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**DIETARY CALCIUM AND PHOSPHORUS FOR LACTATING SWINE AT HIGH
AND AVERAGE PRODUCTION LEVELS**

The Ohio State University

Ph.D. 1985

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DIETARY CALCIUM AND PHOSPHORUS FOR LACTATING SWINE AT HIGH
AND AVERAGE PRODUCTION LEVELS

DISSERTATION

Presented in Partial Fulfillment of the Requirements for
the Degree Doctor of Philosophy in the Graduate
School of The Ohio State University

By

Paul Frank Maxson, B.S., M.S.

* * * * *

The Ohio State University

1985

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May the fruits of this work allow more perfect completion of the Lord's will for my life.

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LITERATURE REVIEW

INTRODUCTION

Emphasis to improve swine production efficiency is currently centered on enhancing sow productivity. Dam lines are being developed to farrow large numbers of live pigs and with high milk production capability. The weaning of pigs at 3 weeks is becoming a common practice, particularly in modern swine facilities where complete environmental control is possible. Consequently, sows under high reproductive performance demands and early weaning practices could easily encounter nutritional inadequacies limiting their reproductive life.

National Research Council (1979) dietary calcium:phosphorus (Ca:P) recommendations for lactating sows, are based upon limited research. A hazardous situation may exist when inadequate Ca:P levels are fed to sows with large litters and heavy milk production. The result can be skeletal tissue demineralization and posterior paralysis. The increased incidence of posterior paralysis would appear to substantiate today's dietary insufficiency of Ca:P for sows. Females kept for multiple parities may further exacerbate the nutritional insufficiency of dietary Ca:P levels with large litters accentuating the problem even more. Consequently, superior females in the swine herd may be eliminated due to structural breakdown.

It is well documented that bone tissue may be depleted of minerals to support lactation, prior to a decline in milk production, litter weight gains or milk mineral concentrations. Therefore, bone tissue should be the most sensitive criterion to assess the dam's dietary Ca:P adequacy.

The objective of the present work was to assess dietary Ca:P adequacy for lactating sows at an average or high litter size over two parities with 21 day lactation periods. In addition to measuring reproductive performance, emphasis was placed on the bone tissue of the dam, the largest and most sensitive source of Ca:P in the body.

TERMINOLOGY

Before considering specific conditions resulting from Ca:P nutrition and a particular state of production (i.e., lactation), it is important to define several terms about the various physiological states which occur in bone tissue.

At the cellular level there are three cell types controlling mineral metabolic activity in the bone, osteocytes, osteoblasts and osteoclasts. Osteocytes are cells involved in maintenance of bone tissue. Osteoblasts are cells which carry out the process of bone formation (calcification). Finally, osteoclasts are cells involved in bone resorption. These three cellular components of bone respond to hormonal stimuli which determines the structural state of bone.

Apart from healthy bone, there are specific disorders of bone considered metabolic bone diseases; they are mediated in part by the cells previously described. Metabolic bone diseases can be

conveniently divided into three general types: (1) those principally characterized by porosis, (2) those principally characterized by malacia and (3) those principally characterized by petrosis.

Osteoporosis is simply a generalized atrophy of total bone (i.e. there is too little bone present) but appears to be properly calcified. This is a term used to denote a failure of normal bone metabolism in the adult.

Osteomalacia (softening of bones) is characterized by failure to mineralize (calcify) osteoid tissue into true bone. Osteomalacia occurs as a result of a failure of new bone formation keeping pace with constant mobilization of Ca and P in the bone's dynamic state. Osteomalacia is considered an adult bone disorder but differs from osteoporosis in that it represents a decrease in the mineral content of bone rather than a reduction in the absolute amount of bone.

Rickets, sometimes called rachitis, is a disease characterized by failure of adequate deposition of calcium hydroxyapatite in the bones of growing animals or children. In the adult, rickets is often used to include the essentially similar osteomalacia in older animals.

Osteopetrosis is characterized by an excess of calcified bone and although it occurs in animals, it is infrequent.

The following classification system should aid in understanding the dynamic states of metabolic bone disorders.

1. Too little bone, e.g. osteoporosis.

2. Defective calcification of matrix, e.g. young - rickets, adult - osteomalacia.
3. Too much calcified bone, e.g. osteopetrosis.

MATERNAL RESPONSES TO DIETARY CA:P

Effect of Previous Nutritional History. It is during the latter stages of pregnancy and throughout lactation that the gilt or sow has a large demand for Ca:P from either developing fetal bone tissue or milk production. The dam must obtain these nutrients either from the diet or from skeletal tissue to meet the late gestation-lactation mineral requirements. The previous dietary Ca:P level regimen fed to developing animals for development of their skeletal reservoir may be an important factor to later overall sow productivity. Ca and P provided during gilt development phase could become particularly significant when dietary provision falls short of production demands (i.e. lactation).

Various measures of maximum skeletal strength or maximum bone mineralization have been generally adopted during the last 25 years as criteria for establishing adequacy of dietary Ca and P of developing swine and subsequent breeding animals. Generally, bone ash plateaus at an approximate .10% higher dietary Ca and P level than that necessary to obtain maximum growth rate and feed conversion (Mahan et al., 1980; Mahan, 1982, Maxson and Mahan, 1983), while breaking strength is maximized at yet a higher dietary level (Cromwell, 1979; Maxson and Mahan, 1983). Data from many sources (Chapman et al., 1962; Miller et al., 1962; Libal et al., 1969;

Fammatre et al., 1977; Mahan et al., 1980; Nimmo et al., 1981; Mahan, 1982; Maxson and Mahan, 1983) have consistently demonstrated with weanling swine through the growing-finishing stages, a growth performance plateau, followed by ash and finally breaking strength, in response to increasing dietary Ca:P levels. Although the supplementation of these minerals to attain maximum skeletal mineralization does not appear necessary for market animals, the levels for reproducing swine has yet to be clearly defined.

The role of dietary Ca:P levels concerning leg unsoundness or longevity in the development of the boar is not clearly established. Past research has produced variable conclusions concerning optimum dietary Ca:P levels for developing boars. Liptrap et al. (1970) reported that when dietary P was maintained at .5%, the Ca requirement for developing boars to 100 kg body weight was not greater than .6%, because feeding higher levels resulted in no improvement in bone strength or bending moment. Bayley et al. (1975) demonstrated that maximum growth could be attained with .6% dietary P, but maximum bone breaking force required a higher dietary level. Tanksley (1974) and Nimmo et al. (1980) demonstrated that much higher dietary Ca:P levels could be fed to achieve greater femoral bone breaking loads without affecting boar performance. A recent study by Hickman et al. (1983) suggests that the developing boar may have a higher Ca:P requirement than previously thought for growth and bone development. Over the entire growth period (5-110 kg), growth rate increased as dietary Ca:P increased up to 55 kg while bone

mineralization responded to the highest dietary Ca:P level, (i.e. 1.17/.90%) throughout the trial. Both the growth and mineralization trials indicated that higher dietary Ca:P levels are necessary for boars than currently suggested by NRC (1979).

The gilt or sow presents even more difficulties in the establishment of proper dietary Ca:P levels for growth as well as subsequent reproductive needs. The problem of posterior paralysis or "downer sows", is present in many swine herds today. The posterior paralysis sow syndrome is commonly encountered in many swine herds during late gestation or lactation, particularly when Ca:P or vitamin D supplementation is inadequate. In posterior paralysis the vertebrae slips effectively pinching the spinal cord, causing a paralysis in the hind quarters. Implicated as contributing factors to posterior paralysis are: increased confinement on concrete floors, reduced exercise, long lactation periods, short rebreeding periods following lactation and increasing number of parities. Several surveys (Jones, 1967; Penny, 1972; Penny, 1980) reported that from 20 to 32% of sows were replaced in the herd because of lameness and paralysis. The problem of sexually mature versus gilts which may be structurally immature, subsequently fed a restricted energy diet, compounds itself when continued skeletal growth, fetal development and a rigorous lactation are expected. The nutritional prerequisites for future gilt or sow participation in modern swine production all provide variables making dietary Ca:P recommendations difficult.

Early work with Hogen et al. (1927), Evans (1929), Davidson (1930) and Elmslie (1930) suggest the supplementation of dietary Ca:P to breeding animals to at least .4% with 1.0% Ca showing the best response in reproductive parameters. Both Evans (1929) and Davidson (1930) postulated that a Ca deficient diet fed to pregnant sows may not produce an immediate effect on the bone structure of developing fetuses since the mother's bones can be depleted to supply the mineral needs of the fetal skeleton. Lenkeit (1959) later suggested that when dietary Ca and P are limiting during the gestation period, a negative balance of these elements may not occur during lactation. This suggests the conservation of nutrients during periods of inadequate or borderline nutrition.

More recent work of Hansard et al. (1966), Itoh et al. (1967) and Hansard and Itoh (1968) evaluated the metabolic fate of Ca (and other minerals) in pregnant sows. Sows showed no significant effects of pregnancy on maternal absorption of plasma ^{45}Ca or tissue Ca concentration occurred during the first, second or third trimester following oral or intravenous dosing of ^{45}Ca . At 35, 70, 105 and 114 days gestation, 0.9%, 60%, 17.8% and 21.3% respectively of the absorbed ^{45}Ca was transferred to the litters whereas less than 1% was retained in the combined placenta and fluids after 168 hours. Fetal bone Ca increases as pregnancy progresses with the utilization of absorbed Ca for fetal development improved in its efficiency as pregnancy advances (Hansard et al., 1966). Itoh et al. (1967) evaluated placental Ca transfer in pregnant sows fed normal and low

Ca diets. Their results indicate that sows fed .70% Ca retained 15 g Ca compared with only 9 g per day for those fed .30% Ca evaluated during the last 2 weeks of gestation. Thus, more total Ca was absorbed and subsequently available for fetal development of sows fed the higher level of Ca. It was noted by these authors that some of the sows provided .30% Ca after 70 days gestation exhibited clinical signs of Ca deficiency by 100 to 110 days gestation. Assistance to the sows fed the low Ca diet was required for them to stand while one sow suffered a fractured femur.

Assessing both gestation and lactation reproductive phases together, Kornegay et al. (1973) conducted a long term study evaluating two levels of Ca:P over 5 reproductive cycles. In their trial a higher percentage of sows completed 5 reproductive cycles when higher Ca:P levels (i.e. 15.5 g Ca, 15.0 g P per day) were fed. Investigating the P requirements of sows during one gestation and lactation, Harmon and coworkers (1975) indicated that an unsupplemented diet, (i.e. .33% P) was adequate during gestation but reduced bone ash was observed in sows fed .45% P during the subsequent lactation. They suggested that sows retained for multiple parities may require higher dietary P levels. Mahan and Fetter (1982) indicated that sows maintained over three parities showed mineral depletion of the rib and vertebrae when provided .65/.50% Ca:P compared to .90/.70% Ca:P. Nonbred females maintained in this trial over the same time period had higher bone ash values than those lactating and similar at the various dietary mineral levels provided.

Utilizing gilts from weaning through one reproductive cycle, Nimmo et al. (1981a,b) and Calabotta (1981a,b) found contrasting results after feeding different Ca:P levels. Both researchers fed current NRC (1979) Ca:P recommendations as their standard treatment group and 150% of the NRC Ca:P levels as the treatment comparison group. Both cases showed no differences in feed intake or feed conversion although there was a trend toward improved pig gains when higher mineral levels were fed from weaning to market weight. Nimmo et al. (1981a) reported that both bone weight and bending moment increased when higher mineral levels were fed. Their data implied a greater mineral reservoir for production reflected in the increased mineral content and strength of the bones. Conversely, the results of (Calabotta et al., 1982a) demonstrated that physical observations and dimensions, toe lesions, bone circumference and hoof dimensions were not influenced by previous dietary Ca:P levels after one parity. In a subsequent study, it was determined that gait characteristics were unresponsive to dietary Ca:P levels in market weight gilts (Calabotta, 1982b). These results suggest that dietary Ca:P levels fed during the growth phase of gilts has little affect on growth parameters, leg size, hoof measurements, hoof lesions and(or) animal gait. Arthur et al. (1983a,b) extended the production period to three parities and evaluated sows previously fed 100 and 150% of the NRC (1979) Ca:P during growth phases, but the same diet through successive reproductive cycles. After three parities the Ca:P intakes during growth and development were found to have only minimal

effects on incidence or severity of lesions on the toes, overall structural soundness or bone characteristics (percent ash and bone breaking strength).

The research cited heretofore indicates that for sows or gilts, dietary Ca:P levels during growth, gestation or lactation will primarily affect the dam's skeletal tissue. Multiple parities may stress the bone tissue more, with the rib or vertebrae being affected before other bones.

Age. Gestation, lactation and multiple parities place demands upon the Ca:P reservoir of the skeleton. Bone acts not only as a supporting or structural component of the body but also serves as a vital physiological tissue providing a readily available source of Ca:P for homeostatic control.

Aging is another factor influencing the Ca:P stores of the skeleton (Flanagan and Nichols, 1969; Smith et al., 1975; Heaney et al., 1982; Schuette and Linkswiler, 1984). Throughout life bone tissue is constantly turning over, a continuous process of resorption and formation. The young animal has a high rate of bone turnover in which bone formation predominates. In the young adult there is a comparatively lower rate of bone turnover, with bone tissue having a very compact appearance. During this time an estimated 3 to 5% of the total skeleton is actively being remodeled (Schuette and Linkswiler, 1984). Later in life there results a gradual increase in turnover rate. Resorption of bone occurs, leading to a gradual loss of bone tissue with an increase in porosity (Jowsey, 1960). It is

important to note that in modern swine production systems, not only are many sows held for more reproductive cycles, but they are almost continually in a gestation or lactation phase of production. Consequently the reproduction phase constantly affects the Ca:P reserves of the skeleton while aging further exerts its detrimental effects on the body tissues.

Osteoporosis, defined at the outset, is one effect of aging. Schuette and Linkswiler (1984), in humans, indicated that osteoporosis develops from: 1) bone loss due to a relative estrogen deficiency resulting in an increase bone resorption; 2) a higher rate of bone turnover, which exacerbates the disparity between resorption and formation; 3) an impairment of Ca absorption due to a reduction in the conversion of 25-OHD to 1,25-(OH)₂D in elderly individuals; 4) an inability to conserve body Ca by reducing urinary Ca when Ca intake is low; 5) a low level of physical activity accelerating the rate of bone loss. Osteoporosis is covered quite extensively for several species (Fourman and Royer, 1968; Smith et al., 1972; Rasmussen and Bordier, 1974; Blood and Henderson, 1979). While Garn et al. (1967) points out that osteoporotic bone loss is a health problem of major magnitude in humans, its occurrence in domestic livestock species from aging may be unexpected due to their relatively young age. The average lifespans of livestock species is, however, shorter than for humans even when allowed to "die naturally". Bone mineral losses resulting from the aging process may occur earlier in livestock species considering old age to be between

10 to 15 years in hogs, cattle and sheep. Van Heukelen (1979) points out that old age in fruit flies is about 2 months and mice 3 years. Although age related bone loss in swine may begin to occur in adult animals much the same as in man the demineralization is intensified by a continual reproductive state in female swine. The following sections will consider several factors which, when added to the effects of age, may accelerate the effect which may, even alone, produce osteoporosis.

Calcium and phosphorus intake during growth or as an adult may affect the rate of osteoporosis. Heaney et al. (1982) suggest several important factors to consider 1) role of Ca intake in early life in determining peak adult bone mass; 2) role of peak adult bone mass in determining fracture susceptibility as age increase; 3) decreased absorption of Ca:P in the adult; 4) the bioavailability of Ca sources for adults where absorption efficiency of Ca:P declines. Fourman and Royer (1968) suggest that the amount of Ca absorbed and stored by age 20 in the human is more important than the day-to-day turnover at age 60.

While items 1 and 2 above are suggested as areas of investigation in humans, Ca:P research in swine has been conducted to evaluate these questions in pigs from 3 weeks to approximately 3 years of age. Measures of skeletal strength or bone mineralization are maximized with increasing dietary Ca:P levels for swine from 5 to 110 kg body weight, 3 weeks to 7 months age, (Chapman et al., 1962; Miller et al., 1962; Libal et al., 1969; Fammatre et al., 1977; Mahan

et al., 1980; Nimmo et al., 1981; Mahan, 1982; Maxson and Mahan, 1983). Peak adult bone mass does not appear necessary for market swine slaughtered between these ages or weights (Miller and Kornegay, 1983). Peak adult bone mass developed in market swine and selected to remain in the reproducing herd beyond 110 kg body weight or 7 months of age, is controversial (Miller and Kornegay, 1983). Several researchers suggest that structural unsoundness or fractures are unrelated to dietary Ca:P levels during growth above NRC (1979) recommended levels (Nimmo et al., 1980; Kornegay and Thomas, 1981; Arthur et al., 1983; Kornegay and Kite, 1983). Conversely, other workers (Kornegay et al., 1973; Thomas and Kornegay, 1981; Nimmo et al., 1981a; Cromwell, 1982; Mahan and Fetter, 1982) indicate that pigs may benefit from increased dietary Ca:P above NRC (1979) recommended levels during growth and as an adult in the reproducing herd. Confounded in these results are sex, age, reproductive status as well as feeding practices, differences in experimental conditions and the criteria used to assess results. One factor of note, particularly with sows, is that no effect from dietary Ca:P on bone parameters (mineralization, breaking strength) or simply reproductive lifespan was usually reported in studies of 3 parities or less (Arthur et al., 1983a,b), whereas responses to elevated dietary Ca:P occurred in older animals, 3 or more parities, (Kornegay et al., 1973; Mahan and Fetter, 1982). Production level also appears involved as longer lactation periods (21-28 day vs 42-48 day) or multiple parities (3 to 5) responded in criteria evaluated to

elevated dietary Ca:P (Kornegay et al., 1973; Harmon et al., 1975; Nimmo et al., 1981a; Mahan and Fetter, 1982). Age and reproductive demands may be exerting an effect on Ca:P stores with the peak bone mass developed during growth taking on more importance as the animal ages.

Related directly to dietary Ca:P levels is the bioavailability of the various Ca:P feedstuff source. The intestinal absorption of Ca and the ability to adapt to low intake appears to diminish with age (Avioli et al., 1965; Smith, 1967; Fourman and Royer, 1968; Heaney et al., 1982). Several investigators report that a substantial proportion of human patients with postmenopausal osteoporosis have impaired intestinal Ca absorption as assessed either by metabolic balance or by absorption of radiocalcium (Szymendera et al., 1972; Gallagher et al., 1973; Gallagher et al., 1979; Gallagher et al., 1982). Whether or not sows encounter the age related absorption problems with Ca:P is not known but the major constituents in swine diets, corn and soybean meal, are low in Ca content and have a poorly available P source (Peeler, 1972, NRC, 1979; Ross et al., 1984). Consequently, sows which may be declining in their absorption efficiency of Ca:P, a highly available Ca:P supplement appears more critical at various ages. Other nutrients in the diet which will interact with Ca:P such as fiber or zinc should also be kept in mind when formulating a diet for adult swine (Underwood, 1977, 1981).

Hegsted (1967), reviewed the role of nutrition and bone loss. He suggested that bone destruction is not simply the reverse mechanism of bone formation and the general idea that one can force bone mineralization or formation by an increased supply of structural materials is probably invalid. The author concludes that while supplying the appropriate structural materials for bone formation are clearly necessary, it is equally possible that nutrition and metabolic regulation through osteoblast and osteoclast cellular function, may be of more significance. What factors control the activities of osteoblasts and osteoclasts are important and subsequent nutrient supply to those cells may be a minor regulator (Hegsted, 1967). Heaney et al. (1982) submits that osteoporosis is a complex, multifactorial disorder, and that factors unrelated to Ca:P nutrition play important, even dominant roles in most osteoporosis conditions.

Two hormones which appear intimately involved in the effect of aging on bone loss are estrogen and vitamin D. Estrogen effects bone mass reduction has been evaluated in women because of the period of rapid bone loss that occurs following menopause as well as the smaller skeletal mass at maturity exacerbating the problem (Schuette and Linkswiler, 1984). Work with premenopausal, postmenopausal and postmenopausal women supplemented with estrogen indicates a lower Ca requirement per day, .99 g vs 1.50 g, in women with higher estrogen levels supplied either naturally or via dietary supplementation (Heaney et al., 1978). Estrogen replacement therapy and Ca

supplementation have subsequently been shown to reduce bone turnover, both resorption and formation (Riggs et al., 1976, Recker et al., 1977). These reports indicate that the level of estrogen in the body has a direct affect on bone mass. Because sows are continually in a reproductive state, gestation or lactation, and the swine industry has adopted breeding shortly upon weaning, the lower estrogen levels may ultimately affect bone mass. Females which do not cycle in the swine herd are usually culled but a comparison between anestrus adult swine and pregnant/lactating sows' estrogen levels would be of interest.

Vitamin D may also exert its effect on bone and Ca:P metabolism toward osteoporosis (Riggs et al., 1976; Gallagher et al., 1982). Short term dosage of $1,25(\text{OH})_2\text{D}_3$ returns Ca absorption to normal, improves Ca balance and reduces bone resorption rate below the bone formation rate. The authors suggested that results after short term usage (i.e. 6 to 8 months) of $1,25(\text{OH})_2\text{D}_3$ are favorable in counteracting osteoporosis and negative Ca balance in humans (Gallagher et al., 1982). Long term effects of vitamin D therapy evaluating correct dosage which will alleviate osteoporosis without mobilizing bone needs to be evaluated. Riggs and coworkers (1976) suggested that vitamin D reduces bone turnover rate most probably by partial inhibition of PTH secretion. The vitamin D system in the regulation of Ca:P metabolism has been recently reviewed (DeLuca, 1979; Fraser, 1980; Stanbury, 1981).

Reduced exercise during growth or as an adult is another proposed factor influencing adult bone loss. It has been suggested that one causative factor in adult osteoporosis is decreased animal activity with increasing age. Studies with humans have demonstrated that bone density is greater in persons in occupations requiring physical exertion than in those involved in sedentary work and is greater in athletes than in non-athletes (Kazarian and Von Gieke, 1969; Donaldson et al., 1970; Nilsson and Westlin, 1971). Inactivity following bone fracture, paralysis, complete bed rest or weightlessness in space flight has resulted in negative Ca balance and significant losses of bone mass in affected limbs (Mack and Cochence, 1967). A decrease in bone formation was the cause of loss of bone in the weightless state (Morey and Baylink, 1978). On the contrary, forced exercise in mature mice results in increased bone weight, mineral content and femoral cortical measurements regardless of dietary Ca:P level, although the improvements were small (Bell et al., 1980). Growing rats subjected to 3 hours of exercise in an electrically operated wire drum 5 days a week for 2, 4, 6, 8 and 10 weeks exhibited significant increases in both muscle and bone weight (Saville and Whyte, 1969). The more intense exercise in the latter experiment with rats versus one hour exercise with the mice, and the age differences (i.e. mature vs growing) suggests that regular physical exercise during growth and early adulthood may produce an increase in skeletal size and thereby decrease the risk of osteoporosis (Emiola and O'Shea, 1978).

Modern swine production has moved toward complete confinement of animals throughout their productive life. The inactivity of young gilts placed in gestation stalls, coupled with large Ca:P demands from fetal growth or milk production, apparently would give rise to circumstances which could reduce bone formation. When pigs were individually penned vs group fed, growth rates as well as bone mass and bone breaking strength were reduced (Elliot and Doige, 1973). Perrin and Bowland (1977) reported that visual leg soundness scores in boars without exercise were poorer, particularly in the forelegs; whereas, when exercise was enforced leg scores improved. Recently, Kesel et al. (1983) indicated that boars which were penned in groups of 20 and provided 150% NRC (1979) recommended Ca:P levels had the heaviest and strongest bones. Thus, there appears to be a positive relationship to bone mass and exercise which may mitigate the later responses to aging in swine.

Structural Soundness Problems (Lameness). Although lameness is well recognized for reproductive failure in swine its cause is not well documented. Few people would disagree, however, under intensive systems of husbandry and management, lameness of known or unknown etiology, is a common occurrence and is increasing in frequency. Previously cited surveys (Jones, 1967; Penny, 1972; Penny, 1980) report that from 20 to 30% of sows are replaced from lameness and posterior paralysis. While posterior paralysis is directly attributable to Ca:P demineralization, lameness is more obscure and its relationship to Ca:P nutrition less well defined. Unsound feet

and legs may stem from abnormal genetic bone development, cartilage degeneration or foot problems. Rapid growth rates, age, sex, flooring materials and floor space per animal have all been proposed as contributing to the problem. The multifactorial etiology of structural unsoundness creates a complex problem involving interrelationships among nutritional, genetic, environmental and conformational factors. The focus here will be on the dietary Ca:P role in precipitating lameness problems.

Several researchers have evaluated the influence of dietary level of Ca:P during growth and development on leg weakness or structural unsoundness scores (Grondalen, 1974; Reiland, 1975; Kornegay and Thomas, 1981; Calabotta et al., 1982). Generally, all of the above researchers have reported no improvement in leg weakness or structural unsoundness when high levels of Ca and P were fed.

Both Kornegay et al. (1973) and Nimmo et al. (1980) reported a high lameness incidence when sows were fed 10 grams of P daily during gestation. Kornegay et al. (1973) conducted a long term study evaluating two dietary levels of Ca:P. They reported that a higher percentage of sows completed 5 reproductive cycles when the higher Ca:P levels were fed. It was also noted that a number of fractured femurs occurred when sows were fed low as well as high Ca:P levels over the trial. Nimmo et al. (1981a) reported that sows fed recommended NRC (1973) Ca:P levels during the growing period, gestation and one lactation cycle incurred lameness more frequently than sows provided Ca:P above current NRC (1979) recommended levels.

The high Ca:P diet resulted in no sows experiencing lameness during gestation or lactation.

Recently, Arthur et al. (1983a,b) evaluated gilts response to dietary Ca:P and energy over a three parity study. Gilts were provided ad libitum or at 75% ad libitum feed intake levels at 100 or 150% NRC (1979) Ca:P levels from weaning to 100 kg body weight. At 100 kg body weight a common 14% crude protein gestation lactation diet was fed for three successive reproductive cycles. Restricting the energy and feeding elevated Ca:P levels during the growth period had no effect on incidence and severity of toe lesions, overall structural soundness and only minimal effects on bone characteristics.

The results suggest that low dietary Ca:P levels during the early growth period or gestation-lactation periods may influence the incidence of sow lameness. However, it appears that dietary Ca:P at or above NRC (1979) recommendations is not necessarily associated with sow lameness. Therefore, lameness probably results from the other factors mentioned previously.

Effect on Bone Tissue. Bone plays a major role in the metabolism of Ca and P. The adult skeleton has two major functions (or three if one includes the marrow cavities): that of providing mechanical support and protection for the organism and that of regulating the concentration of key blood electrolytes. The focus here pertains to Ca and P. Bone metabolism and related factors have been covered extensively by Fourman and Royer (1968). The major

hormones involved in bone mineral homeostasis and skeletal remodeling are parathyroid hormone (PTH), calcitonin (CT) and vitamin D ($1,25-(OH)_2D_3$). These hormones, (PTH, CT, $1,25-(OH)_2D_3$) influence the bone cells (osteoblasts, osteoclasts and osteocytes) to either mobilize minerals in response to physiological demand, increase osteoclastic activity, or deposit Ca:P to replenish depleted supplies from increased osteoblastic activity.

Lactation increases the Ca:P demands on the dam. Both minerals are important components of milk which must ultimately be derived from the diet or bone tissue wherein the circulating blood carries them to the mammary glands for subsequent incorporation into the milk (Kon and Cowie, 1962; Falconer, 1971; Larson and Smith, 1974). If the dietary levels of Ca:P are inadequate to meet the outflow of milk Ca:P, bone minerals are mobilized to compensate for the production deficit. Thus, the diet and bone tissue are both vitally and mutually important Ca:P sources which interact to maintain milk Ca:P levels.

Bone ash either quantitatively or as a percent of the dried fat-free bone are criteria utilized to evaluate bone tissue in response to dietary Ca:P. The largest relative proportions of Ca (99%) and P (80%) are present in bones and teeth. The fact that bone mineral primarily consists of Ca and P, and that these elements depart little from a 2:1 ratio, indicates that ash content can be useful in determining dietary Ca and P adequacy. Ash is generally composed of 26 to 32% Ca, 12 to 15% P and approximately 8% Mg with

lesser percentages of the other minerals (Irving, 1973). Bone ash is obtained from a dried, fat-free sample subsequently ashed in a muffle furnace and expressed as a percentage of the dried fat-free bone.

Bone ash responds to dietary Ca:P levels during the lactation phase. The data of Harmon et al. (1975) demonstrated that lactation dietary P level influenced the percent bone ash of the sow rib. A level of .65% P over a 6 to 8 week lactation period had the highest percent bone ash compared to a .45% P level (59.4% vs 57.3%, respectively). Mahan and Fetter (1982) reported similar responses to that of Harmon et al. (1975) but they also reported the responses of other skeletal bones. This report suggests that sow bones do not demineralize equally throughout the body. It appears from their study that bones which are centrally located (i.e., rib, vertebrae) demineralize at a faster rate than those located peripherally (i.e., femur, humerus). Over their three parity study bone ash values of the high Ca:P treatment level (i.e., .90/.70%), were necessary to maintain equal bone ash status to non-gravid females as compared to lower levels (Mahan and Fetter, 1982). Arthur et al. (1983a) evaluated the bone ash of metacarpals and metatarsals of sows following 3 parities. Their sows had previously been fed at 100 or 150% of NRC mineral standards during the growth phase but all groups were fed the same diets during the three reproductive cycles in an attempt to evaluate the effects of previous nutritional mineral status. Their data did not demonstrate a demineralization response as measured by percent bone ash of the metacarpal or metatarsal bones

after three parities. This is in contrast to the data of Harmon et al. (1975) and Mahan and Fetter (1982), but Arthur and coworkers (1983a), evaluated foot bones rather than the central bones of the body (i.e., rib). Underwood (1981) also pointed out that withdrawal of minerals during periods of inadequate intake does not take place equally from different parts of the skeleton. The spongy bones (i.e. ribs, vertebra and sternum), which are lowest in percent ash content) are the first to be affected, together with the cancellous ends of the long bones. He follows that the compact shafts of the long bones, such as the humerus, femur and tibia, and the small bones of the extremities, are the last mineral reserves to be used. Finally, in each case the essential change is a reduction in the total mineral content of the bones, with little alteration in the relative proportions of the various minerals in the remaining ash (Underwood, 1981). Rib bones also have been demonstrated to be more sensitive to resorption and rehabilitation in cattle and sheep (Little, 1972).

Bone breaking strength is another criterion utilized on bones in Ca:P studies (Crenshaw et al., 1981). Most experiments with pigs have evaluated the metatarsal or metacarpal bones by applying a force directly to the midspan of the bone and concurrently charting the peak force required to break the bone (Miller et al., 1962; Tanksley et al., 1976; Nimmo et al., 1980; Kornegay and Thomas, 1981). Foot bones are commonly selected for determining breaking strength tests because of their ease in removal from the animal and less damage to the carcass upon excision. Nimmo et al., (1981b) evaluated two

levels of Ca:P (.65/.50 and .975/.75%) during the growth period and two gestation levels (13 g Ca, 10 g P/day and 19.5 g Ca, 15 g P/day) on gilts subsequently provided .75% Ca and .50% P for a 42 day lactation period. Peak force required to break the metatarsals was lowest in those gilts which were provided the lower dietary levels of Ca:P during growth and gestation. The authors suggested that the lower levels of Ca:P were not adequate for gilt bone development based upon their bone breaking strength responses following one lactation. Arthur et al. (1983a) fed dietary Ca:P levels during growth to sows of 100% or 150% of NRC as previously described in this section. Providing 150% of NRC standards did not influence breaking strength measurements of the metatarsal following 3 parities. The earlier study, Nimmo et al. (1981b) fed Ca:P levels at or above NRC (1973) whereas the latter experiment, Arthur et al. (1983a), used the NRC (1979) standards. These combined experiments appear to suggest that current NRC (1979) Ca:P levels have a minimal effect on bone breaking strength of metatarsals or metacarpals following 1 to 3 lactations. Rib and vertebra bones have been reported to be more sensitive to resorption and rehabilitation and suggest with the breaking strength results that metacarpals or metatarsals may not be the most responsive bones to dietary Ca:P and reproductive needs (Little, 1972; Underwood, 1981; Mahan and Fetter, 1982).

Owing to the high incidence of leg problems in breeding swine, physical bone measurements, cartilage observations and toe measurements are often collected in response to dietary Ca:P

(Kornegay and Thomas, 1981; Calabotta et al., 1982; Arthur et al., 1983a). The conclusions from these experiments generally suggest that elevating dietary Ca:P to as much as 150% NRC (1979) recommended levels has a minimal affect on bone length, weight, heel or toe lesions, hoof dimensions or articular cartilage lesions in developing gilts through three reproductive cycles. Arthur et al. (1983b), however, did indicate that the distal portion of the humerus and femur showed more evidence of osteochondric lesions than the proximal end but they did not attribute these lesions to the dietary Ca and(or) P regimens provided. The bones usually selected to evaluate physical parameters (length and weight) are the metacarpals and metatarsals which have been suggested to be less responsive to demineralization (Underwood, 1981; Mahan, 1982).

Cartilage and toe problems manifested in osteochondrosis or hoof lesions are not considered to be associated with Ca:P nutrition. Management factors such as housing, flooring materials or exercise have been suggested as potential sources of these structural maladies (Mahan, 1983).

While the previous measurements are commonly employed in evaluating swine nutrition research to assess the effects of dietary Ca:P on bone tissue and responses to reproduction, other methods and criteria have been utilized with swine as with other species. Braithwaite et al. (1969, 1970), evaluated Ca metabolism in pregnant and lactating ewes, by the use of a combination of metabolism balance trials and isotope techniques. They reported that the rate of

absorption of Ca from the intestine increased throughout pregnancy but it was insufficient to meet their requirements during late pregnancy and early lactation. During this latter period, the extra Ca needed was supplied from bone resorption. In late lactation the maternal Ca balance became positive with the ewes able to replenish skeletal stores. Isotope techniques also have been utilized in pigs (Hansard et al., 1966; Itoh et al., 1967) and dairy cattle (Agricultural Research Council, 1965; Ramberg, 1970; Rook and Thomas, 1983) to evaluate dietary Ca:P requirements during reproduction. The combined results of these studies concur with the sheep research that fetal bone development or milk mineral concentration has priority over maternal bone tissue and that bone tissue will demineralize to compensate for these mineral demands which exceed dietary Ca:P supply. When swine are compared to cattle or sheep this brings up different management factors involved in gestation and lactation. Swine have a shorter lactation period (21 to 35 days) which is generally terminated at peak milk production. In contrast, sheep lactate for approximately 60 days and dairy cattle for 310 days, both ending their lactation long after peak milk production. Swine are frequently rebred within 10 days postweaning to farrow again within the same year whereas cows or sheep give birth once per year, both with a longer gestation period. Perhaps the differences in stage and period of lactation, as well as shorter, multiple gestations with 5 to 10 day rebreeding intervals postweaning, does not afford the sow

an ample interval between reproductive cycles as is evident in ewes and cows (Braithwaite et al., 1969, 1970; Rook, 1983).

Bone density is a measure frequently employed to evaluate bone mineral content. The absorption by bone of radiation from ^{125}I has demonstrated changes in bone density as influenced by age (Cameron and Sorenson, 1963; Smith et al., 1973; Smith et al., 1975; Smith et al., 1976; Riggs et al., 1981 and Riggs et al., 1982). The utilization of this technique has been adapted to domestic livestock (Sieman et al., 1974; Little et al., 1978). Little et al. (1978) fed Merino ewes a P deficient ration, with or without supplementary P for 20 weeks, spanning approximately the last 5 weeks of gestation and a 15 week lactation. Non-lactating ewes were employed as controls. Measurement of hock bone density by radiation absorption showed differences with the number of lambs suckled, but failed to detect any effect of P supplementation. Ewes suckling twins had a much lower radiation absorption during early lactation than ewes suckling one lamb or those not lactating. These results indicate that bone density measurements may be useful in evaluating bone tissue changes during lactation.

Effect on Milk Yield and Composition. Understanding the hormonal modulation of mineral metabolism is important in discussing the effects of dietary Ca:P on subsequent milk yield or composition. The reader is referred to Borle (1974), Deluca (1979), Toverud and Boass (1979) and Robinson et al. (1983) for more comprehensive reviews. Pertinent information can also be abstracted from Calcium

and Phosphorus Metabolism (1973) by James T. Irving, The Physiological and Cellular Basis of Metabolic Bone Disease (1974) by Rasmussen and Bordier, Lactation Vol. III (1974) by Larson and Smith, Guyton's Textbook of Medical Physiology (1976) and Duke's Physiology of Domestic Animals (1977), Melvin J. Swenson (ed.).

Pregnancy and lactation present Ca:P stresses on maternal homeostatic mechanisms. Lactation stresses are generally greater than gestation demands in most mammals (Larson and Smith, 1974, Vol. III). As indicated earlier the Ca:P needs are satisfied either through the diet or from body bone stores. Thus, should the lactation demands for Ca:P exceed dietary provisions, Ca:P are mobilized from bone tissue via Vitamin D, parathyroid hormone and calcitonin.

Lactation Ca:P homeostasis through diet or bone tissue has been demonstrated in women (Greer et al., 1982; Greer et al., 1984), rats (Komerkova et al., 1966; Toverud et al., 1978; Toverud and Boass, 1979; Halloran and Deluca, 1980; Robinson et al., 1983), sheep (Benzie et al., 1955, 1959; Braithwaite et al., 1969, 1970), cows (Hart, 1983; Hibbs and Conrad, 1983; Miller, 1983) and pigs (Rook and Witter, 1968; Harmon et al., 1975; Underwood, 1977; Mahan and Fetter, 1982; Rook and Thomas, 1983).

Milk yield in sows has been evaluated extensively in early work (Smith, 1950; Wells et al., 1940; Salmon-Legagneur, 1958; Allen and Lasley, 1960 and Von Neuhaus, 1961) as well as in more recent studies (Mahan et al., 1971; Klaver et al., 1981; Speer and Cox, 1984). The

combined results of this research indicates that milk production in sows depends upon litter size, sow age, stage of lactation, nutrition, breed and season of year. Regarding the role of nutrition on milk yield, dietary Ca:P levels are of immense importance. A limited energy or protein supply rather than a deficiency of Ca:P are, however, the most frequent causes of reduced milk production in sows (Lodge and McDonald, 1959; Elliot et al., 1971; O'Grady et al., 1973; Mahan, 1979; Pettigrew, 1984). The results of Harmon et al. (1975) suggests that dietary P provided during gestation may influence subsequent milk production, but there was only a trend toward increased milk production during lactation (i.e. 42 day study) when dietary phosphorus was increased. Weight gains of suckling pigs or litter weaning weights over a standard period (e.g., 2-3 weeks) are easily and routinely obtained and are commonly recommended as a practical method of assessing the lactation performance of sows (Krider and Carrol, 1971; Bundy et al., 1976; Lewis et al., 1978). Average weaning weight or the number of pigs weaned has been generally reported unaffected by increasing dietary Ca:P in sows from one to five reproductive cycles (Kornegay et al., 1973; Nimmo et al., 1981a, Mahan and Fetter, 1982; Kornegay and Kite, 1983). Therefore, dietary levels of Ca:P, unless they are severely deficient, appear to have little affect on milk production in swine. Similar findings have been reported in sheep (Barnicoat et al., 1949b,c; Robinson et al., 1969; Wilson et al., 1971; NRC, 1975) and dairy cows (Larson and Smith, 1974, Vol. III; NRC, 1978; Hibbs and Conrad, 1983). However,

parturient paresis (milk fever) in high producing dairy cattle complicates the role of dietary Ca:P in response to parturition and lactation. It should be noted that the strategy generally suggested to alleviate parturient paresis is to increase Ca:P absorption through Vitamin D therapy or changing the Ca:P ratio, rather than just elevating the dietary Ca:P levels (Hibbs et al., 1976; Julien et al., 1977; Hibbs and Conrad, 1983).

Milk composition has been studied extensively in several species. Composition of cow's milk has received the most attention due to commercial interest (Larson and Smith, 1974, Vol. III). However, information on the effect of nutritional regime subsequent on milk composition of the sow is limited. Sow's milk obviously lacks the commercial interest of cow's milk, and experimental studies of milk secretion are inherently more difficult to conduct in swine than in the cow. The sow does not voluntarily eject milk in response to stimuli other than those provided by the suckling pig. Consequently, manual or mechanical removal of milk from the udder is difficult. Oxytocin injection into the ear vein of sows was initially introduced in the 1940's to obtain a milk sample and is generally the method currently employed (Braude et al., 1947).

A lactating animal may respond to extreme dietary Ca:P inadequacy by reducing its yield of milk without affecting its mineral composition (Underwood, 1981). In early stages of deficiency, or where the deficiency is moderate, the animal is able to draw on skeletal reserves and several successive lactations may

be necessary before bone defects and other clinical signs become obvious and milk production is impaired (Underwood, 1981).

Early work by Perrin (1955); Plumlee et al. (1956); Pond et al. (1962) and Pond et al. (1965), studied the content of several mineral elements in the colostrum and milk of the sow. Ca:P levels in milk appear to be relatively resistant to dietary levels provided. Linzell (1965), Pond and Houpt (1978) and Underwood (1977, 1981) also suggested that while some mineral elements in milk are influenced by diet composition as a result of transfer from plasma to the mammary gland, Ca:P are generally thought to be more resistant to influence of dietary levels but changes in composition do occur from parturition to 35 days postpartum (Perrin, 1955). Recent evidence confirm previous observations that milk composition is not influenced by dietary Ca:P (Harmon et al., 1975; Mahan and Fetter, 1982). The results of these experiments in conjunction with resulting similar pig birth weights and weaning weights reported earlier, suggest that dietary Ca:P levels have little affect on the subsequent mineral composition and yield of sows milk unless extremely deficient in these minerals but that days postpartum can influence milk composition more.

The maintenance of milk Ca:P composition over a variety of conditions has also been verified in dairy cows (Hibbs and Conrad, 1983) as well as in ewes (Benzie et al., 1955, 1959 and Braithwaite et al., 1969). Concentrations of human milk Ca:P have been reported and mechanisms to maintain these within normal ranges (220 to 340 and

110 to 170 mg/day Ca:P, respectively), have been evaluated in mothers nursing singles as well as twins (Greer et al., 1982; Greer et al., 1984). The rat has been contrasted to lactating women in an extensive review of Ca metabolism in lactation (Toverud and Boass, 1979). The rat appears to maintain a relatively constant Ca content in milk except when the lactating female is subjected to multiple dietary deficiencies (Toverud and Boass, 1979). Dietary deprivation of lactating rats of either Ca or vitamin D did not significantly affect the Ca content relative to total milk solids even though marked reductions in serum Ca and P occurred

These results with swine as well as other species indicate that milk yield and Ca:P composition are very resistant to changes in dietary Ca:P levels. Table 1 indicates Ca:P levels in milk of the rat, pig and cow with responses to different dietary Ca:P levels. The reader is referred to Larson (1974) Vol. III for the differences among species in milk composition.

Effect on Blood. Serum and plasma mineral concentrations have been studied by numerous investigators in order to evaluate the mineral status or dietary requirement of lactating animals.

Ullrey et al. (1967) conducted several trials to ascertain normal levels of serum Ca, P, and Mg in swine from birth to maturity. Calcium values, ranged from 9.3 to 11.8 mg/100 ml and varied little with age, however, the lowest values observed at 24 hr postnatally. Inorganic serum P concentration was lowest at birth, rising to its highest level by 2 weeks postpartum, gradually declining by 5 months

TABLE 1. RESPONSE OF THREE SPECIES TO VARYING DIETARY CALCIUM AND PHOSPHORUS LEVELS ON MILK CALCIUM AND PHOSPHORUS

<u>Species</u>	<u>Reference</u>	<u>Milk Mineral Level</u>			
		<u>Diet Ca/P %</u>	<u>Ca</u>	<u>P</u>	<u>Units</u>
Rat	Toverud 1979	.02/.5	9.1	-	Ca/total
		.24/.4	8.7	-	solid
		.57/.5	9.1	-	(mg/gm)
		1.11/.8	8.6	-	
	Hallovan and Deluca 1980	.44/.30	9.7	5.8	mg/100 ml
Pig	Harmon 1975	.70/.45	245	165	mg/100 ml
		.70/.55	218	151	
		.70/.65	237	160	
	Mahan 1982	.65/.50	240	170	mg/100 ml
		.80/.60	220	160	
		.90/.70	230	170	
	Hill 1983	.71/.45	210	150	mg/100 ml
Cows	Hibbs and Conrad 1983	1.29/.29	29.98	19.43	gms/day
		1.01/.41	29.20	25.40	
		.78/.36	20.37	16.17	
		.53/.38	27.50	16.50	

of age. Reported serum P values ranged from 5.3 to 11.6 mg/100 ml from birth to 2 weeks and averaged 7.1 mg/100 ml by 5 months. Serum Mg values decline in the neonate to 24 hr, and peaked at 2 weeks. Subsequent values varied appreciably but were all 35 mg/100 ml or lower.

Serum Ca is maintained by the parathyroid hormone, calcitonin and metabolically active vitamin D at a concentration of about 10 mg/100 ml (Borle, 1974; Toverud and Boass, 1979). Doige and coworkers (1975) stated that these hormonal mechanisms closely regulates serum changes. Phosphorus does not appear to be as

strictly regulated as Ca, with serum P ranging from 4 to 12 mg/100 ml, but is thought to closely follow Ca regulation (Borle, 1974).

Robinson et al. (1983) indicated that pregnancy and lactation pose a challenge to the Ca:P homeostatic mechanism, the challenge being considerably greater during lactation because of the Ca:P outflow through milk. However, they suggest four alterations in the adaptive processes mediated by PTH, Calcitonin and Vitamin D to maintain blood Ca:P levels: a reduction in urinary Ca excretion; an increase in food intake; an increase in intestinal absorption of Ca and an increase in skeletal demineralization.

Sows provided with dietary Ca:P levels at or above NRC recommendations (1973 or 1979) have had elevated serum Ca and P levels from one to five parities (Kornegay et al., 1973; Harmon et al., 1974; Hedges et al., 1976; Nimmo et al., 1981a; Mahan and Fetter, 1982; Kornegay and Kite, 1983). Although slight variations to mineral supplementation level have been demonstrated, the blood Ca:P levels were not significantly different between the various nutritional and managerial treatments.

Benzie et al. (1955) working with lactating sheep, points out that data provided by blood analysis are usually difficult to interpret and can be a poor guide to evaluate the adequacy of mineral intakes. Blood values give little or no information about the states of mineral reserves in the body. In those cases where extreme deficiency causes a mobilization of bone macro-mineral, the minerals released from bone tissue co-exist in the blood stream with those

absorbed from the diet. Because of the dual origin of Ca, P and Mg, the blood levels of these three minerals do not appear to be a good guide in determining adequacy of intake, mineral reserves status or to whether reserves are in the process of being drawn upon or replenished.

It would appear that the above studies with lactating sheep also apply to swine. The same physiological status and blood Ca, P and Mg would not be the criterion of choice to evaluate mineral adequacy in lactating sows.

Effects on Reproductive Performance. Goals for optimum swine production were described by Cunha (1980). Litters per sow yearly (2.1 to 2.2), pigs marketed per sow yearly (20-24), pig losses from birth to weaning (5 to 10%), and pigs saved per litter (9 to 10) were set as attainable goals for excellent reproductive efficiency. Nutrition researchers have routinely collected the number of live pigs born per litter, pig birth weight, number of pigs weaned per litter and weaning weight (Kornegay et al., 1973; Adam and Shearer, 1977; Mahan and Fetter, 1982).

The relationship of nutrition to these reproductive parameters described above has been covered extensively for gestation and lactation (Salmon-Legagneur and Revet, 1962; Lodge, 1962; Pond and Houpt, 1968; English et al., 1979; Whittemore and Elsley, 1979; ARC, 1981; McDonald et al., 1981; Rook and Thomas, 1983).

The recommended feeding method for gilts or sows generally developed over time has generally emphasized dietary energy or

protein content to maximize these reproductive parameters more so than other nutrients (i.e., vitamins, minerals). The fetus has a high priority for nutrients and if the mother receives insufficient nutriment the fetus is able to maintain its nutrient supplies by drawing on the tissue reserves of the mother. Pond and Houpt (1968), point out that satisfactory reproductive performance in sows fed low Ca diets can be maintained at least through one gestation because the sows draw on their own skeleton to meet the needs of the fetus. The protection afforded the fetus is, however, not absolute and varies from one nutrient to another (McDonald et al., 1981). However, in the case of Ca:P, it appears that protection is adequate to attain normal reproduction over a wide range of dietary Ca:P levels. Gilts fed diets containing 0.2% Ca produced litters not significantly different from the litters of gilts fed adequate calcium diets in total number of live pigs or in individual pig birth weight (Brown et al., 1966). Milk production also was not decreased in the first lactation. Guegen and Perez (1981) report that the net Ca:P requirements for pregnancy are negligible during the first two months, the fetuses being mineralized mainly during the last third of pregnancy. Because liquids and cellular membranes contain little Ca or P the newborn piglet contains approximately 10 and 5 g/kg body weight of Ca:P, respectively. Ca intakes as low as 1 to 2 g per day have been shown to maintain litter size in pregnant sows and gilts although viability of the piglets was reduced (Morstgaard, 1962).

More recent studies also have evaluated the effects of dietary Ca:P levels on pig birth data (Kornegay et al., 1973; Harmon et al., 1975; Nimmo et al., 1981b; Mahan and Fetter, 1982; Kornegay and Kite, 1983). In general, the results of these experiments demonstrate no difference in the number of pigs born or in birth or weaning weight data that could be attributed to dietary Ca and(or) P levels.

It would appear that reproductive measurements are not a sensitive tool to evaluate dietary Ca and P needs.

CONCLUSIONS

Calcium and phosphorus nutrition for sows remains a topic for further research. Past studies have discerned indicators that aid in the understanding of Ca:P needs for sows and have delineated additional research area needs.

Previous nutritional Ca:P levels provided during the growing phase may influence leg soundness but does not apparently influence other reproductive parameters.

Age of the sow may have an effect on bone tissue, particularly, when exacerbated by a continual reproductive state (gestation or lactation). A possible research question is the effect of estrogen level on resulting bone tissue metabolism of the sow, particularly if the continual reproductive state mimics the postmenopausal human situation.

Structural unsoundness or lameness problems may occur when low dietary Ca:P levels are fed but it seems that these maladies may be more attributable to exercise and other management factors. Physical

bone measurements, osteochondrotic lesions, hoof lesions or pig gait characteristics do not appear to be influenced by these dietary minerals in sows. These interactions need to be resolved.

Sow milk yield and its composition apparently are not influenced by practical dietary Ca:P levels. Blood levels of these minerals also appear to be resistant to change from dietary supply of Ca:P. Hormonal regulation maintains both blood and milk minerals concentrations and they are insensitive criteria to evaluate dietary Ca:P status.

Pig birth weights and number of pigs born per litter are not influenced by dietary Ca:P fed during the reproductive cycle.

Bone tissue appears to be the most responsive to dietary Ca:P level either during growth or reproductive cycles. Bone ash, bone breaking strength and bone density measured by radiation have all been affected by dietary Ca:P level. Axial bones (i.e. rib, vertebra) appear to be more sensitive than appendicular bones (i.e. femur, metacarpal).

Future studies on dietary Ca:P needs for the sow should focus on criteria assessing the bone tissue, particularly bones that are centrally located, (i.e., ribs).

DIETARY CALCIUM AND PHOSPHORUS FOR LACTATING SWINE AT HIGH AND AVERAGE PRODUCTION LEVELS

INTRODUCTION

Concern among swine producers over relatively high incidences of leg soundness and posterior paralysis problems during the reproductive cycle suggests inadequate dietary Ca and(or) P levels. The onset of clinical symptoms frequently occur during the last trimester, late lactation or shortly after weaning (Itoh et al., 1967; Harmon et al., 1974).

Clinical problems attributed to nutritional mineral insufficiency during these reproductive stages would be expected because rapid fetal bone development during the last trimester (Hansard et al., 1966; Itoh et al., 1967; Guegen and Perez, 1981), multiple parities and long lactation periods with high milk production all contribute toward depleting body reservoirs of Ca and P (Harmon et al., 1974; Mahan and Fetter, 1982). Posterior paralysis resulting from vertebra demineralization in support of the sow's reproductive Ca:P demands is also logical. It has been demonstrated that the bones of the axial skeleton and ribs are more sensitive to resorption and rehabilitation than long bones or bones of the skeletal extremities (Little, 1972; Underwood, 1981; Mahan and Fetter, 1982). Most of the reproduction studies conducted to date have investigated dietary Ca and(or) P needs for longer lactation periods than the current trend toward a 21 to 28 day lactation period and(or) frequently have not rebred the sow

upon the first estrus postweaning (Harmon et al., 1974, 1975; Nimmo et al., 1981; Mahan et al., 1982).

This study was conducted to evaluate the effects of five dietary Ca:P levels at two litter sizes for a 21 day lactation period over two parities on sow and litter performance and blood and bone measurements of the sow.

EXPERIMENTAL PROCEDURE

A 2 x 5 factorial arrangement of treatments in a split-plot design was conducted with 146 first and 77 second parity sows maintained at two litter sizes (6 to 7 or 11 to 12 pigs/litter). Each production level was fed at five dietary percentage levels of Ca:P (.65:.50, .80:.60, .90:.70, 1.04:.80, 1.17:.90%) in a 21 day lactation period.

Thirty days prior to breeding and through the first gestation animals were individually fed 1.82 kg daily of a 14% protein corn-soybean meal diet containing .80% Ca and .60% P. Upon weaning and during the second gestation period all sows were fed the same gestation diet and at the same quantity as during parity I. A group of unbred females remained on trial for the two parity period and fed the same gestation diet as reproducing sows at 1.82 kg daily.

Lactation diets were formulated to 14% crude protein from corn and soybean meal with dietary Ca and P levels varied as to treatment demands. Inorganic sources of Ca and P were provided from dicalcium phosphate and limestone with their relative proportion altered to

achieve the desired total concentration of these minerals. The percentage composition of experimental diets is presented in table 2.

First-litter sows were assigned to dietary and production level treatment combinations upon farrowing with litter size adjusted within 3 days postfarrowing. Dietary treatments were initially provided at 1 kg upon parturition and increased at the rate of approximately 1 kg daily until ad libitum levels were attained the first week postpartum for those sows nursing 11 to 12 pigs/litter, whereas sows maintained at 6 to 7 pigs/litter had their feed consumption maintained at 4.5 kg for the remaining lactation period. Sows nursing smaller litters were limit fed their treatment diets in order to mimic typical feeding practices, whereas those with larger litters were allowed ad libitum access to their diets.

Sow and litter weight and feed consumption measurements were collected at parturition, 7 and 21 day postpartum. At both 7 and 21 day postpartum, sows were injected with oxytocin, a 50-ml milk sample collected and then bled via the vena cava. Both serum and milk were subsequently analyzed for Ca, P and Mg. Calcium and Mg were determined by atomic absorption spectrophotometry with inorganic serum and milk P determined by the method outlined by Sigma (1981).

Representative sows from each treatment group were selected upon weaning and slaughtered for the collection of various bones. The humerus, femur, metacarpal, metatarsal, 5th and 6th ribs and adjoining vertebra were collected from each and frozen for later measurements and analyses. Remaining first parity sows were continued for a

TABLE 2. PERCENTAGE COMPOSITION OF EXPERIMENTAL DIETS^a

Ingredient	Mineral level, %					
	Ca:	.65	.80	.90	1.04	1.17
	P:	.50	.60	.70	.80	.90
Corn (IFN 4-02-935)		81.70	81.15	80.60	80.05	79.50
Soybean meal, 44% (IFN 5-04-604)		15.70	15.70	15.70	15.70	15.70
Dicalcium phosphate (IFN 6-01-080)		1.00	1.55	2.10	2.65	3.20
Limestone (IFN 6-01-069)		1.05	1.05	1.05	1.05	1.05
Se premix ^b		.05	.05	.05	.05	.05
Trace-mineral salt ^c		.35	.35	.35	.35	.35
Vitamin mix 100 ^d		.10	.10	.10	.10	.10
Antibiotic ^e		.05	.05	.05	.05	.05

^aDiets calculated to contain 14% protein, with treatment Ca and P levels denoting total dietary concentrations. The .80:1.60% Ca:P diet was provided to all non-gravid and gestating animals.

^bSodium selenite was provided in a limestone carrier. The level provided .1 ppm Se in the final mixture.

^cSupplied per kg diet: 10 mg Cu, 100 mg Fe, .2 mg I, 40 mg Mn, 120 mg Zn, 4.27 g NaCl.

^dSupplied per kg diet: 4,400 IU vitamin A, 550 IU vitamin D₃, 22 IU vitamin E, 17.6 mg vitamin K, 5.2 mg riboflavin, 22 mg pantothenic acid, 26.4 mg niacin, 22 g vitamin B₁₂ and 440 mg choline.

^eSupplied per kg of diet: 2.2 mg aureomycin.

second parity and rebred at the first estrus postweaning. They were placed on the same diet and production level as in parity I. Upon weaning their second litter, representative sows from each treatment group and the nongravid females were killed bones collected.

Bones were manually cleaned of residue after immersion in boiling water for approximately 15 minutes with articular cartilage left intact. Femur and humerus bones were weighed and sawed in half longitudinally. Bone wall thickness was determined to the nearest millimeter by averaging the measurements made with Vernier calipers at the shaft midpoint and midway toward both bone ends.

Breaking strengths of metacarpals and metatarsal bones were determined with an Instron Testing Machine. Force was applied at a constant speed (5 cm/min) for parity I but at 1 cm/min for parity II bones with a chart recorder used to plot peak force. Bending moment was calculated as suggested by Crenshaw et al. (1981). Because of the different speeds comparisons between parity was confounded, whereas those between dietary mineral level were valid.

Rib bone mineral density was determined according to the method of Cameron and Sorenson (1963) using a ^{125}I photon source described by Cantor et al. (1980). Although these authors used the term mass rather than density, the latter term should be more descriptive (weight per unit volume). The cleaned intact rib was placed between a well-collimated ^{125}I photon source and a collimated NaI (Tl) scintillation detector. Each rib was placed on two v-shaped supports and scanned perpendicular to the longitudinal axis at the midpoint and at

three other equally spaced intervals toward each end at a rate of .95 mm/min. Measurements were obtained by summing counts over 10-sec intervals. The base count (I_0) was the average of a minimum of 30 10-sec counts with no sample between the source and detector. Relative bone density (RBD) was calculated according to the following formula:

$$RBD = \sum \ln (I_0 I_a)$$

All values of transmission through the bone (I_a) that were less than the average base count (I_0) minus three standard deviations were used in the calculations.

After bone measurements were determined, each bone was reduced in size by sawing, dried, extracted for 24 hour using absolute ether, dried again for 24 hour at 100 C and ashed in a muffle furnace at 600 C. Bone ash is expressed as a percentage of the dried fat-free bone.

The data were analyzed, using sows as the experimental unit, by the least squares method of Harvey (1982) with single degree of freedom comparisons subsequently conducted. Because there were few variable interactions, main effects are presented. Treatment means and two-way interaction responses are presented in the appendix.

RESULTS AND DISCUSSION

Sow and Pig Performance. The main effects of the five dietary Ca:P levels, parity and litter size on sow reproductive performance are reported in table 3 with treatment and two-way interaction responses in appendix tables 8, 9, 10 and 11. Dietary Ca:P levels

TABLE 3. EFFECT OF DIETARY CA AND P LEVEL, LITTER SIZE AND PARITY ON REPRODUCTIVE PERFORMANCE

Item	Litter size, no.			Ca:P level, %						Parity		
	6 to 7	11 to 12	SE	.65	.80	.90	1.04	1.17		I	II	SE
				.50	.60	.70	.80	.90	SE			
No. sows	115	108		52	49	48	38	36		146	77	
Sow weights, kg												
109 d	167	168	2.1	172	164	167	170	166	3.2	161	174	2.4 ^a
Parturition	151	150	1.7	154	149	151	153	149	2.6	145	157	3.7 ^a
21 d postpartum	146	146	3.4	149	144	144	146	145	2.7	137	154	3.4 ^a
Gain (0 to 21 d)	-7	-4	.6 ^b	-5	-5	-7	-7	-4	1.0	-8	-3	.85 ^a
Lactation feed intake, kg												
Total	85	108	1.30 ^b	99	93	97	97	96	2.0	93	99	1.3 ^a
Daily	4.0	5.2	.01 ^b	4.7	4.4	4.7	4.7	4.6	.1	4.5	4.7	.05 ^a
Pigs born live, no.												
Parity I	9.44	11.54	.73 ^b	11.37	11.00	10.00	10.33	11.94	.88			
Parity II	9.85	10.90	.84 ^b	10.95	9.90	9.50	9.90	10.20	.69			
Average	9.78	11.16	.27 ^b	11.16	10.40	9.74	9.99	11.05	.43	10.70	10.27	.22 ^a
Birth weight, kg												
Litter	13.8	15.9	.60 ^b	15.6	14.8	14.3	15.1	14.6	.42	14.2	15.5	.26 ^a
Pig	1.56	1.47	.05 ^b	1.51	1.52	1.53	1.58	1.46	.04	1.48	1.55	.05 ^a
No. pigs weaned	6.78	10.47	.06 ^b	8.82	8.78	8.85	8.79	9.07	.11	8.82	8.90	.06 ^a
Weaning weight, kg												
Litter	41.4	52.0	.60 ^b	47.4	46.8	46.8	46.3	46.10	1.0	45.9	47.5	.58 ^a
Pig	5.83	5.01	.06 ^b	5.55	5.46	5.41	5.43	5.25	.10	5.37	5.46	.07
Pig gain, kg												
Parity I	4.22	3.41	.13 ^b	4.14	3.99	3.85	3.85	3.75	.13			
Parity II	4.41	3.58	.19 ^b	3.91	3.97	3.94	3.85	3.95	.19			
Average	4.32	3.53	.06 ^b	4.02	3.98	3.89	3.85	3.85	.10	3.91	3.91	.06
Litter gain, kg												
Parity I	26.6	35.0	4.6 ^b	31.2	31.2	31.0	31.9	28.5	4.6			
Parity II	25.4	37.8	4.6 ^b	29.4	31.5	33.6	30.2	33.3	4.6			
Average	26.1	35.7	.6 ^b	30.9	31.4	33.0	30.4	30.4	1.0	30.4	32.4	.58

^aParity effect (P<.01).^bLitter size effect (P<.01).

fed during lactation had no effect on sow weights at 109 day postcoitum, parturition or weaning. Others have also reported no difference in dam gestation weight gains when various Ca and(or) P levels have been provided to reproducing female swine (Kornegay et al., 1973; Harmon et al., 1975; Adam and Shearer, 1977; McCrea et al., 1979; Mahan and Fetter, 1982). There was an expected weight increase from the first to second parity ($P<.01$), but no effect of mineral level within parity or interaction between diet and parity was evident. Sows nursing 6 to 7 pigs/litter lost slightly more weight ($P<.01$) than sows nursing larger litters. However, sows nursing the smaller litters had their feed intake maintained at a lower level while females nursing 11 to 12 pigs/litter received feed ad libitum. In addition, main effect responses (table 3) indicated that weight losses were higher during the first than the second parity for sows with lower litter sizes but there was no dietary mineral effect interaction within parity (appendix tables 8,9,10). It is probable that if more feed had been provided from 7 to 21 day to these sows they would have more closely met their energy requirement.

Although feed intake was somewhat restricted, at the lower litter size, sow feed intake within each production level was not influenced by dietary Ca:P level. Parity and sow production level effects on feed intake were both significant ($P<.01$) with higher feed intakes during the second parity and from the larger litter size. Although daily feed intake was maintained at a maximum 4.5 kg for sows nursing 6 to 7 pigs from 7 to 21 day it averaged 3.9 kg for the entire 21 day

lactation when the initial 7 day adjustment is considered. Sows on the higher feed allowance averaged 5.3 kg for the same period, approximately 36% higher feed consumption. As indicated earlier the lower feed intake for sows nursing 6 to 7 pigs probably was the reason for the somewhat larger sow weight losses. There was an increase of approximately 10% in feed intake from parity I to II with those sows nursing the larger litters, but no effect of feed intake as influenced by dietary mineral level within parity. Mahan (1979) also reported increased feed intake at each of three parities attributing it to larger litter size, higher milk production and higher maintenance requirement of the older, heavier sow.

The number of pigs born live particularly during parity II indicated that sows nursing the smaller litters of parity I farrowed fewer live pigs in parity II ($P < .01$) whereas, dietary Ca:P level had no effect on subsequent litter size. These litter size birth parturition responses can be somewhat attributed to some experimental bias stemming from the practice where initial allotment to dietary treatments was perhaps not completely randomly. The data demonstrates that subsequent litter size within each production level was not influenced by previous dietary mineral level fed to the sow. These results do suggest that farrowing performance was not enhanced by dietary Ca and(or) P level provided during the previous lactation.

Litter and individual pig weights and gains from birth to weaning were not influenced by sow mineral level. A carry-over effect from the dietary mineral level provided during lactation I to parity

II was not evident as indicated by similar dietary treatment pig and litter weight gains. This implies that milk production was not hindered by the Ca:P levels provided in this experiment. Although a higher protein level provided during gestation has been previously reported to influence initial milk production (Mahan and Mangan, 1975), Ca:P does not appear to have a carry-over effect into the subsequent lactation.

Parity did affect ($P < .01$) pig and litter birth and weaning weights but no interaction was evident with dietary mineral level. Litter weaning weights were lower but individual pig weights and gains higher at the 6 to 7 pig litter size as contrasted to those from sows nursing 11 to 12 pigs ($P < .01$). Litter gains were approximately 37% higher when sows nursed the larger litter size, consistent with the approximately same relative higher feed intakes.

These results appear to be consistent with other research demonstrating that sow weights, feed intakes, parturition performance and litter and pig gain measurements were not influenced by dietary mineral level (Kornegay et al., 1973; Harmon et al., 1974; Monegue et al., 1980; Nimmo et al., 1981; Mahan and Fetter, 1982; Kornegay and Kite, 1983) and suggest that these measurements are not sensitive indices for Ca and P metabolism in the lactating sow.

Breeding Performance. The number of days postweaning to return to estrus was not influenced by dietary Ca:P level or lactation production level (appendix table 11). Although a number of sows were

not continued into the second parity there was no evidence of posterior paralysis or leg soundness problems attributable to dietary mineral level. Mahan and Fetter (1982) previously reported that the percentage of sows farrowing did not differ between dietary Ca:P levels. Kornegay and Kite (1983) indicated that days return to estrus after weaning was also similar for sows fed low or high dietary P levels over five parities with the number of sows recorded as successfully mated similar between P levels. Kornegay et al. (1973), however, reported a larger number of sows completing five gestation-lactation cycles when fed a high as compared to sows fed a low Ca:P level but this was attributed to several factors and not postweaning anestrus.

Sow Serum and Milk Analyses. Serum Ca, P and Mg levels did not differ by dietary mineral level or litter size at either 7 or 21 day postpartum (table 4, appendix tables 12,13,14). There was a trend toward an increase in serum Ca and P at both 7 and 21 day between parity I to II. Increases in serum Ca:P concentrations for the second parity may reflect the higher skeletal mineral reservoirs and mineral pool for subsequent body circulation and(or) the higher lactation feed intake (table 3) in these older animals. Kornegay et al. (1973), Mahan and Fetter (1982) and Kornegay and Kite (1983) reported that serum Ca and P levels in swine were unaffected by higher dietary Ca and(or) P levels over three to five parities. Although an inverse relationship between serum Ca and P levels as dietary minerals are

TABLE 4. MAIN EFFECT OF DIETARY CA AND P LEVELS, LITTER SIZE AND PARITY ON SOW SERUM AND MILK CA, P AND MG CONCENTRATIONS

Item ^{ab}	Litter size, no.			Ca:P level, %						Parity		
	6 to 7	11 to 12	SE	.65	.80	.90	1.04	1.17	SE	I	II	SE
				.50	.60	.70	.80	.90				
7 d postpartum												
Serum Ca	10.72	10.19	.06	10.28	10.14	10.23	10.21	10.18	.10	10.09	10.33	.06 ^c
P	6.48	6.44	.08	6.52	6.30	6.53	6.50	6.47	.11	6.48	6.45	.06
Mg	1.65	1.68	.02	1.68	1.67	1.66	1.67	1.66	.06	1.70	1.64	.03
Milk Ca	203	204	.84	202	204	203	205	204	1.2	202	205	.90
P	144	143	.99	143	143	144	145	142	1.5	142	145	.95
Mg	9.6	10.9	.07	9.7	9.9	9.8	12.2	9.6	.12	11.3	9.1	.08 ^c
21 d postpartum												
Serum Ca	10.33	10.30	.06	10.21	10.27	10.38	10.39	10.32	.08	10.06	10.57	.05 ^c
P	7.00	7.09	.08	7.14	7.02	6.97	7.10	7.01	.14	6.26	7.83	.08 ^c
Mg	1.60	1.63	.04	1.49	1.57	1.66	1.75	1.60	.06	1.67	1.60	.02
Milk Ca	221	227	3.9	218	228	219	228	226	6.1	222	232	1.7 ^d
P	158	159	2.0	153	160	160	158	161	3.4	161	158	1.2
Mg	10.0	11.4	.07	10.8	10.7	9.4	13.1	9.6	.12	11.5	10.3	.08 ^c

^aFor number of observations see table 3.

^bSerum and milk Ca, P and Mg values are expressed in mg/100 ml.

^cParity effect (P<.01).

^dParity effect (P<.05).

increased has been demonstrated for weanling or growing swine (Reinhard et al., 1976; Fammatre et al., 1977, Mahan et al., 1980, Mahan, 1982; Maxson and Mahan, 1983) such a relationship was not evident in this trial with lactating sows. It would appear that with variable sow feed intakes and the hormonal homeostatic regulation of blood minerals inverse serum mineral response does not occur in animals with mature skeletal frames. Because of the poor responsiveness of serum Ca and P concentration to the various dietary mineral levels, other criteria may be more responsive in evaluating the Ca:P status in lactating sows.

Dietary mineral level and litter size had no affect on milk Ca, P or Mg concentrations at 7 or 21 day postpartum. Sows had an increased milk Ca and P from 7 to 21 day ($P < .05$) in both parities (table 13). The increased milk Ca and P concentrations as lactation progressed again may reflect the larger feed intakes and mineral intake in the sows during the latter phase of the lactation period. Although sow production level and dietary mineral level did not influence milk Mg, there was a decline in milk but not serum Mg from parity I to II ($P < .01$). Milk mineral concentrations reported here are consistent with other reports at similar stages of lactation (Perrin, 1955; Harmon et al., 1974, 1975; Mahan and Fetter, 1982, Hill et al., 1983). The data of this experiment, along with those from Harmon et al. (1974, 1975) and Mahan and Fetter (1982), implies that similar milk mineral compositions will occur at various dietary

mineral levels, particularly if the diet is not severely deficient in these minerals.

Bone Analyses. Sows after both lactations as well as nongravid females were slaughtered and bones collected for ash, breaking strength, bone density and physical measurement determinations with the results reported in table 5 and appendix tables 15 to 20.

Bone ash was influenced by litter size and parity, whereas dietary Ca:P level did not greatly influence bone mineral content over a 21 day lactation period (table 5). None of the bones responded to dietary mineral level within parity. This suggests that providing the various quantities of Ca:P for a relatively short 21 day lactation period did not impose a severe enough nutritional insult to the sows to effect differences in bone mineral content. In contrast, other reports by Harmon et al. (1974, 1975) and Mahan and Fetter (1982) demonstrated a response to increased dietary Ca and(or) P but their experiments were conducted over a 28 to 42 day period as well as more parities. Harmon et al. (1974) observed a high incidence of posterior paralyzes in sows fed a diet unsupplemented with P when sows lactated 8 weeks but not when lactation was terminated at 4 weeks. The shorter lactation period and two parity sequence of this trial is in contrast to other studies and suggests that longer lactation periods or more reproductive cycles may elicit a response in bone mineral content than dietary mineral level (Kornegay et al., 1973; Harmon et al., 1974, 1975; Nimmo et al., 1981; Mahan and Fetter, 1982).

TABLE 5. MAIN EFFECTS OF DIETARY CA AND P LEVELS, LITTER SIZE AND PARITY ON SOW PERCENTAGE BONE ASH

Item	Production state					Ca:P level, %						Parity		
	Non-gravid	SE	Litter size, no.			.65	.80	.90	1.04	1.17	SE	I	II	SE
			6 to 7	11 to 12	SE	.50	.60	.70	.80	.90				
No. sows	7		68	64		26	28	29	24	25		57	75	
Bone ash, % ^a														
Femur	64.4	.02	63.2	62.9	.14	63.0	63.0	63.1	63.2	63.1	.22	62.8	63.4	.14 ^b
Humerus	64.6	.03	63.3	63.4	.14	63.0	63.2	63.5	63.5	63.6	.25	63.4	63.3	.14
Metatarsal	63.7	.04	62.5	62.7	.11	62.9	62.5	62.6	62.5	62.7	.17	62.3	62.9	.11 ^b
Metacarpal	63.0	.04	62.2	62.3	.11	62.4	62.3	61.9	62.1	62.4	.17	62.1	62.3	.11
Vertebra	59.7	.12	57.9	57.3	.23 ^c	57.7	57.5	57.5	57.6	57.7	.37	58.6	56.6	.22 ^b
Rib	60.8	.12	59.4	57.9	.14 ^d	58.8	58.7	58.8	58.7	58.7	.22	58.9	58.5	.13 ^b

^aBone ash expressed as a percentage of dried, fat-free bone.

^bParity effect (P<.01).

^cLitter size effect (P<.10).

^dLitter size effect (P<.01).

Bone ash responses from parity I to II were evident for the vertebra and rib (table 5 and 14). Vertebra and the adjoining rib showed loss of bone mineral from parity I to II within each mineral level indicating a lower mineral content.

When all bones were compared to those of the nongravid females there was a higher percent bone ash in these animals as compared to the reproducing sows of either parity. Estrogen replacement therapy and Ca supplementation in postmenopausal women have been shown to reduce the rate of bone turnover, both resorption and formation (Riggs et al, 1976, Recker et al., 1977; Heaney et al., 1978). Schuette and Linkswiler (1984) indicated, in humans, that one factor involved in osteoporosis is bone loss and was due to an estrogen deficiency resulting in an increase in bone resorption over formation. Sows in this trial were almost continually in gestation or lactation state with rebreeding occurring at the first postweaning estrus. This suggests a possible estrogen level effect could be involved. Bone losses may be exacerbated as animals remain in a pregnant or lactating condition as shown in a study by the decreases in bone mineral observed from parity I to II which was generally not responsive to dietary mineral. Femur and metatarsal bone ash, however, increased slightly from parity I to parity II ($P < .01$) while no difference occurred between humerus and metacarpal bones suggesting that these bones may not be as sensitive to bone resorption when contrasted to the vertebra or rib. This is consistent with the results of

Mahan and Fetter (1982) demonstrating vertebra and rib demineralization after three reproductive cycles. Underwood (1981) points out that bone resorption in livestock during periods of inadequate Ca:P intake takes place first from the spongy bones, i.e., rib, vertebra and sternum with the small bones of the extremities and long bones affected last. Rib responses to dietary Ca and(or) P inadequacy during periods of nutritional depletion or repletion have also been demonstrated in cattle and sheep (Little, 1972; Little and McMeniman, 1973; Little et al., 1978).

Larger litter size also resulted in a larger amount of bone demineralization in the vertebra ($P<.10$) and rib ($P<.01$) when compared to those sows nursing fewer pigs. Either production level, however, demonstrated a larger loss of bone mineral when contrasted to non-gravid females. Although the larger litter size and weight probably reflects increased milk production in these sows (table 3), with similar milk Ca:P concentrations (table 4), the results suggest a greater demineralization of the dam's Ca:P bone reservoir with larger production level. Little et al. (1978) demonstrated a 42 percent loss of bone P in ribs of ewes suckling twins versus only a 17% loss for animals nursing singles. These results indicate that reproductive status, parity and litter size can influence bone mineral reserves more than dietary Ca:P levels, particularly with a 21 day lactation period.

Bone bending moment results are presented in (table 6) but because of the different speeds used in parity I and II to break the

TABLE 6. MAIN EFFECT OF DIETARY CA AND P LEVELS, LITTER SIZE AND PARITY ON BONE BENDING MOMENT^a

Bone ^b	Production state					Ca:P level, %						Parity		
	Non-gravid	SE	Litter size, no.		SE	.65	.80	.90	1.04	1.17	SE	I	II	SE
			6 to 7	11 to 12		.50	.60	.70	.80	.90				
Metatarsal	238.2	2.8	112.4	106.1	2.8	114.2	108.7	103.0	109.5	110.8	4.4 ^c	72.1	146.1	2.9 ^d
Metacarpal	226.1	3.6	126.7	115.8	3.6 ^e	122.5	117.1	118.4	124.4	123.4	5.7	80.1	162.5	3.7 ^d
Rib	118.8	1.9	56.9	55.2	1.9	58.7	52.9	55.3	55.8	57.5	2.9	39.1	73.1	1.9 ^d

^aBending moment (kg-cm) = $\frac{\text{maximum force (kg)} \times \text{fulcrum length (cm)}}{4}$

^bFor number of observations see table 5.

^cQuadratic effect (P<.10).

^dParity effect (P<.01).

^eLitter size effect (P<.05).

bones, comparisons between parities are invalid. However, when evaluating within parity the results suggest that the larger litter size resulted in decreased bending moments compared with those sows nursing fewer pigs. Both production levels in parity II had lower bending moments than those of the nongravid female. Mineral level alone appeared to have a minimal effect on bone bending moment which agrees with the percentage bone ash data. Arthur et al. (1983) reported no improvement in breaking strength of the metacarpal or metatarsal bones or in percent bone ash in sows previously fed 100 or 150% NRC (1979) Ca:P levels during the growing phase and carried over three reproductive cycles. Although the metacarpal and metatarsals are probably less sensitive indicators of the animal's Ca:P status, the rib in this experiment also was similar between production level and litter size (table 18). These bending moment results generally agree with the bone ash data in that reproductive state appeared to affect skeletal mineral reserves more than dietary mineral level.

Although bone density was unaffected by dietary mineral level, parity or litter size which is in contrast to bone ash results, all resulted in lower bone densities when compared to the nongravid female. There was, however, a trend toward sows nursing larger litters to have lower rib bone densities when compared to sows nursing fewer pigs at the same dietary Ca:P concentration (appendix table 9). Little et al. (1978) demonstrated that radiation absorption of bones decreased when ewes were nursing twins more than singles or those not

lactating, but they failed to detect any effect of dietary P supplementation on bone density. Rib bone density results are in general agreement with percent bone ash or bending moment data with nongravid females exhibiting a higher bone density than reproducing sows. However, differences between the unbred females and lactating sows was not as large as other measurement criteria. Attempts were made to scan the femur and humerus bones of sows but because of their larger diameter and(or) degree of mineralization, complete radiation penetration emitted from the ^{125}I source prevented scanning.

Bone thickness measurements of the femur or humerus shaft failed to detect any effect of dietary Ca:P supplementation (table 7). From parity I to II there was a decrease in femur shaft thickness ($P < .10$) but no effect of litter size. These results imply that the shaft of long bones is one of the last bone tissue areas to be affected in response to mineral mobilization. As with all other criteria evaluated, nonbred females had thicker bone shafts when compared to reproducing sows, again implying that reproductive state can affect low priority mineral reservoirs.

The combined results from this experiment suggests that litter size and parity have more of an effect on skeletal tissue than dietary Ca:P for a 21 day lactation period. Vertebra and rib bones appear to be the most sensitive skeletal tissue in response to reproductive demands for Ca:P with the long bones or the bones of the extremities being less responsive. Nongravid females demonstrated the demands and effects of reproduction on bone tissue after a two

TABLE 7. MAIN EFFECT OF DIETARY CA AND P LEVELS, LITTER SIZE AND PARITY ON BONE DENSITY AND BONE THICKNESS MEASUREMENTS

Item ^a	Production state					Ca:P level, %						Parity		
	Non-gravid	Litter size, no.		SE	SE	.65	.80	.90	1.04	1.17	SE	I	II	SE
		SE	6 to 7	11 to 12		.50	.60	.70	.80	.90				
Rib bone density ^b	69.7	.08	65.8	64.3	.08	64.3	63.1	64.5	66.0	67.4	.13 ^c	64.2	66.0	.08
Shaft thickness, mm														
Femur	5.32	.02	4.34	4.23	.08	4.28	4.31	4.14	4.38	4.33	.14	4.40	4.18	.09 ^d
Humerus	6.47	.05	4.94	4.81	.11	4.69	5.07	4.71	4.95	4.97	.18	4.91	4.84	.11

^aFor number of observations see table 5.

^bDetermined by photon-absorption bone scan technique.

^cDiet linear effect (P<.10).

^dParity effect (P<.10).

parity period by maintaining greater skeletal tissue reserves than reproducing sows. Blood and milk Ca:P parameters and commonly collected sow reproductive performance data all demonstrate little or no effect in response to reproductive needs for Ca:P. Sows continuing beyond two parities with longer lactation periods may respond to higher dietary Ca:P supplementation as suggested by previous trials (Kornegay et al., 1973; Mahan and Fetter, 1982).

SUMMARY

An experiment utilizing 146 first litter and 77 second litter sows was conducted to evaluate five dietary Ca:P levels at two litter sizes (6 to 7 or 11 to 12 pigs/litter) over a 21 day lactation period. Total dietary P levels ranged from .50 to .90% in .10% increments with Ca concurrently increased in a 1.3:1 ratio. A 14% protein corn-soybean meal diet was formulated to .80% Ca and .60% P for gestation while lactation diets varied in their Ca and P contents by using dicalcium phosphate and limestone. Sows from each treatment group and parity were selected at weaning and slaughtered with various bones collected for analyses. A counterpart set of nongravid gilts remained on trial for the two parity period and slaughtered with bones collected. Sow dietary mineral level did not affect sow or pig performance nor was there an interaction between diet mineral level, parity or litter size. Serum and milk Ca, P or Mg were unaffected by dietary Ca:P level at 7 or 21 day of lactation but milk Ca and P increased from parity I to II. Percent rib and vertebra bone

ash decreased from parity I to II and for sows on the higher production level while all bones were generally unresponsive to dietary mineral level. Femur thickness decreased from parity I to II but was not influenced by dietary Ca:P level. Bone bending moment of the ribs, metacarpals and metatarsals was not influenced by diet or parity but a lower metacarpal bending moment was observed for sows nursing larger litters. All bones from nongravid females had higher percentage bone ash when compared to reproducing sows. These results suggest that litter size and parity affected sow Ca:P mineral skeletal reserves more so than dietary Ca:P levels over a 21 day lactation period.

APPENDIX A

BONE STRENGTH ASSAY PROCEDURE FOR METATARSAL, METACARPAL OR RIB
(Crenshaw, T. D., E. R. Peo, Jr., A. J. Lewis and B. D. Moser.
1981. J. Anim. Sci. 53:827)

1. Bones manually cleaned of residue are allowed to equilibrate with room temperature.
2. Instron model 1114 (10,000 lbs) is turned on and allowed to warm up for 1 hour.
3. Instron machine is then fitted with crosshead plunger and appropriate gears for the crosshead speed desired.
4. With fulcrum on the load cell to remove its effects, instron machine is calibrated with standard weights to a known range of force per unit on chart paper.
5. After calibrating, bones are placed and centered on the fulcrum and broken with the force required for complete bone failure concurrently charted.
6. Bending moment (kg - cm) is calculated:

$$\frac{\text{force (kg)} \times \text{fulcrum length (cm)}}{4}$$

APPENDIX B

RELATIVE BONE MASS DETERMINATION

(Cantor, A. H., M. A. Musser AND W. L. Bacon. 1978.
J. Poul. Sci. 59:563)

Principle: Developed by Cameron and Sorenson (1963), the mineral content of bone can be determined by measuring the absorption by bone of a monochromatic, low-energy photon beam which originates in a radioactive source (^{125}I). The intensity of the beam transmitted by the bone is measured by counting with a scintillation detector.

1. Rib bones manually cleaned of residue are marked at the mid-point and three other locations equidistant toward both ends along the longitudinal axis.
2. The base count from a well-collimated ^{125}I photon source is obtained from a minimum of 30 10-second intervals with no sample between the source and NaI scintillation detector and the standard deviation is subsequently calculated.
3. A rib is then placed on two V-shaped supports and aligned so that the premarked location is perpendicular to the ^{125}I source.
4. The bone scanner drive mechanism is set at .95 mm/min and engaged to scan across the rib.
5. Using all values of transmission through the bone (I_a) that were less than the average base count I_o minus three standard deviations relative bone mass is calculated:

$$\text{RBM} = \sum \ln (I_o/I_a)$$

TABLE 8. TREATMENT EFFECTS OF DIETARY CA AND P LEVELS AND PARITY ON REPRODUCTIVE PERFORMANCE AT TWO PRODUCTION LEVELS

Item	Litter size, no:		6 to 7					11 to 12					SE
	Ca, %:	P, %:	.65	.80	.90	1.04	1.17	.65	.80	.90	1.04	1.17	
			.50	.60	.70	.80	.90	.50	.60	.70	.80	.90	
Parity I													
No. sows			22	19	24	19	18	20	21	19	16	20	
Sow weights, kg													
Breeding			115	115	116	119	111	120	121	114	120	115	7.4
109 d			161	156	160	169	157	165	161	158	164	160	5.5
Parturition			145	144	144	154	142	146	145	140	145	143	4.4
21 d postpartum			135	135	134	143	136	140	139	135	136	137	4.6
Gain (0 to 21 d)			-10	-9	-10	-11	-6	-6	-6	-5	-9	-6	1.6
Lactation feed intake, kg													
Total ^a			86	82	83	84	82	98	102	106	104	102	3.4
Daily ^a			4.1	3.9	4.0	4.0	3.9	4.7	4.9	5.1	5.2	4.9	.16
Pigs born live, no			10.42	10.00	8.00	9.00	9.80	12.33	12.00	11.00	11.66	12.75	.98
Birth weight, kg													
Litter			12.9	13.2	11.5	12.5	12.5	16.6	16.0	15.5	15.5	16.1	.72
Pig			1.57	1.57	1.52	1.62	1.49	1.42	1.41	1.42	1.36	1.34	.06
No. pigs weaned			6.68	6.66	6.88	6.84	7.10	10.72	10.84	10.33	11.18	11.00	.17
Weaning weight, kg													
Litter			41.5	41.5	39.7	40.7	37.2	53.6	52.2	50.2	52.2	50.4	1.5
Pig			6.26	6.23	5.76	6.00	5.38	5.03	4.78	4.87	4.71	4.68	.17
Pig gain (0 to 21 d), kg			4.68	4.65	4.24	4.37	4.16	3.60	3.34	3.45	3.34	3.32	.13
Litter gain (0 to 21 d), kg			25.8	28.7	27.4	26.8	24.5	36.5	33.8	34.5	37.0	32.5	4.6
Parity II													
No. sows			8	9	11	7	6	7	6	8	7	8	
Sow weights, kg													
Breeding ^a			142	135	139	138	132	146	139	132	145	137	8.2
109 d			183	165	175	177	176	174	174	174	171	170	7.6
Parturition			166	152	161	159	156	158	156	157	153	154	6.1
21 d postpartum			160	150	156	153	155	160	151	151	152	152	6.4
Gain (0 to 21 d)			-6	-2	-5	-6	-1	2	-5	-6	-1	-2	2.2
Lactation feed intake, kg													
Total ^a			86	78	81	78	85	125	110	118	119	113	4.7
Daily ^a			4.1	3.8	3.9	3.8	4.1	6.0	5.3	5.6	5.7	5.4	.23
Pigs born live, no			9.62	10.75	8.09	9.14	10.66	12.28	9.00	11.87	10.57	10.75	.71
Birth weight, kg													
Litter			15.5	14.7	13.8	15.3	14.6	17.4	15.1	16.4	16.9	15.4	1.00
Pig			1.59	1.41	1.75	1.75	1.51	1.41	1.65	1.39	1.56	1.48	.08
No. pigs weaned			6.75	6.77	6.81	6.57	6.83	11.14	10.83	11.37	10.57	11.37	.25
Weaning weight, kg													
Litter			41.2	39.3	40.5	39.0	40.7	54.1	54.1	56.9	53.6	55.9	2.1
Pig			6.13	5.82	6.02	5.93	6.01	4.78	4.99	4.99	5.07	4.91	.24
Pig gain (0 to 21 d), kg			4.52	4.62	4.27	4.18	4.48	3.69	3.22	3.60	3.51	3.62	.19
Litter gain (0 to 21 d), kg			25.8	24.2	26.7	23.7	26.3	33.0	38.8	40.5	36.7	40.3	4.6

^aParity II breeding weights represent four observations per mean.

TABLE 9. EFFECT OF DIETARY CA AND P BY LITTER SIZE ON SOW AND PIG PERFORMANCE

Item	Litter size, no:						6 to 7						11 to 12					
	Ca, %: .65 .80 .90 1.04 1.17																	
	P, %: .50 .60 .70 .80 .90 SE																	
No. sows	30	28	35	26	24		27	27	27	23	28							
Sow weights, kg																		
109 d	172	161	167	173	166	4.6	172	167	166	167	165	3.8						
Parturition	156	148	153	157	149	3.6	152	151	149	149	148	2.1						
21 d postpartum	147	143	145	148	146	3.8	150	145	143	144	144	3.9						
Gain (0 to 21 d)	-9	-5	-8	-9	-3	.20	-2	-6	-6	-5	-4	.20						
Lactation feed intake, kg																		
Total	86	80	82	81	83	2.8	112	106	112	112	108	2.9						
Daily	4.1	3.8	3.9	3.9	4.0	.30	5.3	5.1	5.4	5.5	5.1	.31						
Pigs born live, no.	10.02	10.31	8.04	9.00	9.73	.52	12.31	10.50	11.43	11.11	12.37	.61						
Birth weight, kg																		
Litter	14.2	14.0	12.7	13.9	13.5	.60	17.1	15.6	15.9	16.2	15.8	.61						
Pig	1.59	1.50	1.64	1.69	1.50	.05	1.42	1.54	1.41	1.50	1.41	.05						
No. pigs weaned	6.72	6.72	6.85	6.70	6.96	.15	10.93	10.83	10.85	10.87	11.18	.15						
Weaning weight, kg																		
Litter	41.2	40.4	40.1	39.8	39.1	1.3	53.5	53.2	53.5	53.0	53.1	1.3						
Pig	6.20	6.02	6.45	5.97	5.70	.21	4.90	4.88	4.93	4.89	4.80	.21						
Pig gain (0 to 21 d), kg	4.60	4.64	4.25	4.28	4.32	.11	3.44	3.33	3.52	3.42	3.37	.12						
Litter gain (0 to 21 d), kg	25.8	26.5	27.1	25.2	25.4	3.3	34.8	36.3	37.5	36.8	36.4	3.3						

TABLE 10. EFFECT OF DIETARY CA AND P BY PARITY ON SOW AND PIG PERFORMANCE

Item	Parity: Ca, %: P, %:	I					II					SE
		.65	.80	.90	1.04	1.17	.65	.80	.90	1.04	1.17	
		.50	.60	.70	.80	.90	.50	.60	.70	.80	.90	
No. sows		42	40	43	35	38	15	15	19	14	14	
Sow weights, kg												
109 d		163	158	159	166	158	5.4	180	170	174	174	7.6
Parturition		145	145	142	150	143	4.4	162	154	159	156	6.0
21 d postpartum		137	137	134	140	136	4.6	160	151	154	153	6.2
Gain (0 to 21 d)		-8	-8	-8	-10	-7	.20	-2	-3	-5	-3	.20
Lactation feed intake, kg												
Total		92	92	95	95	92	3.4	106	94	99	99	3.0
Daily		4.4	4.4	4.6	4.6	4.4	.18	5.4	4.5	4.7	4.7	.23
Pigs born live, no.		11.37	10.93	9.50	10.13	11.90	.88	10.95	9.90	9.98	9.86	.70
Birth weight, kg												
Litter		14.8	14.6	13.5	14.0	14.3	.71	16.5	14.9	15.1	16.1	.97
Pig		1.50	1.49	1.48	1.50	1.41	.06	1.50	1.54	1.57	1.66	.06
No. pigs weaned		8.70	8.75	8.60	9.01	9.05	.17	8.95	8.80	9.09	8.57	.24
Weaning weight, kg												
Litter		47.6	46.9	45.0	46.4	44.0	1.4	47.3	46.7	48.7	46.3	1.4
Pig		5.65	5.50	5.32	5.36	5.03	.17	5.45	5.41	5.51	5.50	.24
Pig gain (0 to 21 d), kg		4.06	4.00	3.85	3.85	3.74	.16	3.90	3.98	3.93	3.84	.16
Litter gain (0 to 21 d), kg		31.2	31.2	30.9	31.9	28.5	4.0	29.4	31.5	33.6	30.2	4.0

TABLE 11. EFFECT OF DIETARY MINERAL LEVEL AND LITTER SIZE ON DAYS POSTWEANING TO ESTRUS RETURN^a

Days	Ca, % P, %	Mineral level					Litter size	
		.65	.80	.90	1.04	1.17	6 to 7	11 to 12
		.50	.60	.70	.80	.90		
0 to 5	-	-	-	-	-	-	-	
5 to 10	1	4	3	2	4	7	7	
10 to 15	2	1	3	2	2	6	4	
15 to 20	1	-	1	-	1	3	-	
>-20	5	6	4	6	7	18	10	
Total	9	11	11	10	14	34	21	
Percent (0 to 15 day)	33	45	55	40	43	38	52	

^aValues reflect no. of sows.

TABLE 12. TREATMENT EFFECTS OF DIETARY CA AND P LEVELS AND PARITY AT TWO PRODUCTION LEVELS AND TWO PERIODS ON SOW SERUM AND MILK CA AND P

Item ^{ab}	Litter size, no:											
	6 to 7						11 to 12					
	Ca, %	.65	.80	.90	1.04	1.17	Ca, %	.65	.80	.90	1.04	1.17
	P, %	.50	.60	.70	.80	.90	P, %	.50	.60	.70	.80	.90
	SE						SE					
Parity I (7 d postpartum)												
Serum Ca		10.28	9.88	10.10	10.26	10.40	.22	9.86	9.88	10.03	10.26	9.91
P		6.60	5.91	6.58	6.85	6.20	.23	6.78	6.29	6.63	6.22	6.73
Mg		1.75	1.65	1.56	1.72	1.75	.10	1.73	1.64	1.72	1.79	1.72
Milk Ca		197.3	203.2	202.8	201.7	204.8	2.87	199.3	203.8	202.5	202.5	201.0
P		144.2	145.0	143.8	145.5	137.3	3.81	140.5	140.2	140.0	144.7	141.2
Mg		10.1	11.3	11.0	11.3	11.2	2.71	11.5	11.6	12.1	12.0	11.3
Parity I (21 d postpartum)												
Serum Ca		10.04	10.05	10.04	10.23	10.02	.17	9.96	10.03	10.26	9.93	10.05
P		6.51	5.94	6.15	6.03	5.94	.29	6.11	6.48	6.18	6.14	6.51
Mg		1.69	1.68	1.56	1.84	1.73	.09	1.62	1.62	1.72	1.64	1.60
Milk Ca		222.0	227.5	221.8	221.5	218.0	5.73	221.0	226.8	222.8	222.0	220.5
P		154.0	162.0	166.0	160.6	159.3	3.78	165.3	166.3	154.7	156.0	167.8
Mg		12.5	11.8	11.2	11.3	10.0	2.71	11.5	11.1	11.6	12.3	11.1
Parity II (7 d postpartum)												
Serum Ca		10.46	10.40	10.46	10.11	10.18	.19	10.54	10.38	10.33	10.22	10.23
P		6.48	6.49	6.47	6.47	6.37	.20	6.21	6.49	6.42	6.48	6.60
Mg		1.63	1.64	1.64	1.66	1.50	.08	1.60	1.75	1.71	1.53	1.68
Milk Ca		203.7	202.5	203.9	205.4	204.3	2.48	207.3	205.0	204.0	209.4	207.5
P		147.8	141.1	145.4	144.3	145.2	2.94	141.0	145.6	145.6	146.6	147.0
Mg		9.2	8.5	8.4	7.7	7.4	2.33	7.9	7.9	7.6	7.9	8.5
Parity II (21 d postpartum)												
Serum Ca		10.51	10.47	10.61	10.68	10.55	.15	10.35	10.51	10.61	10.72	10.66
P		7.89	7.89	7.78	7.84	7.74	.25	8.03	7.75	7.76	7.79	7.85
Mg		1.45	1.49	1.74	1.87	1.53	.08	1.53	1.65	1.61	1.64	1.52
Milk Ca		231.3	227.6	228.3	234.7	232.5	4.94	230.0	231.6	230.8	235.4	232.9
P		157.2	156.4	158.0	158.1	157.7	3.22	157.4	157.0	161.3	157.7	157.8
Mg		11.6	11.4	8.1	8.0	8.0	2.34	9.3	8.3	7.4	10.9	9.4

^aSerum and milk Ca, P and Mg values are expressed in mg/100 ml.

^bFor number of observations see table 3.

TABLE 13. EFFECT OF DIETARY CA AND P LEVEL AND LITTER SIZE ON SERUM AND MILK CA, P AND MG CONCENTRATIONS^a

Litter size, no:		6 to 7					11 to 12						
Item ^b	Ca, %:	.65	.80	.90	1.04	1.17	Ca, %:	.65	.80	.90	1.04	1.17	
	P, %:	.50	.60	.70	.80	.90	P, %:	.50	.60	.70	.80	.90	
SE													
7 d postpartum													
Serum Ca		10.37	10.14	10.28	10.19	10.29	.14	10.21	10.13	10.18	10.24	10.07	.14
P		6.49	6.39	6.53	6.35	6.66	.15	6.54	6.20	6.52	6.66	6.29	.15
Mg		1.69	1.64	1.61	1.69	1.63	.07	1.66	1.70	1.72	1.66	1.70	.07
Milk Ca		200	203	203	204	205	1.9	203	204	203	206	204	1.9
P		146	143	145	145	141	2.5	141	143	143	146	144	2.5
Mg		9.7	9.9	9.7	9.5	9.3	.2	9.7	9.8	9.9	10.9	10.0	.2
21 d postpartum													
Serum Ca		10.27	10.26	10.32	10.45	10.28	.11	10.16	10.27	10.44	10.33	10.35	.11
P		7.20	6.92	6.97	6.93	6.84	.19	7.07	7.12	6.97	7.26	7.18	.18
Mg		1.57	1.59	1.65	1.65	1.63	.06	1.58	1.63	1.67	1.65	1.57	.06
Milk Ca		227	228	225	228	225	3.8	226	229	227	229	227	3.8
P		156	159	162	159	158	2.5	161	162	158	157	163	2.5
Mg		12.0	11.6	9.6	9.7	9.3	.2	10.4	9.7	9.6	11.6	10.2	.2

^aSerum and milk Ca, P, and Mg values are expressed in mg/100ml.^bFor number of observations see table 3.

TABLE 14. MAIN EFFECT OF DIETARY CA AND P LEVEL AND PARITY ON SERUM AND MILK CA, P AND MG CONCENTRATIONS

Item ^{ab}	Parity:		I					II				
	Ca, %:		.65	.80	.90	1.04	1.17	.65	.80	.90	1.04	1.17
	P, %:		.50	.60	.70	.80	.90	.50	.60	.70	.80	.90
							SE					SE
7 d postpartum												
Serum Ca			10.07	9.88	10.06	10.26	10.15	.18	10.50	10.39	10.39	10.18
P			6.69	6.10	6.60	6.53	6.43	.22	6.35	6.49	6.44	6.48
Mg			1.74	1.65	1.65	1.75	1.74	.09	1.62	1.70	1.69	1.60
Milk Ca			198	203	203	202	203	2.7	205	204	204	207
P			142	143	141	145	140	3.2	144	143	145	146
Mg			10.8	11.4	11.0	11.6	11.2	.31	9.2	8.5	8.4	10.0
21 d postpartum												
Serum Ca			10.00	10.04	10.15	10.08	10.04	.16	10.43	10.49	10.61	10.70
P			6.31	6.21	6.16	6.38	6.23	.27	7.96	7.82	7.77	7.81
Mg			1.66	1.65	1.64	1.74	1.66	.08	1.50	1.57	1.67	1.65
Milk Ca			222	227	222	222	219	5.3	231	229	229	235
P			160	164	160	158	163	3.5	157	157	156	158
Mg			12.0	11.5	11.4	11.3	10.5	.25	10.5	9.9	9.0	12.0

^aSerum and milk Ca, P, and Mg values are expressed in mg/100ml.^bFor number of observations see table 3.

TABLE 15. TREATMENT EFFECTS OF DIETARY CA AND P LEVELS ON SOW BONE ASH (PARITY I AND II) AT TWO PRODUCTION LEVELS

		Litter size, no:		6 to 7					11 to 12						
Item	Parity	Ca, %:		.65	.80	.90	1.04	1.17		.65	.80	.90	1.04	1.17	
		P, %:		.50	.60	.70	.80	.90	SE	.50	.60	.70	.80	.90	SE
No. sows	I			6	7	6	5	6		5	5	7	5	5	
	II			8	9	8	7	6		7	7	8	7	8	
Bone ash, % ^a															
Femur	I			63.6	63.1	62.0	63.1	62.6	.5	62.3	62.9	62.7	62.7	62.4	.5
	II			63.2	62.9	63.8	63.5	63.7	.5	62.9	63.1	63.7	63.3	63.6	.5
Humerus	I			63.6	63.2	63.0	63.6	63.9	.5	62.5	63.7	63.5	63.2	63.7	.5
	II			62.8	62.5	63.7	63.8	63.2	.5	63.4	63.4	63.7	63.5	63.4	.5
Metatarsal	I			62.3	61.9	62.2	62.1	62.5	.4	62.2	62.9	62.0	62.6	62.7	.4
	II			63.4	62.4	63.2	62.6	62.7	.4	63.7	62.8	62.8	62.9	62.8	.4
Metacarpal	I			62.2	62.1	61.9	61.6	62.6	.4	61.8	62.5	61.8	62.1	62.3	.3
	II			62.5	62.3	62.2	62.3	62.0	.4	62.9	62.3	61.9	62.3	62.5	.3
Vertebra	I			58.6	59.4	58.2	58.7	59.1	.8	58.8	57.6	58.0	58.2	58.5	.8
	II			57.4	56.5	56.8	57.0	57.4	.7	56.0	56.6	55.7	56.6	55.9	.7
Rib	I			60.1	59.3	59.8	59.4	59.0	.5	58.4	58.3	57.9	58.5	58.6	.5
	II			59.9	59.3	59.5	59.0	59.1	.4	56.8	57.8	57.8	57.7	57.9	.4

^aBone ash is expressed as a percentage of dried, fat-free bone.

TABLE 16. EFFECT OF DIETARY CA AND P LEVEL AND LITTER SIZE ON SOW PERCENTAGE BONE ASH

Litter size, no:													
6 to 7							11 to 12						
Item	Ca, %:	.65	.80	.90	1.04	1.17		.65	.80	.90	1.04	1.17	
	P, %:	.50	.60	.70	.80	.90	SE	.50	.60	.70	.80	.90	SE
No. sows		14	16	14	12	12	-	12	12	15	12	13	-
Bone ash, % ^a													
Femur		53.3	63.0	62.9	63.3	63.2	.3	62.7	63.0	63.2	62.9	62.9	.3
Humerus		63.1	62.8	63.4	63.7	63.6	.4	62.9	63.5	63.6	63.3	63.6	.4
Metatarsal		62.8	62.2	62.7	62.4	62.6	.2	62.9	62.8	62.4	62.7	62.7	.2
Metacarpal		62.3	62.4	62.0	61.9	62.3	.3	62.4	62.2	61.9	62.2	62.5	.3
Vertebra		58.1	57.9	57.6	57.8	58.3	.5	57.4	57.2	57.4	57.4	57.2	.5
Rib		60.1	59.3	59.6	59.2	59.1	.3 ^b	57.6	58.1	57.9	58.1	58.3	.3 ^b

^aBone ash is expressed as a percentage of dried, fat-free bone.^bDiet x litter size interaction (Linear P<.05).

TABLE 17. EFFECT OF DIETARY CA AND P LEVEL AND PARITY ON SOW PERCENTAGE BONE ASH

Item ^{ab}	Parity:		I					II					SE	
	Ca, %:		.65	.80	.90	1.04	1.17	.65	.80	.90	1.04	1.17		
	P, %:		.50	.60	.70	.80	.90	.50	.60	.70	.80	.90		
Bone ash, %														
Femur			62.9	63.0	62.4	62.9	62.5	.3 ^c	63.0	63.0	63.8	63.4	63.6	.3 ^d
Humerus			63.0	63.4	63.3	63.4	63.8	.3	63.1	62.9	63.7	63.6	63.3	.4
Metatarsal			62.3	62.4	62.1	62.4	62.6	.2 ^c	63.5	62.6	62.9	62.7	62.7	.2 ^d
Metacarpal			62.0	62.3	61.8	61.8	62.5	.3	62.7	62.3	62.1	62.3	62.3	.3
Vertebra			58.7	58.5	58.7	58.4	58.8	.5	56.7	56.5	56.3	56.8	56.7	.5
Rib			59.2	58.8	58.8	58.9	58.8	.3	58.4	58.6	58.7	58.4	58.5	.3

^aBone ash is expressed as a percentage of dried, fat-free bone.^bFor number of observations see table 5.^cDiet x parity interaction (Linear P<.10).

TABLE 18. TREATMENT EFFECTS OF DIETARY CA AND P LEVELS ON BONE BENDING MOMENT (PARITY I AND II) AT TWO PRODUCTION LEVELS

		Litter size, no:		6 to 7					11 to 12					
Item ^{ab}	Parity	Ca, %:	.65	.80	.90	1.04	1.17	SE	.65	.80	.90	1.04	1.17	SE
		P, %:	.50	.60	.70	.80	.90		.50	.60	.70	.80	.90	
Metatarsal	I		80.4	73.5	75.3	81.3	67.6	14.7	83.1	91.3	83.6	83.2	81.1	14.7
	II		193.4	162.2	166.2	183.9	183.8	13.2	133.6	141.5	151.0	150.3	160.7	13.2
Metacarpal	I		75.1	68.3	66.4	66.8	75.5	11.4	72.0	80.2	70.4	72.4	74.2	11.4
	II		157.8	147.9	147.4	168.6	148.1	10.2	151.3	138.8	126.8	130.4	143.9	10.2
Rib	I		29.4	32.7	40.9	42.2	46.4	7.6	40.6	44.3	39.2	38.2	37.4	7.6
	II		91.2	63.9	71.2	74.4	77.1	6.8	74.1	70.7	71.4	68.4	68.7	6.8

^aFor number of observations see table 5.

^bBending moment (kg-cm) = maximum force (kg) x fulcrum length (cm)

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TABLE 19. TREATMENT EFFECTS OF DIETARY CA AND P LEVELS ON BONE DENSITY MEASUREMENTS (PARITY I AND II) AT TWO PRODUCTION LEVELS

Item ^{abc}	Litter size, no:											
	6 to 7						11 to 12					
	Ca, %	.65	.80	.90	1.04	1.17	.65	.80	.90	1.04	1.17	SE
	P, %	.50	.60	.70	.80	.90	.50	.60	.70	.80	.90	SE
Parity I												
Rib Bone Mass		63.6	62.2	65.1	66.3	69.2	.3	63.9	61.6	61.0	65.3	63.6 .2
Parity II												
Rib Bone Mass		62.4	64.1	68.2	66.9	70.2	.3	67.4	64.6	63.2	65.6	67.0 .3

^aDetermined by photon-absorption bone scan technique.

^bAverage of six scans per rib.

^cFor number of observations see table 5.

TABLE 20. TREATMENT EFFECTS OF DIETARY CA AND P LEVELS AND PARITY AT TWO PRODUCTION LEVELS ON FEMUR AND HUMERUS SHAFT THICKNESS

Litter size, no:		6 to 7					11 to 12						
Item ^a	Ca, %:	.65	.80	.90	1.04	1.17		.65	.80	.90	1.04	1.17	
	P, %:	.50	.60	.70	.80	.90	SE	.50	.60	.70	.80	.90	SE
Parity I													
Shaft thickness, mm ^b													
Femur		4.55	4.42	4.13	4.73	3.99	.27	4.39	4.59	4.42	4.46	4.33	.27
Humerus		4.66	5.14	4.53	5.33	5.05	.36 ^c	4.26	4.73	4.85	5.06	5.39	.36 ^c
Parity II													
Femur		3.79	4.37	4.12	4.42	4.99	.25	4.37	3.88	3.88	3.90	4.12	.25
Humerus		4.70	5.12	4.95	4.99	4.94	.33 ^c	5.13	5.27	4.38	4.42	4.58	.33 ^c

^aFor number of observations see table 5.

^bAverage of three measurements per bone.

^cDiet x parity x litter size interaction.

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