.30 kg, $P<.01$). In the 3rd trimester, when T sows were fed only 1.5 $kg \cdot sow^{-1} \cdot day^{-1}$ while the daily feed intake for each C sow was 2.5 kg, sow cumulative liveweights were similar.

The pattern of feeding during gestation had no significant effect on sow liveweight in early pregnancy. In Trial 1, T sows tended to be slightly heavier than C sows and remained so until the end of the 2nd trimester, indicating that initial allotment weight was associated with subsequent weight (Whittemore et al., 1980). However, in the 3rd trimester, this relationship did not hold true, most likely due to the lower plane of nutrition of T sows. In Trial 2, sow liveweights of C and T sows were similar at all stages of gestation, although T sows tended to be heavier.

Mean weight gains for gravid sows are presented in Table 5. In Trial 1, overall weight gains during the 1st trimester were low



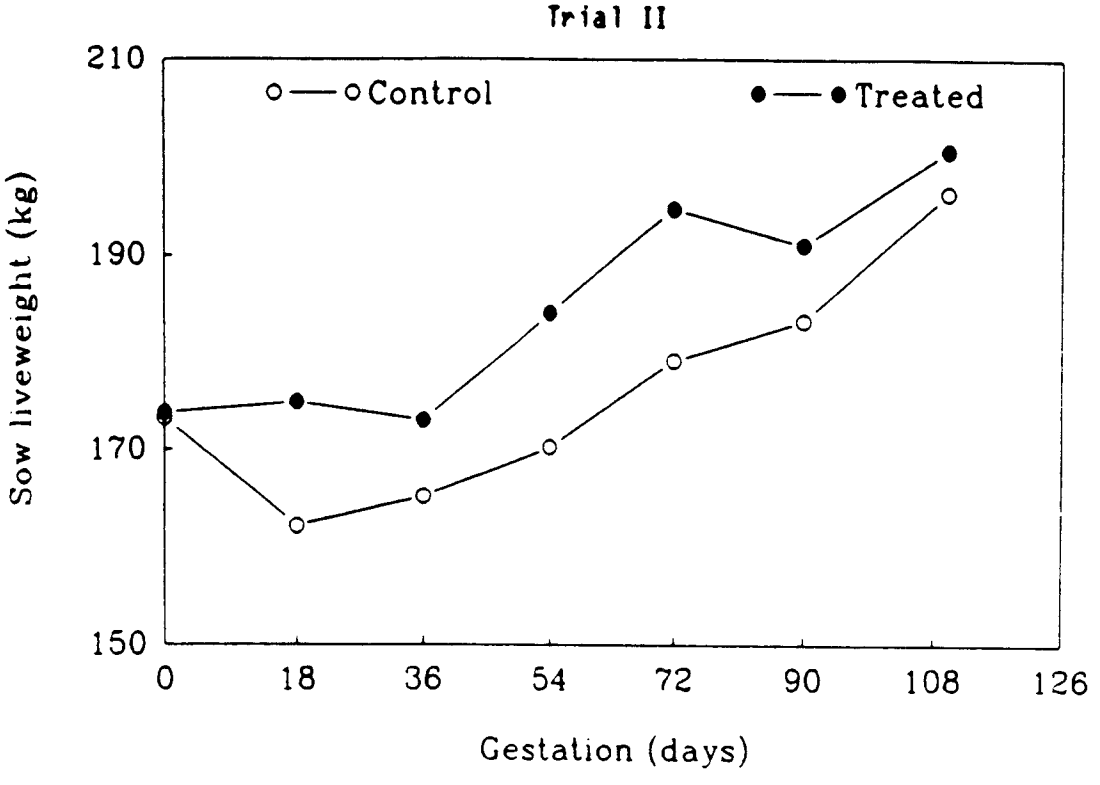


Fig. 2. Liveweight of sows during gestation (*P<.05, **P<.01)

Table 5

Weight gain of sows during gestation

Trial	Days		Sow Weight Gain (kg)[a] Control	Treated
			(n=20)	(n=20)
I	0-36	(1st trimester)	3.41 ± 2.39	0.59 ± 2.39
	37-54		5.00 ± 2.29	15.34 ± 2.29[b]
	55-72		3.07 ± 1.30	8.61 ± 1.30[b]
	37-72	(2nd trimester)	7.98 ± 2.81	21.86 ± 2.81[c]
	73-90		4.75 ± 1.98	-5.11 ± 1.98[c]
	91-110		14.14 ± 1.24	8.46 ± 1.24[b]
	73-110	(3rd trimester)	18.68 ± 1.88	3.30 ± 1.88[c]
			(n=7)	(n=8)
II	0-36	(1st trimester)	-8.12 ± 3.53	-0.80 ± 3.30
	37-54		5.13 ± 2.08	11.02 ± 1.95[d]
	55-72		8.96 ± 3.96	10.63 ± 3.70
	37-72	(2nd trimester)	14.09 ± 3.66	21.65 ± 3.42
	73-90		4.09 ± 2.40	-3.70 ± 2.27[e]
	91-110		12.99 ± 1.50	9.60 ± 1.40
	73-110	(3rd trimester)	17.08 ± 3.10	5.91 ± 2.09[e]

[a] Means ± SE

[b] $P<.01$

[c] $P<.001$

[d] $P<.10$

[e] $P<.05$

and similar for the two groups. Average weight gains for T sows were significantly higher ($P<.001$) at the end of the 2nd trimester (21.86 kg vs 7.98 kg), but significantly lower ($P<.001$) at the end of the last trimester (5.91 kg vs 17.8 kg). In Trial 2, treatment had no significant influence on sow weight changes during the first two trimesters; however, the weight gain of T sows in the 3rd trimester was significantly lower ($P<.05$) than that for C sows.

The results indicate that weight gains during each trimester corresponded to the pattern of feeding, supporting the suggestion that sow liveweight gains in gestation may be directly related to feed intake (Elsley et al., 1969). Since level of feeding of T sows was high during the 2nd trimester, when growth of the porcine fetus was low, nutrients in excess of maintenance were repartitioned for deposition in maternal tissues, resulting in marked increase in weight gain of T sows during that trimester. During the 3rd trimester, low level of feed intake of T sows, combined with the rapid growth of the developing fetuses, resulted in the mobilization of energy reserves from adipose tissue, especially subcutaneous fat, to maintain pregnancy functions and, thus, accounted for the low weight gain of T sows.

Sow backfat thickness. The body condition of the sow, as indicated by level of sow backfat (BF), is presented in Fig. 3 and Table B2 (Appendix B). In Trial 1, initial BF levels of C and T sows were similar; but after 18 days on the same plane of nutrition, the mean BF level for T sows was 1.22 mm higher than that for C sows ($P<.10$). However, the T sows did not maintain this advantage to the

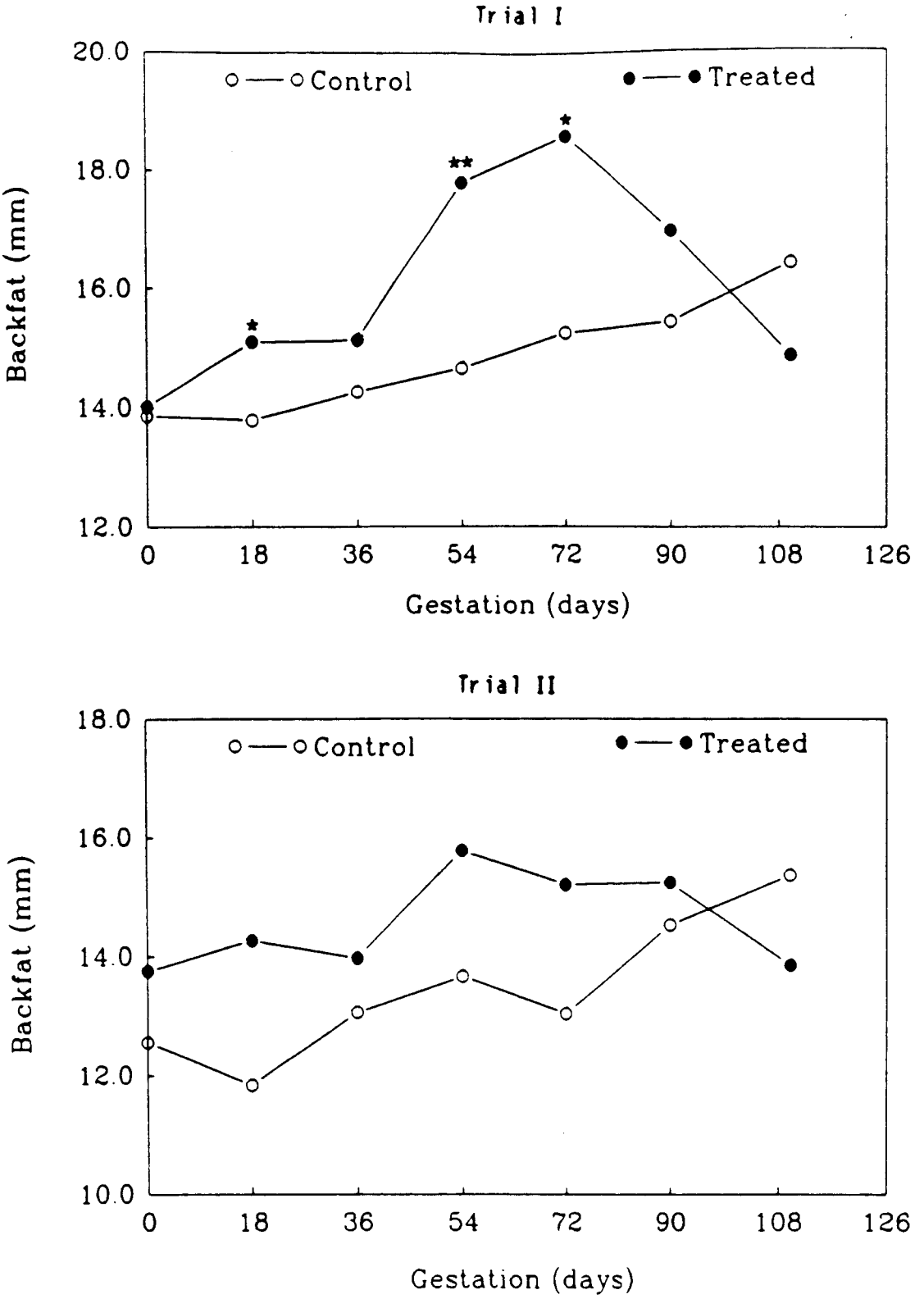


Fig. 3. Sow backfat level during gestation (*P<.05, **P<.01)

end of the trimester. In the 2nd trimester, the effect of higher level of feeding on T sows was evident in mean BF levels. Compared to C sows, T sows were in better body condition at the middle ($P<.01$) and end of the 2nd trimester ($P<.05$). The effect of lower level of feeding on T sows in the last trimester of gestation was reflected in reduction in average BF level by almost 4 mm. In the 3rd trimester, backfat level for T sows ($P<.10$) was lower than for C sows. In Trial 2, treatment did not have any significant effect on backfat thickness, although T sows tended to have slightly higher BF levels than C sows, a trend similar to that observed in Trial 1.

The levels of BF thickness observed in this study were similar to levels reported by Whittemore et al. (1980). The reduction of about 4 mm in BF in T sows (Trial 1) in the 3rd trimester may indicate that the sows were mobilizing subcutaneous fat to provide them with additional energy to meet the needs of the developing fetuses and to prepare for lactation. In Trial 2, the lack of significance of treatment on sow BF thickness could be due to the small sample size (7 controls and 8 treated sows).

Maternal blood metabolites. One of the questions addressed in this study was whether lowering feed intake in late gestation, thereby increasing the rate of fat mobilization in the gravid sow, would make higher concentrations of circulating energy substrates, particularly fatty acids, available to the developing fetuses and, if so, whether this improved fetal energy storage would result in better postnatal piglet survival. Sow blood metabolites--namely, plasma fatty acids, serum glycerol, and serum glucose--were measured in an attempt to answer that question.

1. Plasma fatty acids. Table 6 presents mean fatty acid concentrations in plasma for C and T sows during gestation. In Trial 1, mean plasma fatty acid levels for the two groups were similar initially, but by the end of the 1st trimester, the mean level for T sows was significantly higher ($P<.10$) than that for C sows. Pattern of feeding did not have a significant effect on plasma fatty acid level in mid gestation (2nd trimester), but during the 3rd trimester, in which T sows were fed lower levels, plasma fatty acid concentration in T sows were significantly higher ($P<.05$), compared to the C sows. A similar pattern was observed in Trial 2, when T sows had a significantly higher ($P<.05$) plasma fatty acid level at the end of the 3rd trimester.

As indicated later in this thesis, litters of T sows tended to have a slightly higher proportion of small piglets and a slightly higher mortality rate (Tables B8 and B9, respectively) despite the significantly higher fatty acid concentration in the blood of T sows at the end of pregnancy. These results concur with results of other studies (Ruwe et al., 1991; Kasser et al., 1982). Kasser et al. (1982) reported that fasting increased combined calories of free fatty acids (FFA) and beta-hydroxybutyrate (BOHB) levels in the sow's blood nearly twofold, but the higher levels of maternal FFA and BOHB did not affect levels of these metabolites in offspring. The authors suggested that failure to sustain higher FFA and BOHB concentrations in fetuses of fasted dams may be due to: (1) greater placental FFA and BOHB utilization; (2) failure to increase placental FFA and BOHB transport; or (3) greater FFA and BOHB utilization by fetal tissues. However, Ruwe et al. (1991) suggested that neither the placenta nor

Table 6

Plasma fatty acid concentration of sows during gestation

Trial	Days	Plasma Fatty Acid Level (μEq/L)[a] Control	Treated
		(n=20)	(n=20)
I	0	226.42 ± 23.18	264.27 ± 23.18
	36	322.37 ± 31.72	399.00 ± 31.72[b]
	72	290.71 ± 29.39	347.71 ± 29.39
	110	405.75 ± 57.09[c]	584.24 ± 55.64[d]
		(n=7)	(n=8)
II	0	274.80 ± 35.10	304.07 ± 30.40
	36	272.27 ± 46.43	271.94 ± 43.43
	72	290.94 ± 49.71	345.31 ± 46.68
	110	296.09 ± 61.13	500.13 ± 57.18[d]

[a] Means ± SE

[b] $P<.10$

[c] n = 19 (control group)

[d] $P<.05$

the fetus appeared to have had access to the available maternal FFA. The implication was that the degree of actual uptake of the substrates was responsible for the ineffectiveness of nutritional manipulation during gestation.

2. Serum glycerol: Mean serum glycerol levels for C and T sows are presented in Table 7. In Trial 1, serum glycerol levels for the groups were similar at the beginning and end of the 1st trimester, but T sows had significantly higher serum glycerol levels at the end of the 2nd and 3rd trimesters ($P<.05$ and $P<.10$, respectively). In Trial 2, the only significant effect of treatment on serum glycerol level was at the beginning and end of the 1st trimester, when T sows had significantly lower levels ($P<.10$ and $P<.01$, respectively).

Mersmann (1982) suggested that concentration of glycerol, rather than FFA, in the blood was a better indicator of the extent of fat mobilization from adipose tissue, because the turnover for FFA was higher. The significantly higher serum glycerol level in T sows in late gestation (Trial 1) therefore suggests a higher rate of adipose breakdown to provide energy substrates for maintenance of pregnancy and preparation for lactation.

3. Serum glucose: Table 8 presents mean serum glucose levels for C and T sows. In Trial 1, serum glucose levels of T sows, compared to those of C sows, were significantly lower at the beginning and end of the 1st trimester ($P<.10$ and $P<.01$, respectively). However, in the 2nd and 3rd trimesters, serum glucose levels of C and T sows were similar. In Trial 2, serum glucose levels of C and T sows were similar except at the end of the 1st trimester, when T sows, compared to C sows, had significantly higher levels.

Table 7

Serum glycerol concentration of sows during gestation

Trial	Days	Serum Glycerol Level (μm/L)[a] Control	Treated
		(n=20)	(n=20)
I	0	10.21 ± 1.01	11.42 ± 1.01
	36	11.77 ± 1.29	14.13 ± 1.29
	72	8.55 ± 1.07	12.28 ± 1.07[b]
	110	11.64 ± 1.62	15.80 ± 1.62[c]
		(n=7)	(n=8)
II	0	10.59 ± 1.18	7.46 ± 1.10[c]
	36	12.18 ± 1.06	7.41 ± 0.99[d]
	72	10.45 ± 1.53	6.99 ± 1.43
	110	8.09 ± 1.85	11.75 ± 1.73

[a] Means ± SE

[b] $P<.05$

[c] $P<.10$

[d] $P<.01$

Table 8

Serum glucose level of sows during gestation

Trial	Days	Serum Glucose Level (mg/100ml)[a]	
		Control	Treated
		(n=20)	(n=20)
I	0	74.02 ± 2.37	67.66 ± 2.37[b]
	36	75.97 ± 1.93	84.67 ± 1.93[c]
	72	73.13 ± 2.53	76.94 ± 2.53
	110	79.65 ± 2.81	80.92 ± 2.81
		(n=7)	(n=8)
II	0	78.05 ± 4.40	75.70 ± 4.40
	36	68.56 ± 3.70	80.46 ± 3.46[d]
	72	81.41 ± 2.98	86.52 ± 2.79
	110	79.11 ± 5.48	84.02 ± 5.12

[a] Means ± SE

[b] $P<.10$

[c] $P<.01$

[d] $P<.05$

The finding that serum glucose levels of C and T sows were similar in the 2nd and 3rd trimesters agrees in part with reports by Atinmo et al. (1974a, 1974b) which indicated that changes in fasting blood glucose did not differ significantly among treatments. However, levels of blood glucose reported in their study were twice as high as levels in the present study. The reason for the disparity is not clear.

Physical and Physiological Characteristics in Lactation

Sow liveweight and weight changes. Mean sow liveweights within 24 hours of farrowing and weekly weight until day 21 postpartum are presented in Table B3 (Appendix B). In Trials 1 and 2, liveweights of C and T sows were similar throughout lactation. Table 9 presents mean weekly weight gains of C and T sows up to 21 days after farrowing. In Trial 1, weight gains were low and similar for the first 3 weeks of lactation. A similar observation was made in Trial 2 during the first two weeks; but during the 3rd week of lactation, C and T sows lost weight (-3.57 kg and -1.02 kg, respectively).

The weight gain observed during the first week of lactation varied from that reported by Lodge et al. (1961) to be typical. They reported that normal weight change during lactation included a significant weight loss in the first 7 days, even though feed intake was ad libitum and milk production was relatively low. This pattern of weight change was commonly observed in primiparous sows (Lodge, 1969). He also indicated that weight gain from the 2nd week of lactation closely reflected feed allowance. The fact that sows in both trials of the present study were multiparous, were fed ad libitum, and nursed a similar number of piglets might explain

Table 9

Sow weight gain during first 21 days of lactation

Trial	Days	Sow Weight Gain per Week (kg)[a] Control	Treated
		(n=20)	(n=20)
I	1-7	4.18 ± 2.00	1.61 ± 2.00
	8-14	2.55 ± 2.19	5.48 ± 2.19
	15-21	0.20 ± 1.87	1.81 ± 1.87
		(n=7)	(n=8)
II	1-7	0.85 ± 0.71	4.43 ± 2.11
	8-14	2.86 ± 2.03	5.91 ± 1.90
	15-21	-3.57 ± 4.93	-1.02 ± 4.61

[a] Means ± SE

why nutritional weight changes in the present study were similar and minimal, rather than extreme.

It has been suggested that overall efficiency of energy utilization by the sow would be greater if weight gain during pregnancy and weight loss during lactation were minimal so that the sow remained at a more constant body weight (Lodge, 1969). In Trial 2, T sows appeared to perform better than C sows in terms of desirable weight changes; but the slightly better performance could have been because T sows, compared to C sows, farrowed and nursed about 1.5 fewer piglets per sow.

Sow backfat thickness. The effect of gestational feeding pattern on level of sow backfat (BF) is shown in Table B4 (Appendix B). In general, there was no significant difference in sow body condition between the groups in either Trial 1 or 2. However, compared to C sows, T sows tended to have slightly higher BF levels in Trial 1 and lower BF levels in Trial 2.

Yang et al. (1989) suggested that fat changes during a 28-day lactation were influenced by: (1) fatness at parturition, (2) lactational feeding, and (3) the number of piglets nursed by the sow. It is important to avoid severe backfat loss in lactation, particularly in primiparous sows, due to possible delay in subsequent estrus after weaning (Armstrong et al., 1986). On the other hand, excessive feeding throughout gestation may increase the incidence of agalactia (Penny, 1970). Low appetite, especially in young sows, in early lactation is common, and dams have to rely heavily on mobilization of body fat, particularly subcutaneous fat, to meet the energy demands for milk production. Excessively fat dams, however, are unable to

effectively mobilize fat stores in early lactation (Penny, 1970). Low appetite combined with lack of ability to mobilize fat efficiently for lactation results in the inability of the sow to let down milk (agalactia) or nurse well. Inadequate and irregular nutrition, especially in the critical first 3 days of life, results in a reduction in piglet survival and growth rate from birth to weaning (England, 1974; English and Wilkinson, 1982).

Sow lactational feed intake. Feed intake of sows during the first 21 days of lactation is presented in Table B5 (Appendix B). There was no significant difference between the two groups, although, compared to C sows, T sows tended to have slightly heavier levels of feed intake. A similar observation was made in Trial 2. Dean and Tribble (1961) and Lodge et al. (1966b) reported a negative relationship between level of feed intake in gestation (and therefore sow weight gain during pregnancy) and lactational feed intake (and thus sow weight loss during lactation). The fact that total feed intake during gestation was the same for both C and T sows might explain why lactational feed intake and lactational weight changes of sows were similar for both C and T sows.

Sow productivity.

1. Litter size: Table B6 (Appendix B) presents the means of litter sizes at different stages after birth for C and T groups. In Trial 1, the average number of piglets born alive was similar for C and T sows. There were twice as many stillbirths in T sow litters, compared to C sow litters, but the difference was not significant. Although T sows tended to have more piglets at birth and on days 3, 7, 14, and 21, there was no significant difference between the groups in

litter size. In Trial 2, there were 2.5 pigs fewer livebirths per T sow litter, compared to livebirths per C sow litter, but no significant difference was found between the groups in litter size at birth or at other stages during lactation; however, this result may be due to the small sample size.

In this study, there was no indication that the experimental pattern of feeding during gestation influenced litter size. The slightly higher number of stillbirths by T sows in Trial 1 may have been due to the slightly higher litter sizes in the T group. In Trial 2, the tendency for T sows to farrow fewer piglets, compared to C sows, may indicate a long-term adverse effect of the gestational feeding pattern; however, data from Trial 2 should be interpreted with caution since the sample size was small (7 control sows, 8 treated sows).

According to O'Grady (1967), total feed intake during gestation is more critical than the pattern of feeding; so, it is possible that had the average feed intake in the present study been lower than 2.2 $kg \cdot sow^{-1} \cdot day^{-1}$, reproductive performance of the T group might have suffered.

2. Piglet liveweight and weight gains: Table B7 (Appendix B) presents mean piglet liveweight (PLW) for C and T sow litters. In Trial 1, mean PLW at birth and on day 3, and weekly up to 21 days after birth, was similar for both groups. A similar trend was observed in Trial 2, but with T litters having a slight edge in PLW, compared to C litters, as shown in growth curves for the piglets in the first 21 days of life (Fig. 4).

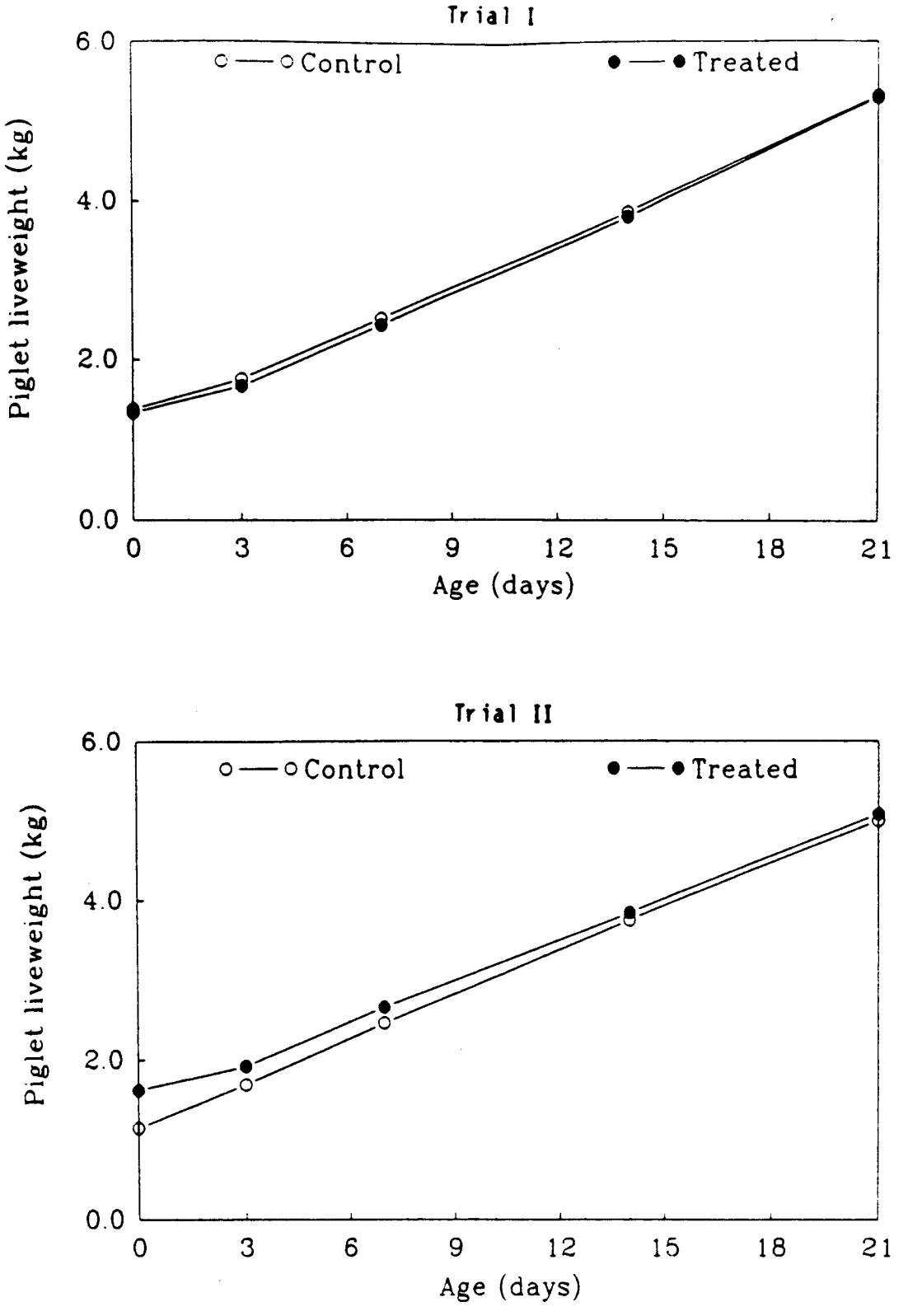


Fig. 4. Growth curve of piglets from birth to 21 days of age

There was no indication from the results that the gestational feeding pattern influenced piglet weight at birth or on subsequent days. Piglet weights at birth and day 21 were of the same order as those observed by Atinmo et al. (1974a, 1974b). Mean daily weight gains of C and T piglets in the first 3 weeks of life are shown in Table 10. In Trial 1, average piglet weight gain for both groups increased from about 150 g to over 200 g per day in the third week. A similar observation was made in Trial 2, except for the second week, when weight gain was significantly lower ($P<.10$) for T piglets than for C piglets. It is not clear why piglet growth in C and T groups in Trial 2 tended to be poorer than in Trial 1, even though piglet liveweight tended to be higher in Trial 2 and milk consumption was similar. However, it must be stressed that, because the sample size in Trial 2 was small, the results should be interpreted with caution.

3. Piglet classification and preweaning mortality: Piglets were classified according to birthweight: small = <1.0 kg; medium = 1.0-1.59 kg; large = >1.59 kg. Compared to C sows, T sows in Trial 1 tended to produce more piglets in the extreme groups (Fig. 5): there were 5% more small piglets and 4% more large piglets in T litters. Results from Trial 2 indicated that T sows farrowed a lower percentage of small and medium piglets, but a higher percentage of large piglets. The means for C and T sows, however, were not significantly different.

Table B9 (Appendix B) shows mortality rates for piglets from birth to 21 days of age. In Trial 1, piglet mortality rates tended to be higher for T sows than for C sows, with rates increasing from the critical first 3 days of life up to 21 days of age (Fig. 6).

Table 10

Weight gain of piglets from birth to 21 days of age

Trial	Period (days)	Weight Gain (g/day)[a] Control	Treated
		(n=20)	(n=20)
I	0-7	[a]154.77 ± 10.07	150.00 ± 10.07
	8-14	193.09 ± 16.62	193.99 ± 16.62
	15-21	206.40 ± 18.46	212.96 ± 18.46
		(n=7)	(n=8)
II	0-7	142.76 ± 19.79	150.73 ± 18.51
	8-14	236.64 ± 24.14	169.24 ± 22.84[b]
	15-21	178.38 ± 34.52	176.70 ± 32.89

[a] Means ± SE

[b] $P<.10$

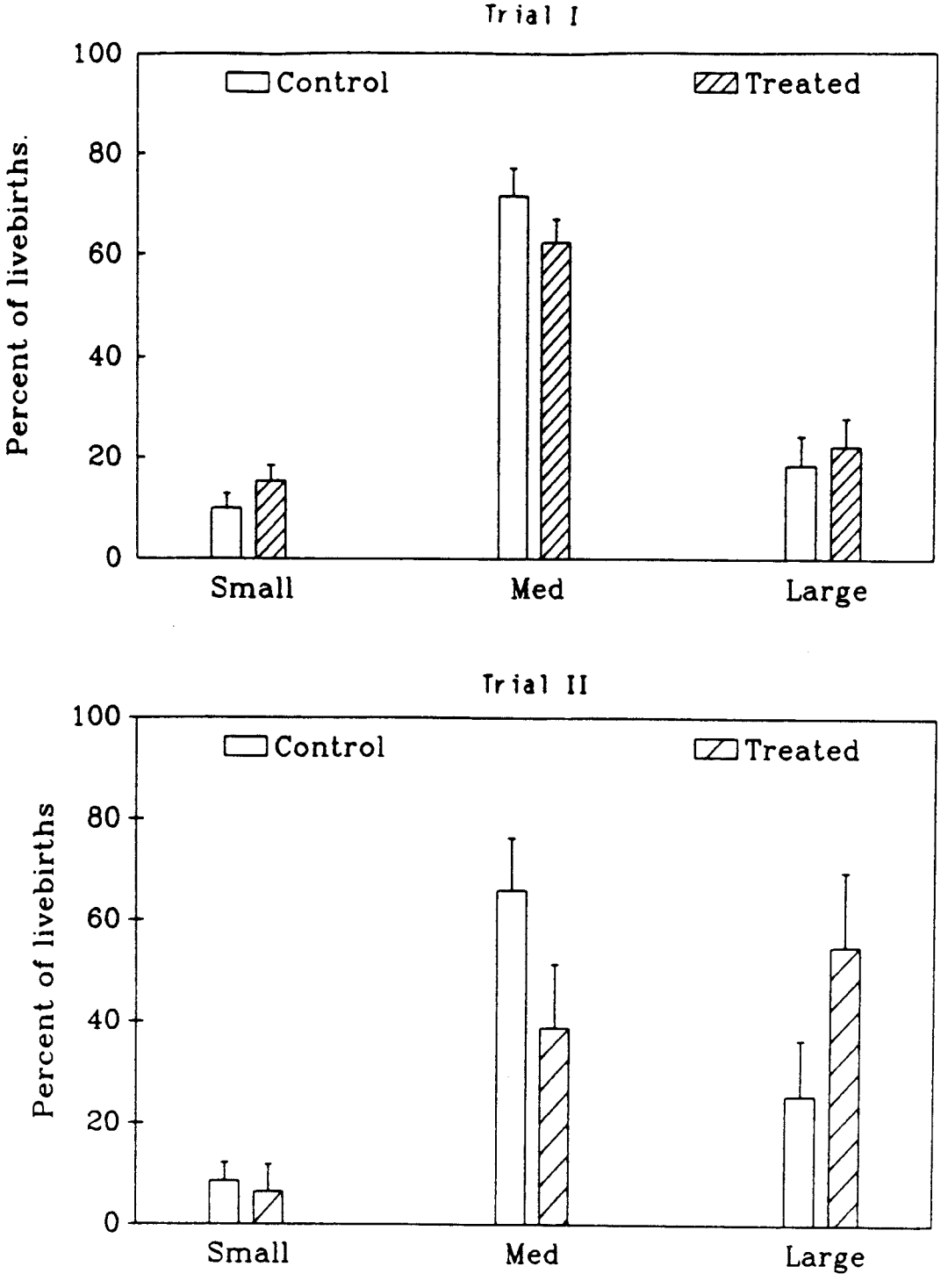


Fig. 5. Classification of piglets by birthweight (small <1.0 kg, medium 1.0-1.59 kg, large >1.59 kg)

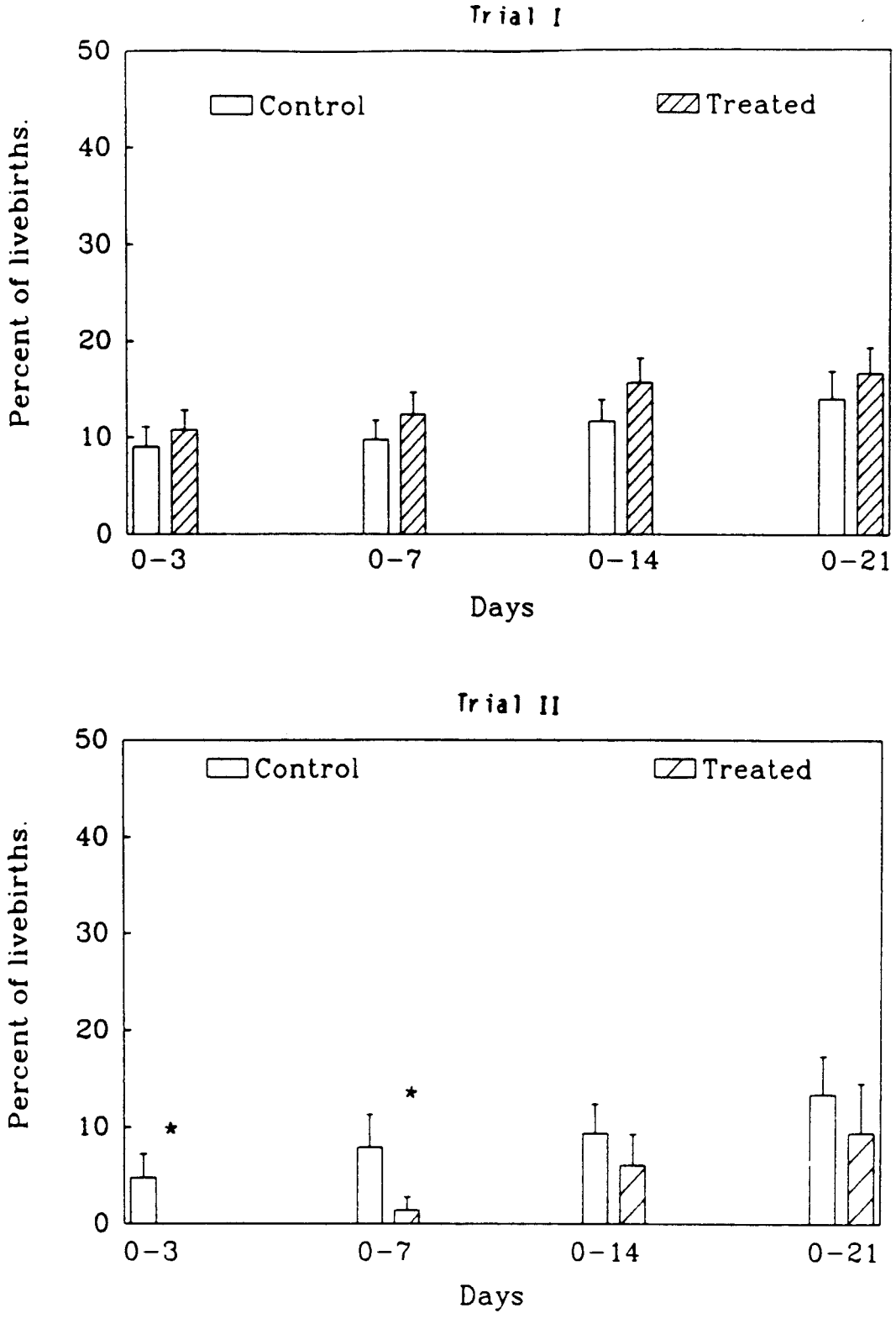


Fig. 6. Postnatal mortality of piglets from birth to 21 days of age (*P<.10)

In Trial 2, piglet mortality rates during the first 3 weeks of life were generally lower for T group than for C group (Fig. 6); but piglet mortality rates for T sows, compared to C sows, were significantly different at 3 days of age ($P<.10$) and 7 days of age ($P<.10$). Beyond 7 days of age, mortality rates of offspring from the two groups were similar.

Since low birthweight reportedly contributes most to piglet mortality in the first 7 days after birth (England et al., 1961; English et al., 1977), mortality rates for small piglets (<1.0 kg) of C and T sows in the present study were compared. In Trial 1, death losses of small piglets were slightly higher for T sows than for C sows (Table 11), but the differences in mean mortality rates between the two groups were not significant. In Trial 2, postnatal mortality for small piglets was similar for both groups during the first 2 weeks of life, but by the end of the 3rd week (day 21), average mortality rate for C sows was 5.6% higher than that for T sows ($P<.0001$).

The slightly higher mortality rate for piglets of T sows (Trial 1) was probably due to the tendency of T sows to farrow a slightly higher proportion of small piglets. In Trial 2, the tendency of T sows to farrow fewer but larger piglets may have been the reason for the significantly lower mortality rates in the critical first 3 and 7 days of life. The smaller the piglet, the less able it is to compete for a nursing position, hence the more it is at risk for starvation, hypothermia, and, thus, overlying by the sow. Procedures such as (1) cross-fostering to ensure uniformity among litter mates, (2) split-nursing to give small piglets twice as much time at the

Table 11

Mortality rate of small piglets from birth to 21 days of age

Trial	Age (days)	Percentage of Piglets[a]	
		Control	Treated
		(n=14)	(n=10)
I	0-3	10.92 ± 1.64	11.63 ± 1.22
	0-7	13.68 ± 1.89	14.09 ± 1.41
	0-14	13.68 ± 2.29	14.52 ± 1.62
	0-21	13.68 ± 2.29	15.52 ± 1.62
		(n=4)	(n=2)
II	0-3	12.50 ± 4.17	11.11 ± 5.90
	0-7	12.50 ± 4.17	11.11 ± 5.90
	0-14	12.50 ± 4.17	11.11 ± 5.90
	0-21	16.67 ± 0.00	11.11 ± 0.00[b]

[a] Means ± SE

[b] $P<.0001$

udder compared to their larger litter mates, (3) supplemental feeding via stomach tube, and (4) holding small piglets to teats to assist them in suckling (English et al., 1977) are essential to help small piglets become established and survive. The practice of some of these procedures in this study may have been responsible for the similarity in mortality rates for small piglets of C and T groups in Trial 1. It might also explain why survival rate of small piglets in this study were 20% higher than levels reported in another study (Stahly et al., 1979).

4. Piglet milk consumption. Piglet milk consumption is presented in Table B10 (Appendix B). In Trial 1, average milk consumption for C and T piglets at 3 days of age was similar (80.53 g vs 81.44 g/piglet). Milk consumption for C piglets tended to be higher from days 3 to 14 postpartum but then leveled while intake by T piglets continued to increase up to 21 days of age (Fig. 7). A similar trend was observed in Trial 2. By day 21, average milk consumption per piglet was 16 g more per suckling for T piglets than C piglets.

Average milk consumption of piglets was used as a rough estimation of sow's milk yield. The average amount of milk consumed per piglet per suckle was twice the amount reported by other researchers (Campbell and Dunkin, 1982; Hemsworth et al., 1976). The much higher level of milk consumption in the present study could have been due to several reasons: (1) According to Elsley (1971), the method of weighing pigs before and after the suckling itself is

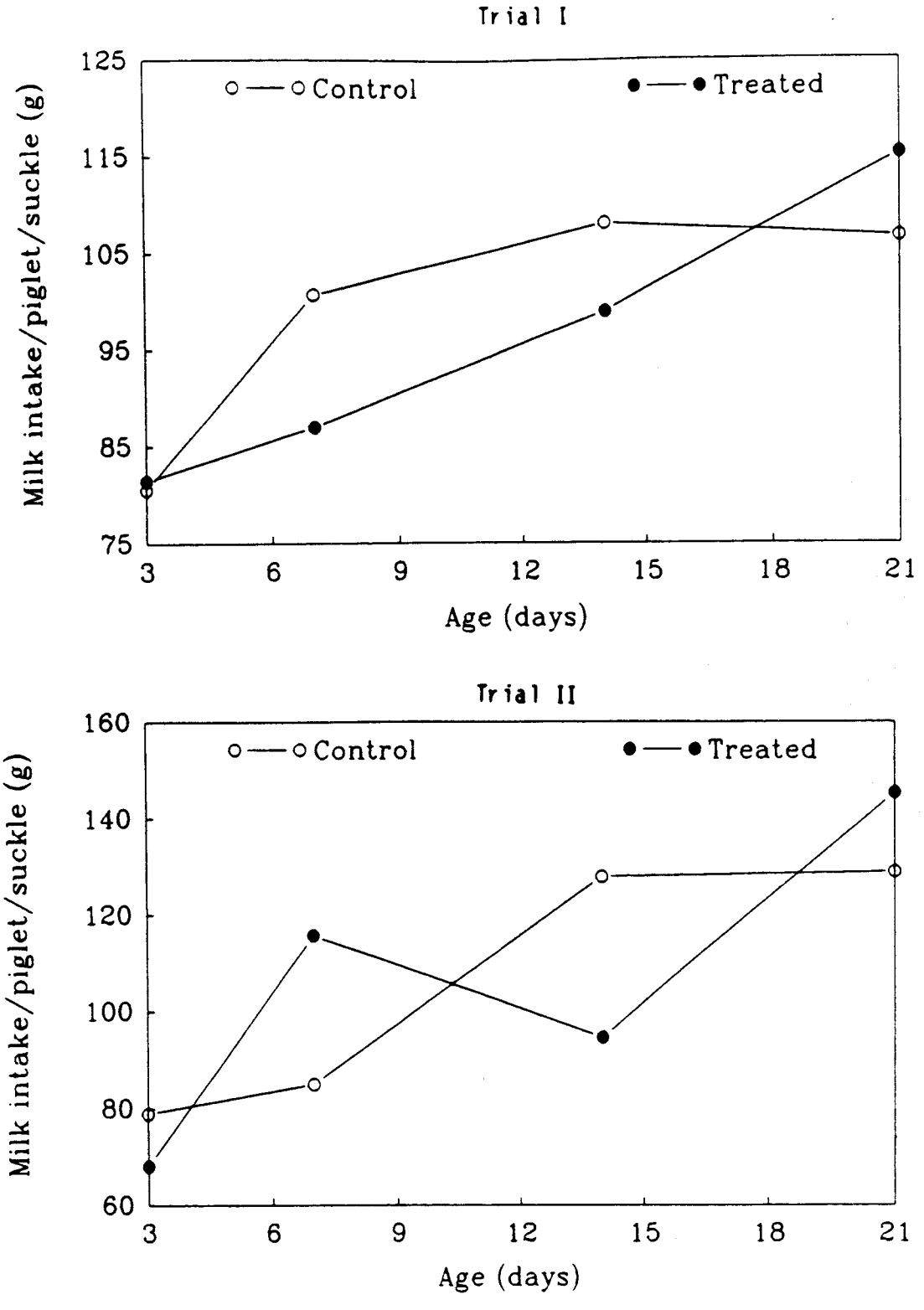


Fig. 7. Milk consumption by piglets from 3 to 21 days of age

subject to a number of errors. Salmon-Legagneur (1968) stated that even with a carefully controlled and accurate weighing procedure, deviation between true milk yield and estimated milk yield is likely to be 20% on average and could reach 50% in some cases. (2) More frequent measurement of sucklings reportedly resulted in higher milk yield estimates (Elsley, 1971). In the present study, suckling intervals were 40 minutes, compared to the hourly intervals used in the reported studies. (3) Differences in precision of the weighing scales used could have contributed towards the differences between milk consumption values obtained in the present study and those of reported studies. Precision in the present study was within 20 g, but in the reported studies, it was within 5 g.

The reason for the pattern of milk consumption in the present study, especially the leveling off of milk intake by offspring of C sows in both Trials 1 and 2, was not evident.

5. Milk composition. Mean levels of fat, protein, lactose, and solids-not-fat (SNF) in colostrum and milk are presented in Tables 12, 13, 14, and 15, respectively.

In general, fat content was 2-3% lower in colostrum than in milk. In Trial 1, levels of fat as measured at day of farrowing, day 3, and once weekly till day 21 were similar for C and T sows. A similar trend was observed in Trial 2 (Table 12). There was no significant difference in mean protein levels of protein in colostrum and milk in the first 21 days of lactation between C and T sows in either trial (Table 13).

Table 12

Fat level in colostrum and milk of sows during the first 3 weeks of lactation

Trial	Days	Fat Level (%)[a] Control	Treated
		(n=20)	(n=20)
I	0 (colostrum)	4.31 ± 0.33	3.83 ± 0.33
	3	6.64 ± 0.25	6.67 ± 0.25
	7	6.39 ± 0.29	6.16 ± 0.31[b]
	14	5.98 ± 0.29	6.30 ± 0.30[c]
	21	6.19 ± 0.24	6.18 ± 0.24
		(n=7)	(n=8)
II	0 (colostrum)	4.96 ± 0.73	4.57 ± 0.68
	3	6.43 ± 0.90	7.89 ± 0.78
	7	6.05 ± 0.32	5.74 ± 0.30
	14	5.66 ± 0.32	5.62 ± 0.29
	21	5.42 ± 0.37	5.98 ± 0.35

[a] Means ± SE

[b] n = 17 (treated group)

[c] n = 19 (treated group)

Table 13

Protein level in colostrum and milk of sows during the first 3 weeks of lactation

Trial	Days	Protein Level (%)[a] Control	Treated
		(n=20)	(n=20)
I	0 (colostrum)	10.88 ± 0.07	10.83 ± 0.07
	3	5.06 ± 0.29	4.90 ± 0.29
	7	4.53 ± 0.18	4.49 ± 0.19[b]
	14	4.15 ± 0.08	4.30 ± 0.08
	21	4.43 ± 0.17	4.46 ± 0.17
		(n=7)	(n=8)
II	0 (colostrum)	10.98 ± 0.07	11.03 ± 0.07
	3	5.27 ± 0.99	5.98 ± 0.78
	7	4.45 ± 0.14	4.50 ± 0.13
	14	4.38 ± 0.18	4.51 ± 0.17
	21	4.69 ± 0.37	5.27 ± 0.35

[a] Means ± SE

[b] n = 18 (treated group)

Table 14

Lactose content of colostrum and milk of sows during the first 3 weeks of lactation

Trial	Days	Lactose Content (%)[a] Control	Treated
		(n=20)	(n=20)
I	0 (colostrum)	2.28 ± 0.15	2.44 ± 0.15
	3	4.80 ± 0.16	4.97 ± 0.16
	7	5.48 ± 0.13	5.49 ± 0.14[b]
	14	5.80 ± 0.23	5.56 ± 0.23
	21	5.54 ± 0.21	5.69 ± 0.21
		(n=7)	(n=8)
II	0 (colostrum)	1.59 ± 0.32	2.02 ± 0.30
	3	4.66 ± 0.39	4.40 ± 0.31
	7	5.41 ± 0.30	5.07 ± 0.28
	14	5.23 ± 0.35	5.39 ± 0.33
	21	4.76 ± 0.57	4.89 ± 0.54

[a] Means ± SE

[b] n = 18 (treated group)

Table 15

Level of solids-not-fat (SNF) in colostrum and milk of sows during the first 3 weeks of lactation

Trial	Days	SNF Level (%)[a] Control	Treated
		(n=20)	(n=20)
I	0 (colostrum)	13.88 ± 0.28	13.48 ± 0.28
	3	10.73 ± 0.16	10.69 ± 0.16
	7	10.61 ± 0.12	10.73 ± 0.12
	14	10.69 ± 0.14	10.59 ± 0.14
	21	10.71 ± 0.09	10.88 ± 0.09
		(n=7)	(n=8)
II	0 (colostrum)	13.31 ± 0.25	11.03 ± 0.23[b]
	3	10.52 ± 0.77	11.10 ± 0.61
	7	10.59 ± 0.32	10.30 ± 0.29
	14	10.34 ± 0.29	10.63 ± 0.27
	21	10.20 ± 0.27	10.90 ± 0.25[c]

[a] Means ± SE

[b] $P<.0001$

[c] $P<.10$

Lactose levels in colostrum and milk for C and T sows in Trials 1 and 2 were similar throughout the 21-day period following parturition (Table 14). In general, there was about 50% less lactose in colostrum than in milk. This difference in levels was particularly true as lactation progressed.

Table 15 presents percent solids-not-fat (SNF) in colostrum and milk from day of farrowing to "peak" lactation, 3 weeks later. In general, SNF levels were 2% higher in colostrum than in milk. In Trial 1, SNF levels were practically the same from day 3 to day 21. In Trial 2, compared to SNF levels of C sows, level in colostrum (day 0) of T sows was significantly lower ($P<.0001$), but level in milk on day 21 was significantly higher ($P<.10$).

Pattern of feeding during gestation did not influence milk composition in either trial. The percentage of lactose agreed with findings of other studies (Klobasa et al., 1987; Noblet and Etienne, 1986). The level of fat was similar to that reported in another study (Seerley et al., 1974), but lower, in general, than levels observed by other researchers (Klobasa et al., 1987; Noblet and Etienne, 1986). Colostral protein level was on the same order as levels reported by Miller et al. (1971), but lower than levels in other reports (Klobasa et al., 1987; Seerley et al, 1981). In most of the reported studies, milk composition was determined on only a few samples and milk sampling was done at only one or two specific stages. In the present study, milk composition was determined at regular intervals in a 21-day period, similar to a few of the studies (Klobasa et al., 1987; Noblet and Etienne, 1986).

Correlation

Tables 16-20 present within-treatment correlations of selected parameters in Trial 1.

Correlation of sow weight gain and backfat level with components of colostrum and milk. Table 12 shows the correlation of sow weight gain and backfat level with components of colostrum and milk. In general, correlation of sow weight gains in the 2nd and 3rd trimesters (LWG4 and LWG7, respectively) with milk fat or lactose were low and not significant; whereas correlation of backfat level with milk fat or lactose was significant at various stages in the 21-day period.

1. Treated group: Sow BF levels within a day of farrowing (BF1) had a positive effect on percent fat in colostrum (day 0). Correlations between milk fat on day 3 of lactation and BF levels at different stages of reproduction were positive and significant. On the other hand, there were negative but significant correlations between lactose and sow weight gain ($P<.05$), and lactose and sow BF levels during gestation ($P<.10$).

The positive correlation between milk fat level and backfat levels in late gestation and early lactation, within treated group, was desirable. Sow performance during lactation depends on body condition at parturition. Since sows mobilize subcutaneous fat to maintain milk yield, adequate backfat level at parturition is desirable. In the present study, adequate backfat thickness at the beginning of lactation, coupled with the generous feeding, may have ensured that the dams had minimal weight loss. Sows were, therefore,

Table 16

Correlation of sow weight gain and backfat level with components of colostrum and milk

Variable	LWG4	LWG7	BF72	BF110	BF1	BF7
Treated						
Milk fat						
Day 0	-0.22	0.18	-0.33	-0.16	0.49[b]	0.19
Day 3	0.23	-0.07	0.60[c]	0.46[b]	0.51[b]	0.45[a]
Day 21	0.25	-0.32	-0.08	-0.26	-0.20	-0.25
Lactose						
Day 0	-0.47b	-0.25	-0.23	-0.08	-0.08	-0.22
Day 3	0.22	0.16	-0.33	-0.16	-0.20	-0.40[a]
Day 21	-0.22	0.20	-0.24	-0.11	-0.42[a]	-0.06
Control						
Milk fat						
Day 0	-0.13	-0.00	0.17	0.12	0.10	0.16
Day 3	0.11	0.21	0.30	0.17	0.38	0.44[a]
Day 21	0.16	-0.07	-0.45[b]	-0.52[b]	-0.54[b]	-0.31
Lactose						
Day 0	0.26	-0.20	-0.26	-0.48[b]	0.48[b]	0.48[b]
Day 3	-0.08	-0.08	0.18	0.08	-0.11	-0.12
Day 21	-0.22	0.20	-0.24	-0.11	-0.42[a]	-0.06

Note: LWG4 = weight gain in 2nd trimester
LWG7 = weight gain in 3rd trimester
BF72 = backfat level at end of 2nd trimester
BF110 = backfat level at end of 3rd trimester
BF1 = backfat level within day of farrowing
BF7 = backfat level 7 days after farrowing

[a] $P<.10$

[b] $P<.05$

[c] $P<.01$

Table 17

Correlation of sow weight gain and backfat level with piglet characteristics

Variable	LWG4	LWG7	BF72	BF110	BF1	BF7
Treated						
Piglet weight						
Day 0	-0.15	0.17	-0.19	-0.32	-0.35	-0.20
Day 21	-0.12	-0.09	-0.06	-0.58[c]	-0.35	-0.44[b]
Milk Intake						
Day 3	-0.00	0.05	0.06	0.20	-0.26	-0.15
Day 7	-0.51[b]	0.15	0.04	-0.31	-0.13	-0.40[a]
Piglet mortality						
Days 0-3	0.36	-0.50[b]	-0.10	0.06	-0.44[a]	-0.01
Days 0-7	0.24	-0.51[b]	-0.01	0.22	-0.24	0.09
Control						
Variable	LWG4	LWG7	BW72	BF110	BF1	BF7
Piglet weight						
Day 0	0.10	-0.10	-0.11	-0.07	-0.28	-0.06
Day 21	-0.24	-0.09	-0.30	-0.08	-0.48[b]	-0.26
Milk intake						
Day 3	0.04	-0.15	-0.24	-0.09	-0.61[c]	-0.42[a]
Day 7	-0.49[b]	0.17	0.21	0.07	-0.08	0.18
Piglet mortality						
Days 0-3	-0.23	0.05	0.05	-0.27	0.15	0.04
Days 0-7	-0.14	0.13	0.08	-0.23	0.23	0.02

Note: LWG4 = weight gain in 2nd term
LWG7 = weight gain in 3rd term
BF72 = backfat level at end of 2nd term
BF110 = backfat level at end of 3rd term
BF1 = backfat level within day of farrowing
BF7 = backfat level 7 days after farrowing

[a] $p<.10$

[b] $p<.05$

[c] $p<.01$

Table 18

Correlation of percent small, medium, and large piglets with piglet liveweight, weight gain, number born alive, number born dead, and piglet mortality

Variable	Treated Small	Treated Medium	Treated Large
Weight			
Day 0	-0.78[e]	0.60[c]	0.91[e]
Day 21	-0.22	-0.16	0.28
Average weight gain			
Days 0-3	0.05	0.42[a]	-0.31
Days 0-7	-0.15	-0.18	-0.06
No. born alive	0.42[a]	0.35	-0.52[b]
No. born dead	-0.41[a]	0.08	0.16
Piglet mortality			
Days 0-3	0.45[b]	0.01	-0.25
Days 0-7	0.63[c]	0.03	0.37

Variable	Control Small	Control Medium	Control Large
Weight			
Day 0	-0.58[c]	0.69[d]	0.91[e]
Day 21	-0.55[b]	-0.03	0.30
Average weight gain			
Days 0-3	-0.41[a]	0.13	0.08
Days 0-7	-0.41[a]	0.13	0.08
No. born alive	0.62[c]	-0.02	-0.17
No. born dead	-0.41[a]	0.08	0.16
Piglet mortality			
Days 0-3	0.31	0.08	-0.23
Days 0-7	0.31	0.13	-0.27

[a] $P<.10$

[b] $P<.05$

[c] $P<.01$

[d] $P<.001$

[e] $P<.0001$

able to return to estrus promptly after weaning (4-7 days weaning to service interval). This supports findings by Kirkwood et al. (1986). Prompt return to heat after weaning ensures high productivity in the sow. A note of caution: beneficial as high backfat thickness at the beginning of lactation is, care should be taken not to overfeed pregnant animals. Overfed dams are at risk for agalactia (inability to let down milk) during the first days of lactation, when adequate and regular nutrition (milk) from the dam is critical for piglet establishment and survival.

2. Control group: Unlike in the treated group, there was no significant correlation between percent milk fat in colostrum and sow BF level within a day after parturition (BF1). However, there was a positive and significant ($P<.10$) correlation between milk fat level on day 3 and sow backfat level 7 days after farrowing (BF7). Percent milk fat on day 21 was negatively but significantly correlated ($P<.05$) to sow BF level at the end of the 2nd and 3rd trimesters (BF72 and BF110, respectively) and within 24 hours of farrowing (BF1).

The negative correlation between milk fat level and backfat level in late lactation (day 21), within control sows, may indicate that sows normally mobilize subcutaneous fat to maintain milk production, which at day 21 was close to peak level.

Correlation of sow weight gain and backfat level with piglet characteristics. In general, there was no significant correlation between piglet birthweight and sow weight gain, and between piglet birthweight and sow backfat level, for both groups in Trial 1 (Table 17).

1. Treated group: There was a negative correlation between piglet liveweight at 3 weeks of age and sow BF level at the end of pregnancy (BF110) ($P<.05$) and for early lactation (BF7) ($P<.01$). There was a negative but significant correlation between piglet milk consumption on day 7 (MI7) and sow weight gain in the 2nd trimester of gestation (LGW4) and also sow BF level on day 7 postpartum (BF7) ($P<.05$ and $P<.10$, respectively).

Rates of piglet mortality during the first 3 days and 7 days of life were negatively but significantly correlated with sow weight gain in the 3rd trimester of gestation (LWG7) ($P<.05$). The correlation between piglet death loss in the critical first 3 days of life was negative but significant ($P<.10$).

2. Control group: As in the treated group, there was a negative but significant correlation between piglet liveweight on day 21 and sow BF level at the end of pregnancy ($P<.05$) and also between piglet milk intake at 7 days of age and sow weight gain in the 2nd trimester (LWG4) ($P<.05$). Unlike in the treated group, there was a negative but significant correlation between piglet milk intake on day 3 and sow backfat level in early lactation (BF1 and B7) ($P<.01$ and $P<.10$, respectively) and no significant correlation between piglet mortality in the first 7 days and either sow weight gain or backfat level. No reason was evident for the low and negative correlation between piglet birthweight and sow gestational weight gain or backfat thickness.

Correlation between percent small, medium, and large piglets and piglet characteristics. The correlation of percent small, medium, and large piglets at birth and piglet characteristics is presented in Table 18.

1. Treated group: Piglet birthweight was negatively correlated with percent small piglets ($P<.0001$), but positively correlated with percent medium piglets ($P<.01$) and large piglets ($P<.0001$). There was a positive correlation between percent small piglets and number of piglets born alive ($P<.10$). Piglet mortality in the first 3 days and first 7 days of life was positively correlated with percent small pigs ($P<.05$ and $P<.01$, respectively).

2. Control group: As in the treated group, piglet birthweight was negatively correlated with percent small piglets ($P<.01$) and positively correlated with percent medium piglets ($P<.0001$) and percent large piglets ($P<.0001$), and proportion of small piglets was positively correlated with number of piglets born alive ($P<.01$). Unlike in the treated group, correlation between mortality and percent small piglets was low and not significant in the control group.

For both groups, the relationship between percent small, medium, and large piglets and piglet performance was a common finding. Mean piglet birthweight was low for litters containing a high proportion of small piglets. Likewise, mean piglet birthweight was higher the more medium or large piglets a sow farrowed. It is interesting to note that within the treated group, piglet birthweight did not appear to influence weight on day 21; but within the control group, the lower the piglet birthweight, the slower the growth rate and lower the day 21 weight. The direct relationship found between percent small piglets and piglet mortality in the first 3 days agrees with English et al. (1977), who reported that although piglets with birthweights of 1.0 kg or less made up only 17% of the number in the litter, they contributed to about 50% of preweaning mortality, with most of the

deaths occurring in the first 7 days of life and particularly in the first 3 days.

Study 2

Physical and Physiological Characteristics

Sow liveweight, weight gain, and backfat levels. Table 19 presents the mean liveweight, weight gain, and backfat (BF) levels of sows a week prior to, and a week after, farrowing. There was no significant difference between mean sow weights of C and T sows on day 105 and 112 of gestation and day 7 of lactation; however, C sows tended to be slightly heavier than T sows.

In general, sow weight gains 7 days prior to parturition (days 105-112) were similar for the two groups (Table 19). Average daily gain during the last week of gestation was nearly 7 kg per sow in both C and T groups, but the means were not significantly different. Weight loss in early lactation (days 1-7) and overall weight loss (days 105 of gestation to day 7 of lactation) were low but similar for the two groups. Backfat level of T sows declined throughout the 14 days of the study; whereas C sows lost backfat up to parturition, then the level stabilized.

Peripartal feeding regime had no significant effect on sow liveweight or weight changes, even though C sows tended to weigh more than T sows, which was probably a reflection of the C group having slightly higher initial weight. The weight loss in both groups during the first week of lactation was not unusual. Sows lose weight in the first 7 days of lactation even if they are fed to appetite (Lodge et al., 1961; Lodge, 1969). This is because at this early stage, younger

Table 19

Liveweight, weight gain, backfat level, and feed intake of peripartal sows[a]

Parameter	Stage	Control	Treated
Liveweight (kg)	d105	193.50 ± 7.29	186.25 ± 7.29
	d112	201.02 ± 7.74	192.42 ± 7.95
	d7	190.25 ± 7.84	183.76 ± 8.04[b]
Weight gain (kg)	d105-d112	6.91 ± 1.17	6.86 ± 1.17
	d112-d7	-9.84 ± 2.17	-9.63 ± 2.17
	d105-d7	-2.84 ± 2.16	-3.70 ± 2.16
Backfat (mm)	d105	17.02 ± 0.81	17.20 ± 0.81
	d112	16.23 ± 0.77	17.03 ± 0.77
	d7	16.40 ± 0.52	15.74 ± 0.52
ADFI	d0-3	5.64 ± 0.35	4.89 ± 0.35

Note: d105, d112 = day 105 and 112 of gestation
d7 = day 7 of lactation
d0-3 = days 0 to 3 of lactation
ADFI = Average daily feed intake ($kg \cdot sow^{-1} \cdot day^{-1}$)

[a] Means ± SE

[b] n = 19 (treated group)

sows are expending more energy (for milk production) than they are taking in as feed; so, mobilization of subcutaneous fat for milk synthesis is inevitable. This was confirmed by the reduction in backfat level in T group from day 112 of gestation to day 7 of lactation.

Sow feed intake. As shown in Table 19, T sows consumed slightly less feed in early lactation (days 0-3) than did C sows (4.89 vs 5.64 $kg \cdot sow^{-1} \cdot day^{-1}$), but the means were not significantly different. Sows fed lower dietary energy during lactation reportedly consume a higher level of feed during lactation (O'Grady et al., 1975). The similarity of feed intake for C and T sows in the present study may have been due to the short period in which lactational feed intake was measured (days 0-3) or the 15% reduction in dietary energy not being severe enough to affect average feed intake by T sows in early lactation.

Blood metabolites. Mean levels of blood metabolites--namely, plasma fatty acids, serum glycerol, and serum glucose--of sows and piglets are presented in Table 20. The 15% reduction in dietary energy did not have a significant effect on sow blood metabolites.

Initial plasma fatty acid levels of T sows were significantly higher ($P<.05$) than those of C sows, but fatty acid levels were similar for the rest of the experimental period. Plasma fatty acid levels of piglets were determined on day of birth. Even though plasma fatty acid levels just prior to parturition tended to be higher in T sows, their offspring did not appear to benefit from it: piglet plasma fatty acid levels at time of birth were similar for both groups. This result is, in general, similar to results reported

Table 20

Concentrations of blood metabolites of sows and neonatal piglets[a]

Parameter	Stage	Control (n=20)	Treated (n=20)
Plasma NEFA (μEq/L)			
Sow	d105	368.17 ± 23.00	441.41 ± 23.00[b]
	d112	443.22 ± 46.67	527.05 ± 46.67
	d7	373.51 ± 28.20	336.25 ± 28.20
Piglet	d0	428.47 ± 30.50	439.79 ± 32.15[c]
Serum glycerol (μm/L)	d105	11.37 ± 1.15	10.83 ± 1.15
	d112	11.91 ± 1.24	13.40 ± 1.24
	d7	9.76 ± 0.91	8.13 ± 0.91
Serum glucose (mg/100 ml)	d105	86.81 ± 3.19	87.91 ± 3.19
	d112	82.70 ± 3.85	82.68 ± 3.85
	d7	96.70 ± 3.82	100.00 ± 3.82

Note: d105, d112 = day 105 and 112 of gestation
d7 = day 7 of lactation
d0 = day of birth

[a] Means ± SE

[b] $P<.0.05$

[c] n = 18 (treated group)

by Ruwe et al. (1991). In their study, fatty acid levels in treated sows increased twofold to sevenfold without improvement in sow or piglet performance.

Concentrations of sow serum glycerol were similar, but initial (day 105 of gestation) and final (day 7 of lactation) levels tended to be slightly higher for C sows. However, serum glycerol at the end of gestation (day 112) was slightly higher for T sows. The tendency of T sows to have slightly higher glycerol concentrations just prior to parturition indicates a relatively higher rate of fat mobilization.

Mean serum glucose concentrations did not differ between the two groups. In general, concentration of serum glucose decreased slightly from day 105 of pregnancy till day 7 of lactation. Concentration of serum glucose was not influenced by treatment; however, the level of serum glucose was similar to levels reported in another study (Pond et al., 1986).

Sow productivity.

1. Piglet characteristics: Table 21 presents litter size, piglet weight, and piglet weight gain from birth to 7 days of age. There was no significant difference between the means for number of livebirths, number of stillbirths, piglet weight, or piglet weight gain; however, compared to T piglets, offspring of C sows had slightly better performance in all these parameters.

The lack of significant effect of treatment on litter size, piglet weight, or piglet growth agrees with findings by Stahly et al. (1979).

Table 21

Litter size, piglet weight, and piglet weight gain from birth to 7 days[a]

Parameter	Control (n=20)	Treated (n=20)
Litter size (#)		
Day 0		
Total number born	11.60 ± 0.47	11.15 ± 0.47
Number born alive[b]	11.25 ± 0.49	10.80 ± 0.49
Day 3	10.50 ± 0.47	9.90 ± 0.47
Day 7	10.40 ± 0.47	9.40 ± 0.47
Piglet weight (kg)		
Day 0	1.24 ± 0.05	1.19 ± 0.05
Day 7	2.31 ± 0.07	2.22 ± 0.07
Piglet weight gain (kg)		
Day 0-7	1.07 ± 0.07	1.03 ± 0.07

[a] Means ± SE

[b] Total number born less total number born dead

2. Piglet classification and postnatal mortality. Piglets were classified as small, medium, or large, based on their birthweights (Fig. 9, Table B11 in Appendix B). Compared to controls, T sows tended to produce a higher proportion of small piglets (24.86% vs 20.24%), but a lower proportion of medium and large piglets (67.15% vs 68.96% and 8% vs 10.8%, respectively).

Mean piglet mortality rate tended to be higher in T litters from birth to days 3 and 7 (8.63% vs 5.33% and 10.79% vs 6.04%). Although the average death loss of T piglets from birth to day 7 was nearly 5% higher than that of C piglets, there was no significant difference between the means (Table B11, Appendix B).

Classification of piglets by birthweights did not indicate any significant treatment effect. However, since T sows tended to produce more small piglets, and small piglets are at greater risk for preweaning mortality, it is not surprising that there was a slightly higher death rate within T litters in the first 7 days of life. This finding agrees, in general, with findings of Stahly et al. (1979).

3. Milk composition. Composition of sow colostrum and milk during the first 7 days of lactation is presented in Table 22. Milk fat levels in sow colostrum (day 0) and milk on day 7 were similar, but on day 3 of lactation, the level was significantly higher ($P<.10$) for T sows (8.12% vs 7.04%), indicating that reduction in dietary energy intake in late gestation and early lactation might have influenced the rate of mobilization of subcutaneous fat to the extent that milk fat level was increased. Levels of milk protein, lactose, and solids-not-fat (SNF) were similar for both groups.

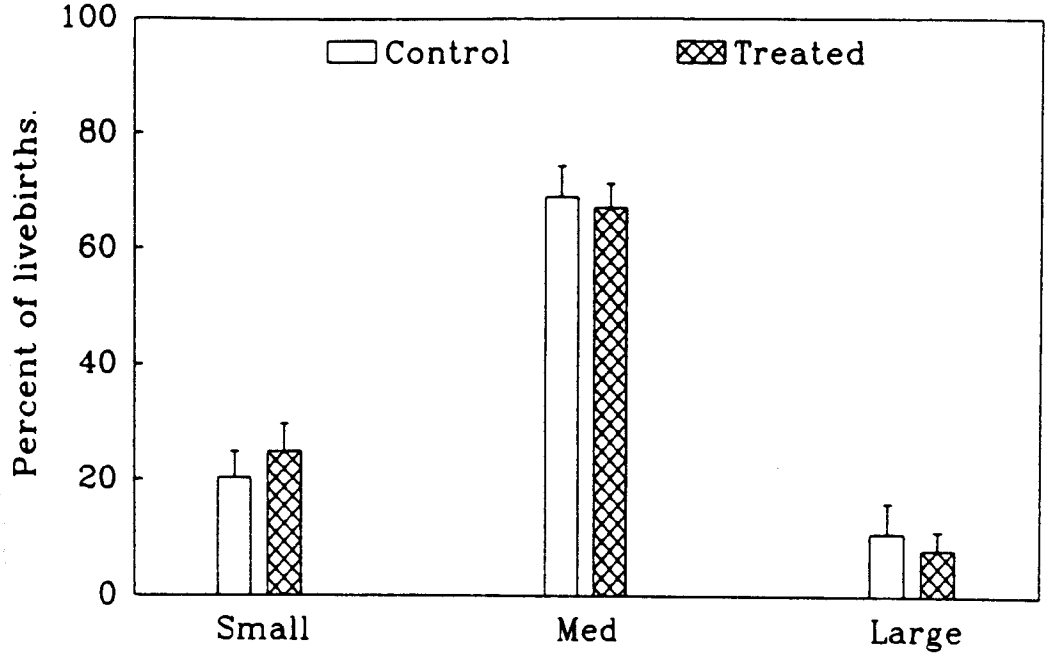


Fig. 8. Classification of piglets by birthweight (Study 2) (Small <1.0 kg, medium 1.0-1.59 kg, large >1.59 kg)

Table 22

Composition of colostrum and milk during the first 7 days of lactation[a]

Parameter	Day	Control (n=20)	Treated (n=20)
Milk fat (%)	0 (colostrum)	4.91 ± 0.48	4.62 ± 0.48
	3	7.04 ± 0.45	8.12 ± 0.45[b]
	7	6.10 ± 0.20	6.53 ± 0.20
Protein (%)	0 (colostrum)	10.95 ± 0.04	10.98 ± 0.04
	3	5.22 ± 0.25	5.47 ± 0.25
	7	4.57 ± 0.10	4.60 ± 0.10
Lactose (%)	0 (colostrum)	1.85 ± 0.12	1.86 ± 0.12
	3	4.62 ± 0.22	4.34 ± 0.22
	7	5.48 ± 0.14[c]	5.32 ± 0.13
Solids-not-fat (%)	0 (colostrum)	13.51 ± 0.12	13.56 ± 0.12
	3	10.61 ± 0.11	10.56 ± 0.11
	7	10.75 ± 0.09	10.63 ± 0.09

[a] Means ± SE

[b] $p < .10$

[c] n = 18 (control group)

SUMMARY AND CONCLUSION

Two studies were conducted to assess the responses of Landrace x Yorkshire crossbred sows and their offspring to (a) same total but different patterns of gestational feeding (Study 1), and (b) dietary energy restriction in late gestation and early lactation (Study 2).

Summary

Study 1

Study 1 utilized 20 controls and 20 treated dams (Trial 1), with a repeat of 7 controls and 8 treated dams at next pregnancy for determination of longer term effects of treatment (Trial 2).

In Trial 1, high amount of feed (3.0 vs 2.0 $kg \cdot sow^{-1} \cdot day^{-1}$) in mid-gestation and low amount of feed (1.5 vs 2.5 $kg \cdot sow^{-1} \cdot day^{-1}$) in late gestation resulted in significant sow gestational weight changes and backfat levels. The results support reports that these parameters are influenced by pattern of feeding during pregnancy.
The experimental feeding pattern significantly increased maternal plasma fatty acid concentration and serum glycerol level ($P<.05$) by the end of gestation, but the increased levels of these energy substrates did not significantly influence the composition or estimated yield of the sow's milk. For gravid sows, the pattern of feeding did not adversely affect sow reproduction performance for litter size, piglet birthweight, piglet survival, or piglet growth from birth to 21 days of age.

The partial repeat of Study 1, using 7 controls and 8 treated sows (Trial 2), indicated results similar to those of Trial 1.

Study 2

In Study 2, 20 controls received standard dietary energy while 20 treated sows received 85% of the standard dietary energy. The reduction of dietary energy by 15% for peripartal sows for 7 days prepartum and 3 days postpartum did not significantly influence sow weight changes and backfat thickness, but might have influenced the rate of mobilization of subcutaneous fat to the extent that milk fat level was increased on the 3rd day of lactation. The ability of the sow to maintain reproductive performance when faced with moderate nutritional insult (restricted energy intake) was supported by the data collected in this study.

Conclusion

The results of this study indicate the ability of the pregnant sow to perform gestational functions adequately when nutrient intake is provided by different patterns of feeding during gestation; thus, flexibility in amount consumed during the gestational period allows for flexibility of feed intake under conditions for which compensation for temporary shortages of nutritional intake can subsequently be made.

This study agrees with others cited that the rate of fat mobilization in pregnant sow can be increased by the pattern of feeding throughout pregnancy, or by dietary energy restriction in the peripartal period, but increased level of circulating energy substrates does not improve sow productivity.

There is need to repeat the experiment over 3 to 4 parities to determine long-term effects and the factor(s) that influence the transfer of energy metabolities to the developing fetus.

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APPENDICES

Appendix A

Laboratory Analysis Procedures

Blood samples were analyzed for:

1. Serum glucose
2. Serum glycerol
3. Plasma nonesterified fatty acids

1. Serum Glucose

Serum glucose was analyzed by quantitative enzymatic (Glucose oxidase) determination. Sigma Diagnostics, procedure number 510. The Sigma procedure is based on the following coupled enzymatic reactions:

$$\text{Glucose} + 2H_2O + O_2 \xrightarrow{\text{Glucose oxidase}} \text{Gluconic acid} + 2H_2O_2$$

$$H_2O_2 + \underset{\text{(colorless)}}{\text{o-Dianisidine}} \xrightarrow{\text{Peroxidase}} \underset{\text{(brown)}}{\text{oxidized o-Dianisidine}}$$

The intensity of the brown color measured at 450 nm is proportional to the original glucose concentration.

Reagents

a. PGO enzymes: Each capsule contains 500 units of units of glucose oxidase (Aspergillus niger), 100 Purpurogallin units of peroxidase (horseradish) and buffer salts.

b. Enzyme solution: Prepared by adding content of 1 capsule to 100 ml distilled water in an amber bottle. Bottle is inverted several times with gentle shaking to dissolve enzyme. Solution is stored refrigerated (2-6°C). Solution is stable up to 1 month, or for at least 6 months frozen (-20°C).

c. Combined enzyme-color reagent solution: Prepared by combining 100 ml of enzyme solution and 1.6 ml of color reagent solution and mixed by inverting the bottle several times or with mild shaking. Solution is stable up to 1 month refrigerated (2-6°C) unless turbidity or color forms.

d. o-Dianisidine dihydrocholoride: Preweighed vial containing 50 mg o-Dianisidine dihydrocholoride. Stored refrigerated (2-6°C).

e. Color reagent solution: Prepared by reconstituting vial with 20 ml water. Stable for 3 months when refrigerated (2-6°C).

f. Glucose standard solution: Beta-glucose, 100 mg/dL in 0.1% benzoic acid solution. Stored refrigerated (2-6°C) unless turbidity develops.

g. Barium hydroxide solution: 0.3 N barium hydroxide. Stored tightly capped at room temperature (18-26°C). Only clear supernatant used should percipitate appear.

h. Zinc sulfate solution: 0.3 N zinc solution. Satisfactory to use as long as neutralized with equal amount of barium hydroxide solution. Stored at room temperature (18-36°C).

Procedure Sample Preparation

Serum samples which were stored at -20°C were removed from the freezer, arranged in a plastic tube rack, and placed in a plastic dish pan half filled with tap water to facilitate the thawing process. Some samples were markedly hemolyzed, so protein-free filtrates were prepared.

Deproteinization Process

Since the glucose concentration of the samples was read directly from the standard curve, the glucose standard solutions were included in the deproteinzation process. This ensured the validity of the direct reading of the sample glucose concentration off a linear curve passing through the origin (zero). Samples were analyzed in batches of twenty (10 controls and 10 treated samples), and a fresh batch of five standards (50, 100, 150, 200, and 300 mg/dL) and a blank (0 mg/dL or water) were prepared daily.

Steps

(1) Twenty-six pairs of 15 x 85 mm snap cap tubes were labelled blank, standards, and samples.

(2) 1.8 ml of water was added to each tube.

(3) To the tubes labelled blank, 0.2 ml of water was added.

(4) To the tubes labelled standard, 0.2 ml of 50, 100, 150, 200, and 300 mg/dL standard glucose solutions were added to corresponding tubes.

(5) To the sample or test tubes, 0.2 ml of serum was added and swirled to mix and hemolyze the samples.

(6) To each tube, 1.0 ml of barium hydroxide solution (0.3 N) was added and swirled to mix.

(7) 1.0 ml of 0.3 N zinc sulfate solution was then added to each tube and vortexed (low speed) to mix well (setting of vortex = 2).

(8) All tubes were centrifuged at 580 x g for 25 minutes in a Sovall General Purpose (RC-3) automatic refrigerated centrifuge.

(9) 0.3 ml of supernatant was transferred into corresponding labelled cuvets (in triplicates).

(10) 3.0 ml of color reagent was added to each cuvet and mixed well using parafilm to cover open end, inverting cuvet several times.

Incubation

(11) Cuvets were placed in styrofoam container covered with lid, wrapped in aluminum foil, and placed in a dark cupboard to shut out any light.

(12) The solutions were incubated for 45 minutes at room temperature (18-26^{o}C).

Reading

After 45 minutes of incubation, absorbance, plotting of standard curve, and glucose concentration of the samples were automatically determined and printed out on a Shimadzu UV-visible recording spectrophotometer at 450 nm. The serum glucose concentration of each sample was the mean of the triplicate (provided all three figures were very close; otherwise extreme concentrations were eliminated and duplicates were used to determine the average value).

Calculation

$$\text{Serum glucose mg/100 ml} = \frac{A_{\text{test}}}{A_{\text{standard}}} \times (\text{glucose std in mg/dL})$$

2. Serum Glycerol

Determination of serum glycerol was by the fluorometric method. The principle of the method is:

a. $\text{Glycerol} + \text{ATP} \underset{\longrightarrow}{\overset{\text{GK}}{\longleftarrow}} \text{L-(-) Glycerol-3-P} + \text{ADP}$

b. $\text{L-(-) Glycerol-3-P} + \text{NAD}^{+} \underset{\text{GPDH}}{\rightleftarrows} \text{Dihydroxyacetone phosphate} + \text{NADH} + \text{H}^{+}$

The formation of NADH as measured by an increase in absorbance at 340 nm is proportional to the amount of glycerol (GK = Glycerokinase; GPDH = Glycerophosphate dehydrogenase).

The equation for calculating unknown concentration of serum samples is:

$$U_{conc} = \frac{(\text{Fluo. of U - blank})}{(\text{Fluo. of std. - blank})} \times \text{conc. of } std_{100}$$

where

U_{conc} = unknown concentration of serum samples

Fluo. of U = fluorescence of unknown (sample)

Fluo. of std = fluorescence of standards

Conc. of std_{100} = concentration of standard (100 µmol/liter)

Reagents and Solutions

a. 1 M magneisum chloride ($MgCl_2$)

b. Buffer: The reagents and solutions for buffer preparation were added in the following order:

(1) 1.59 g glycine was dissolved in distilled water.

(2) 5.89 ml 85% hydrazine hydrate.

(3) 0.2 ml 1 M $MgCl^2$

(4) 10 N potassium hydroxide (KOH) used to adjust buffer pH to 9.8.

(5) Volume was brought up to 100 ml.

(6) Buffer was aliquoted and frozen (-20°C).

c. 50 mM Adenosine triphosphate (ATP)

(1) 60.5 mg ATP (purity 97%) was dissolved in about 1 ml distilled water.

(2) Solution was neutralized (pH 7) with 1 N sodium hydroxide (NaOH).

(3) Volume was brought up to 2 ml.

(4) Aliquoted and frozen (-20°C).

d. 20 mM β-Nicotinamide adenine dinucleotide (β-NAD)

(1) 34.6 mg NAD (about 85% enzymatically active β-NAD in 2 ml distilled water.

(2) Aliquoted and frozen (-20°C).

e. Glycerokinase (GK) Sigma G5751

- 100 U/mg x 5 mg/ml = 500 U/ml bottle
- 1 U/0.02 ml required = 5 U/ml
- 1 in 10 dilution using 2.0 M ammonium sulfate (made fresh daily)

f. Glycerophosphate dehydrogenase (GPDH)

- 50 U bottle (Sigma G-6880, Type X)
- Lyophilized material was stored in the freezer
- 1 U/0.02 ml required
- Reconstituted with 2.0 M ammonium sulfate

$$\frac{50\ \text{U}}{1\ \text{U}/0.02\ \text{ml}} = 1.0\ \text{ml of 2.0 ammonium sulfate per 50 U bottle}$$

- Refrigerated after reconstitution

g. Ammonium sulfate (2.0 M)

26.43 g of ammonium sulfate was dissolved in 100 ml of distilled water and stored in the refrigerator.

h. Glycerol standard stock solution (10 mM)

92.1 mg of glycerol was dissolved in about 60 ml of distilled water. Volume was brought up to 100 ml and frozen.

i. 0.6 N perchloric acid

Preparation of standard solutions:

Concentration of Standards	Dilution with Distilled Water
400 μm/liter	1:24 (stock solution)
200 μm/L	1:1 (400 μm/L)
100 μm/L	1:1 (200 μm/L)
50 μm/L	1:1 (100 μm/L)
25 μm/L	1:1 (50 μm/L)
0	Blank = distilled water

Deproteinization Process

(1) 0.5 ml of serum was added to 0.5 ml of 0.6 N perchloric acid (PCA) in a 1.7 ml polypropylene micro-centrifuge. Final CPA concentration was 0.3 N.

(2) Step 1 was repeated for all the standards and the blank. (This was necessary to ensure that sample values could be read directly off the linear standard curve.)

(3) Contents of the micro-centrifuge tubes were mixed well by vortexing (Vortexer set on 2).

(4) Tubes were iced for 15 minutes and centrifuged at 15,850 x g for 2.5 minutes on a Beckman Microfuge = E.

(5) Supernatant was transferred into 12 x 75 mm labelled disposable culture tubes (borosilicate glass).

(6) Sampling procedure.

0.1 ml of standard or sample was pipetted into labelled 10 x 75 borosilicate glass tubes in triplicates.

The following reagents and solutions were combined and added to the supernatant in one pipetting of 1.92 ml per tube.

Buffer	1.40 ml/tube
GPDH	0.02 ml/tube
ATP	0.05 ml/tube
DI H_2O	0.40 ml/tube
β-NAD	0.05 ml/tube

(7) Each tube was vortexed thoroughly (VWR Vortexer II, set on 1).

(8) 0.02 GK was added to each tube to start the reaction, and tubes were vortexed (set on 1) to thoroughly mix contents.

(9) Samples were read after 100 minutes, using a Fluoro-colorimeter II (SLM AMINCO). Fluorometer was turned on after 60 minutes to warm it up and set it for reading.

(10) A standard linear curve was drawn for each batch of twenty samples.

(11) Glycerol content of samples was determined using the slope of the curve.

3. Nonesterified Fatty Acids (NEFA)

Nonesterified fatty acids were analyzed by titrimetric determination.

Reagents

a. Dole's extraction mixture. Combined by volume:

40 parts isopropanol
10 parts heptane
1 part sulfuric acid (H_2SO_4)

b. Titrant (stock solution)

15 ml of tetra-n-butyl ammonium hydroxide in methanol (Eastman No. 7774) was diluted to 100 ml by adding 85 ml of methanol.

Titrant for daily use:

1.0 ml titrant stock solution
+ 9.0 ml methanol
10.0 ml

c. Indicator

(1) 0.5 ml of 1% phenol red was put into a 500 ml flat-bottom flask.

(2) 49.5 ml of ethanol was added.

(3) 280.0 ml of heptane was added, and the mixture stirred well for 15 minutes using a magnetic stirrer and filtered.

Indicator was ready for use.

d. 1% Phenol red

0.1 g Phenol red was brought to 10 ml with distilled water, to produce 1% phenol red suspension.

e. 0.9% Saline solution

0.9 g NaCl was brought to 100 ml with distilled water.

f. Standard solutions

(1) 256 mg of palmitic acid (crystals) were weighed into a 100 ml measuring cylinder.

(2) About 60 ml of heptane was added and the cylinder gently swirled until all the crystals of palmitic acid had dissolved. More heptane was added to bring volume to 100 ml and refrigerated.

Working standard solutions from stock solution:

1 ml of stock solution (conc. 10,000 µmol/L)
+ 9 ml of heptane
10 ml of standard solution (conc. 1,000 µmol/L)

Analytical Procedure

(1) Screw cap tubes were labelled in duplicates corresponding to number of standards and samples.

(2) 2.5 inches of teflon tape were wrapped around mouth of each tube to prevent spillage during shaking.

(3) 12 x 75 mm tubes were labelled accordingly in duplicates for each screw cap tube, making a total of four tubes per standard, sample, or blank.

Extraction: 1.0 ml of 0.9% saline solution was pipetted into each screw cap tube labelled blank or standard but 0.5 ml of the saline solution into "sample" tubes.

(4) 5.0 ml of Dole's reagent was pipetted into each tube.

(5) 0.5 ml of serum (sample) was pipetted into corresponding tubes.

(6) Tubes were allowed to sit for 5 minutes, and 3.0 ml of heptane added to "blanks" and "samples," but 2.5 ml of heptane was added to standards.

(7) Finally, 2.0 ml distilled water was pipetted into each screw cap tube.

(8) Shaking: The screw cap tubes were tightly closed and shaken at high speed for 10 minutes in an Eberbach mechanical shaker.

(9) 1.5 ml of heptane layer (upper layer) was pipetted into correspondingly labelled 12 x 75 mm tubes.

(10) 0.5 ml of indicator was added to each tube.

Titration

The lemon-yellow samples were carefully titrated to the first indication of a color change (light purple). 2-3 µl titrant was expelled between titrations.

Apparatus for Titrations

A microburette was set up such that a movable clamp could hold a 15 x 85 mm disposable culture tube. The microburette was mounted at eye level on a heavy stand and the apparatus arranged so that the operator could sit down comfortably with elbows on the bench top while titrating. Behind the tube was a sheet of white paper. In front and slightly above it was a lamp for optimal lighting. Nitrogen (N_2) was bubbled through the solution to stir it and also prevent absorption of carbon dioxide from the atmosphere, which would increase the acidity and affect the results. The N_2 was filtered with Mallcosorb absorbant in the line.

Calculations

$$\frac{\mu l \text{ unknown} - \mu l \text{ blank}}{\mu l \text{ standard} - \mu l \text{ blank}} \times 1000 = \mu Eq \text{ NEFA/l}$$

Standard Curve Preparation

Conc. (μmol/L)	Vol. of Stock (ml)	Vol. of Heptane (ml)
1,000	0.500	0
750	0.375	0.125
500	0.250	0.250
250	0.125	0.375
0	0	0

100 μEq/liter = concentration of the highest standard

Standard Curve

A standard curve, which was a linear curve passing through the origin (zero), was plotted daily for each set of standards. The purpose of the standard curve was to verify the validity of using the equation given previously or to be able to read the concentration of the unknown directly off the curve, particularly in cases where the points (corresponding to standards) fall exactly in a straight line.

Appendix B

Results

Table B1

Liveweight of sows during gestation

Trial	Days	Sow Liveweight (kg)[a] Control	Treated
		(n=20)	(n=20)
I	0	150.80 ± 5.50	159.48 ± 5.50
	18	149.77 ± 6.14[b]	158.69 ± 6.48
	36	154.23 ± 5.18	160.07 ± 5.18
	54	159.23 ± 4.79	175.41 ± 4.79[c]
	72	162.30 ± 4.91	181.93 ± 4.91[d]
	90	166.84 ± 5.17	176.82 ± 5.17
	110	180.98 ± 5.39	185.23 ± 5.39
		(n=7)	(n=8)
II	0	173.23 ± 10.92	173.87 ± 10.22
	18	162.12 ± 11.90	174.94 ± 11.02
	36	165.13 ± 10.10	173.03 ± 9.45
	54	170.26 ± 10.76	184.09 ± 10.09
	72	179.22 ± 8.40	194.72 ± 7.85
	90	183.31 ± 9.06	191.02 ± 8.47
	110	196.30 ± 9.04	200.63 ± 8.50

[a] Means ± SE

[b] n = 18 (control group)

[c] $P<.05$

[d] $P<.01$

Table B2

Backfat levels of sows during gestation

Trial	Days	Backfat Level (mm)[a] Control	Treated
		(n=20)	(n=20)
I	0	13.86 ± 0.52	14.02 ± 0.52
	18	13.78 ± 0.48	15.10 ± 0.48[b]
	36	14.25 ± 0.59	15.13 ± 0.59
	54	14.64 ± 0.81	17.82 ± 0.81[c]
	72	15.23 ± 0.94	18.59 ± 0.94[d]
	90	15.42 ± 0.80	16.95 ± 0.30
	110	16.42 ± 0.57	14.86 ± 0.57[b]
		(n=7)	(n=8)
II	0	12.57 ± 0.90	13.76 ± 0.84
	18	11.84 ± 1.48	14.27 ± 1.37
	36	13.07 ± 1.29	13.97 ± 1.20
	54	13.67 ± 1.59	15.77 ± 1.49
	72	13.05 ± 1.07	15.20 ± 1.00
	90	14.52 ± 1.24	15.24 ± 1.16
	110	15.36 ± 1.39	13.86 ± 1.30

[a] Means ± SE

[b] $P<.10$

[c] $P<.01$

[d] $P<.05$

Table B3

Sow liveweight during first 21 days of lactation

Trial	Day	Sow Liveweight (kg)[a] Control	Treated
		(n=20)	(n=20)
I	0	178.73 ± 4.74	180.02 ± 4.74
	7	182.80 ± 4.60	184.93 ± 4.60
	14	184.27 ± 4.61	187.36 ± 4.61
	21	182.77 ± 4.89	188.41 ± 4.89
		(n=7)	(n=8)
II	0	196.95 ± 7.26	200.86 ± 6.79
	7	194.94 ± 7.86	205.06 ± 7.36
	14	197.79 ± 9.20	210.97 ± 8.60
	21	194.22 ± 8.72	209.94 ± 8.16

[a] Means ± SE

Table B4

Backfat levels of sows during first 21 days of lactation

Trial	Day	Sow Backfat Level (mm)[a] Control	Treated
		(n=20)	(n=20)
I	0	15.00 ± 0.61	15.14 ± 0.61
	7	15.30 ± 0.47	15.41 ± 0.47
	14	15.90 ± 0.56	16.35 ± 0.56
	21	14.78 ± 0.54	15.84 ± 0.54
		(n=7)	(n=8)
II	0	15.36 ± 1.13	14.92 ± 1.06
	7	15.60 ± 0.53	15.77 ± 0.50
	14	14.63 ± 1.08	15.56 ± 1.01
	21	15.12 ± 1.10	15.56 ± 1.03

[a] Means ± SE

Table B5

Feed intake of sows during first 3 weeks of lactation

Trial	Days	Feed Intake (kg/day)[a] Control	Treated
		(n=20)	(n=20)
I	0-7	6.33 ± 0.23	6.33 ± 0.23
	8-14	7.38 ± 0.27	7.83 ± 0.27
	15-21	7.37 ± 0.31	7.54 ± 0.31
	0-21	144.75 ± 4.34	152.51 ± 4.34
		(n=7)	(n=8)
II	0-7	6.51 ± 0.31	6.47 ± 0.29
	8-14	7.26 ± 0.55	7.72 ± 0.52
	15-21	7.04 ± 0.50	7.30 ± 0.47
	0-21	144.22 ± 6.20	150.48 ± 5.80

[a] Means ± SE

Table B6

Piglet litter size from birth to 21 days of age

Trial	Age (days)	Number of Piglets[a] Control	Treated
		(n=20)	(n=20)
I	0 - total born	11.05 ± 0.51	12.10 ± 0.51
	born alive[b]	10.70 ± 0.51	11.25 ± 0.51
	3	9.75 ± 0.50	10.20 ± 0.50
	7	9.65 ± 0.47	10.00 ± 0.47
	14	9.40 ± 0.47	9.65 ± 0.47
	21	9.20 ± 0.47	9.40 ± 0.47
		(n=7)	(n=8)
II	0 - total born	11.43 ± 0.96	9.63 ± 0.90
	born alive	11.00 ± 0.98	9.50 ± 0.92
	3	10.43 ± 0.96	9.38 ± 0.90
	7	10.14 ± 0.96	9.38 ± 0.95
	14	10.00 ± 0.99	8.88 ± 0.92
	21	9.57 ± 1.00	8.50 ± 0.94

[a] Means ± SE

[b] Total born less number born dead

Table B7

Piglet liveweight from birth to 21 days

Trial	Age (days)	Liveweight (kg)[a] Control	Liveweight (kg)[a] Treated
		(n=20)	(n=20)
I	0	1.38 ± 0.05	1.34 ± 0.05
	3	1.77 ± 0.06	1.68 ± 0.06
	7	2.52 ± 0.08	2.44 ± 0.08
	14	3.86 ± 0.16	3.80 ± 0.16
	21	5.31 ± 0.23	5.29 ± 0.23
		(n=7)	(n=8)
II	0	1.42 ± 0.10	1.62 ± 0.10
	3	1.69 ± 0.16	1.92 ± 0.14
	7	2.46 ± 0.17	2.66 ± 0.16
	14	3.75 ± 0.27	3.84 ± 0.25
	21	5.00 ± 0.37	5.08 ± 0.35

[a] Means ± SE

Table B8

Classification of piglets by birthweight

Trial	Class	Percent Piglets[a] Control	Percent Piglets[a] Treated
		(n=20)	(n=20)
I	Small (<1.0 kg)	9.92 ± 3.02	15.32 ± 3.02
	Medium (1.0-1.59 kg)	71.89 ± 5.06	62.42 ± 5.06
	Large (>1.59 kg)	18.50 ± 5.78	22.25 ± 5.78
		(n=7)	(n=8)
II	Small	8.55 ± 4.97	6.39 ± 4.65
	Medium	66.66 ± 12.06	38.73 ± 11.28
	Large	25.39 ± 13.83	54.89 ± 12.94

[a] Means ± SE

Table B9

Mortality rate of piglets from birth to 21 days of age

Trial	Age (days)	Percent Piglets[a] Control	Treated
		(n=20)	(n=20)
I	0-3	9.03 ± 2.03	10.83 ± 2.03
	0-7	9.77 ± 2.13	12.39 ± 2.13
	0-14	11.65 ± 2.35	15.64 ± 2.35
	0-21	13.96 ± 2.74	16.60 ± 2.74
		(n=7)	(n=8)
II	0-3	4.76 ± 1.68	0.00 ± 1.57[b]
	0-7	7.94 ± 2.52	1.39 ± 2.36[b]
	0-14	9.36 ± 3.24	6.09 ± 3.02
	0-21	13.44 ± 4.84	9.40 ± 4.52

[a] Means ± SE

[b] $P<.10$

Table B10

Milk consumption of piglets from day 3 to day 21

Trial	Days	Grams per Piglet per Suckle[a] Control	Treated
		(n=20)	(n=20)
I	3	80.53 ± 7.63	81.44 ± 7.87
	7	100.78 ± 10.41	86.98 ± 10.41
	14	108.00 ± 9.31	98.86 ± 9.31
	21	106.62 ± 11.77	115.19 ± 12.07[b]
		(n=7)	(n=8)
II	3	78.93 ± 6.92	68.18 ± 5.85
	7	84.96 ± 12.91	115.63 ± 18.51
	14	127.92 ± 25.84	94.50 ± 24.17
	21	128.93 ± 18.81	145.21 ± 17.41

[a] Means ± SE

[b] n = 19 (treated group)

Table B11

Piglet class by birthweight and piglet mortality (Study 2)

Parameter	Percent Piglets[a]	
	Control	Treated
Piglet class at day 0		
Small (<1.0 kg)	20.24 ± 4.64	24.86 ± 4.64
Medium (1.0-1.59 kg)	68.96 ± 4.77	67.15 ± 4.77
Large (>1.59 kg)	10.80 ± 4.30	8.00 ± 4.30
Piglet mortality		
Day 0-3	5.33 ± 1.81	8.63 ± 1.81
Day 0-7	6.04 ± 2.21	10.79 ± 2.21

[a] Means ± SE

Appendix C

Definitions Pertinent to This Study

Body condition of sow: Applies to sow backfat thickness.

Colostrum: Milk secreted for the first 24 hours after parturition and characterized by high protein and antibody content.

Creep area: Warm area on both sides of the farrowing crate, where piglets sleep or escape to avoid being overlain by sow when she is lying down.

Ear notching: Making notches in ears of newborn pigs. Notches identify piglets by litter number and individual number.

Farrowing: Parturition; giving birth to piglets.

Fat mobilization: Breaking down of laid down body fat to supply fatty acids to be used as source of energy by the body.

Gestation: Pregnancy.

Gestation period: Pregnancy period; from time of service by boar or artificial insemination to time of giving birth to piglets (range 111 to 117 days; average = 114 days).

Gilt: Young female pig that has never given birth to piglets.

Gravid sow: Pregnant sow.

Multiparous: Applies to female pig that has given birth to piglets two or more times.

Parity: Complete reproductive cycle; therefore, 1st parity sow has completed one reproductive cycle or has farrowed once.

Peripartal: Applies to period shortly before and soon after farrowing.

Porcine: Refers to pig (adjective).

Postpartum: After birth.

Prepartum: Before birth.

Primiparous: Applies to female pig that has given birth to piglets for the first time.

Sow: Female pig that has given birth to piglets at least once.

Tail docking: Cutting part of a newborn piglet's tail off, to prevent tail chewing in adult pigs.

Teeth clipping: Cutting sharp edges of needle teeth off. Done on newborn piglets to prevent injury to udder of sow during first 3 days after birth when piglets fight to establish permanent nursing positions on udder of sow.

Trimester: One-third of gestational period.
Days 0-36 = 1st trimester
Days 37-72 = 2nd trimester
Days 73-112 = 3rd trimester

Unconventional feeding pattern: Experimental feeding pattern.