EFFECT OF RESTRICTED GROWTH RATE AND ELEVATED LEVELS OF MINERALS AND VITAMINS ON FEET AND LEG CHARACTERISTICS, SOUNDNESS SCORES AND METACARPAL AND METATARSAL CHARACTERISTICS OF GROWING BOARS

by

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TABLE OF CONTENTS

Page

LIST OF TABLES

Table		Page

Chapter I

INTRODUCTION

As a result of economic conditions in recent years the swine industry has been forced to adopt more efficient methods of operation. This need has lead to the raising of pigs in total confinement to minimize labor expense. Additionally, selection pressure has been toward pigs with rapid growth, efficient feed conversion, low body fat and high muscle content. With these advancements the problem of structural unsoundness, or leg weakness, has intensified. It is evident that the foot and leg structure of the pig has not evolved to handle the stresses placed upon it by complete confinement housing on hard, abrasive surfaces such as concrete. Environmental factors such as these may predispose animals to lameness problems. The breeding herd is especially susceptible since they are housed in this manner for an extended period of time. These environmental factors may be potentially complicated by rapid growth rate forcing the skeletal system to support greater body weight at an earlier age. Thus the need for development of a structural system capable of withstanding the stresses of modern swine operations is evident. A better understanding of nutritional influences on the development of the foot and leg as a structural component is an essential step towards this goal.

The objective of this study was to investigate the effects of restricted growth rate and elevated mineral and vitamin levels (above National Research Council recommendations) on feet and leg characteristics, structural soundness scores and metacarpal and metatarsal characteristics in growing boars.

Chapter II

REVIEW OF LITERATURE

EFFECT OF DIETARY CALCIUM AND PHOSPHORUS ON GROWTH PERFORMANCE

The current NRC (1979) Ca/P recommendation for young pigs of 1 to 5 kg body weight is .90/.70%. This recommendation is reduced to .80/.60% Ca/P at 5 to 10 kg body weight. Growth studies support this estimate as a good approximation of the true requirement. Combs and Wallace (1962) reported that when dietary Ca for weaned pigs was increased by increments of .10% from .40 to .80% with P maintained at .44% average daily gain and feed efficiency were depressed. Rutledge et al. (1961) observed no consistant effect on rate of gain or feed utilization of 3 wk old pigs fed .6% dietary P and varying Ca levels (.4 to 1.0%). In studies altering both the Ca and P levels in the diet, Zimmerman et al. (1960, 1963) reported that high Ca levels (above .8%) reduced feed efficiency while P up to approximately .6% of the diet improved feed utilization. Dietary Ca and P levels for young weaned pigs above those recommended by NRC did not affect daily gain, feed/gain or feed consumption (Schiefelbein et al., 1979). Likewise, Mahan (1982) and Mahan et al. (1980) reported that the performance of 7 to 20 kg pigs plateaued at .80/.60% Ca/P.

Altering dietary Ca and P levels for growing and growing-finishing swine has been widely studied and provides a wide variety of conflicting results. Dietary Ca/P levels of .65/.55, .60/.50, .55/.45 and .50/.40% for body weights of 10 to 20, 20 to 35, 35 to 60 and 60 to 100 kg, respectively are presently recommended by NRC (1979). Libal et al. (1969) reported that feeding growing-finishing swine elevated dietary P (.30 to .70% with Ca maintained at .35%) improved daily gain in a linear manner. Similar results have been reported by Cromwell et al. (1970). Further support is provided by Cromwell et al. (1974) who fed basal diets (.28% P) supplemented with .1, .15 or .2% P to growing pigs from 14 to 45 kg body weight followed by P supplementation of 0, .05 or .1%. Calcium level of basal diet was .60%. Daily gains were reduced and feed/gain increased as P decreased. In contrast, Parker et al. (1975a) and Harmon et al. (1974b), using basal diets containing .65 and .72% Ca, respectively, reported no effect on growth performance with dietary P levels increased above NRC recommendations. Elevated dietary Ca and P levels for growing-finishing swine have been shown by several investigators to have little effect on growth performance (Arthur et al., 1980; Doige et al., 1975; Scherer et al., 1970). Alternatively, Reinhard et al. (1976) reported that increased dietary Ca and P levels for growing swine above those recommended by NRC produced trends toward improved growth rate and feed intake. Fammatre et al. (1977) similarly observed increased feed intakes and gains during the growing period (19 to 52 kg) of growing-finishing swine fed .90% Ca, .70% P as compared with swine fed .65% Ca, .50% P, but over the entire growing-finishing period, mineral had no affect. Nimmo et al. (1981) reported that increased dietary Ca and P (.975/.75 vs .75/.65%, Ca/P) level did not affect average daily gain or feed/gain of growing gilts but did produce increased daily feed intake. In contrast, Calabotta et al. (1982) found an increase in average daily gain, but no significant change in average daily feed intake or feed efficiency with elevated (150% NRC) Ca and P levels fed to growing gilts. Feeding gilts 100 or 150% NRC Ca and P levels from weaning to 100 kg produced no effect on overall daily gain, daily feed intake or feed per unit gain (Kornegay et al., 1982a).

Dietary Ca and P levels for growing boars are presently the same as those recommended for growing-finishing swine (NRC, 1979). Liptrap et al. (1970) fed dietary Ca levels of .6, .9 or 1.2% with P maintained at .5% and reported depressed daily gain in boars fed 1.2% dietary Ca. Feed efficiency was slightly depressed by the high Ca levels in the diet. Bayley et al. (1971, 1975b) reported that elevation of dietary P from .4 to .6% in combination with .8% dietary Ca resulted in increased average daily gain for growing boars. Elevation of both minerals in the diet of growing boars above NRC recommendations has been shown to have no effect on average daily feed intake, average daily gain or feed:gain ratio (Hines et al., 1979; Nimmo et al., 1980a, b). In contrast, Kesel et al. (1982) observed that daily gain was greater for boars fed 150% NRC Ca and P as compared with 100% NRC recommendations and that feed efficiency favored boars fed 150% Ca and P. In general agreement, Kornegay et al. (1981a) reported a trend for improved daily gain during the growing period for boars fed 125% NRC Ca and P recommendations while feed/gain was non-significantly lower. Daily feed intake did not differ due to dietary Ca and P level. Likewise, levels of 125% NRC Ca and P levels improved daily gain for boars during the finishing phase (Thomas and Kornegay, 1981).

Present evidence lends support to the NRC (1979) Ca/P recommendations for weaned pigs and growing-finishing swine. Growth performance is depressed when sub-NRC Ca/P levels are fed and is not enhanced at Ca/P levels above NRC recommendations. The adequacy of NRC Ca/P recommendations for growing boars is less certain as several recent studies have reported improved growth performance with feeding Ca/P levels 25 or 50% above NRC levels (Kesel et al., 1982; Kornegay et al., 1981a; Thomas and Kornegay, 1981).

EFFECT OF DIETARY CALCIUM AND PHOSPHORUS LEVEL ON BONE

Although NRC (1979) Ca and P recommendations generally appear to maintain an acceptable level of growth performance, its adequacy for producing optimal skeletal development remains in doubt. Research results provide a variety of conflicting results; several studies raise the possibility that dietary Ca and P levels above those currently recommended (NRC, 1979) may result in increased bone size, ash content and Ca and P content and in improved mechanical properties. The hope arising from this study is the possibility of a more desirable structural support system for the modern, rapidly growing pig.

Dimensional Characteristics

Liptrap et al. (1970) reported that increasing dietary Ca levels from .6 to 1.2% with dietary P maintained at .5% caused a decrease in fresh femur weight in growing boars. The wide Ca:P ratio in the 1.2% Ca level may have induced a P deficiency which was detrimental to rate of gain and feed utilization. Miller et al. (1962) fed diets containing .5% P supplemented with 0 to 1.6% dietary Ca to baby pigs and found that fresh weight of the humerus, femur and rib did not significantly differ between treatments. In agreement, Harmon et al. (1974b) observed that altering the dietary P level (.45 and .65%) in the presence of a constant Ca level

(.72%) had no effect on fresh rib weight. Forsyth et al. (1972) found no effect on fresh humerus weight of growing-finishing barrows when diets containing either .5/.4 or 1.2/1.0% Ca/P were fed. In contrast, Schroeder et al. (1974) reported that increasing Ca from .5 to 1.2% of the diet and P from .5 to 1.0% of the diet produced a linear increase in dry femur weight of growing boars. This result is further supported by Chapman et al. (1962) who observed a highly significant increase in dry femur weights of growing-finishing swine as Ca increased for P levels of .2 through .5%. The same trend occurred when P was increased for levels of Ca of .2 and .6%. Increasing the dietary Ca (.53 to 1.26%) and P (.43 to .70%) levels has also produced a significant linear increase in the radius weight of growing pigs (van Kempen et al., 1976). Scapula weight of growing pigs has similarly been shown to be responsive to increased dietary Ca levels (.48 to 1.20% with a constant 1.2:1 Ca:P ratio; Nielsen et al., 1971).

Cromwell et al. (1972) observed that increasing the dietary Ca level in .15% increments from .50 to .95% for pigs from 16.7 to 45.5 kg and from .35 to .80% thereafter tended to increase the weight of the third and fourth metacarpal. Likewise, Nimmo et al. (1981) reported that gilts fed .975/.75% Ca/P had heavier fourth metatarsals than gilts fed .65/.50% Ca/P. The fourth metatarsal heavier than the third metatarsal when compared across treatments. Growing boars also displayed an increased dried metacarpal weight when fed 125 and 150% of NRC Ca and P levels (Kornegay et al., 1981a). In contrast, Doige et al. (1975) fed 50, 100 or 150% of NRC Ca and P to growing swine and observed that the weight of the third metacarpal was greater for the 100% Ca level than for the 50% Ca level but not different from the 150% Ca level. Dietary P level had little effect. Kornegay and Thomas (1981) reported that feeding gilts, boars and barrows Ca and P levels 25% higher than NRC recommendations did not increase metacarpal dried weight but feeding Ca and P levels 25% below NRC recommendations resulted in reduced metacarpal dried weight. Feeding Ca and P levels in excess of NRC recommendations has been shown to have no significant effect on fresh metacarpal or metatarsal weight in growing boars (Nimmo et al., 1980b) or in developing gilts (Arthur et al., 1982b). In contrast, Kesel et al. (1982) reported a linear increase in fresh metacarpal weight of growing boars fed 150% NRC Ca and P levels as compared with 100% NRC recommendations.

van Kempen et al. (1976) reported no significant effect on humerus length of growing pigs when dietary Ca levels were increased from .53 to 1.26% and dietary P levels increased from .43 to .70%. Similar Ca and P levels fed to growing-finishing barrows also did not affect humerus length (Forsyth et al., 1972). Ca and P levels 25 and 50% (Kornegay et al., 1981a) or 50 and 100% (Nimmo et al., 1980b) above NRC recommendations did not affect metacarpal length in growing boars. A response was noted in gilts by Nimmo et al. (1981) with .975% Ca and .75% P levels producing longer third and fourth metatarsals as compared with dietary Ca and P levels of .65 and .5%, respectively. In contrast, however, Arthur et al. (1982b) reported that Ca and P levels of 150% NRC reccommendations fed during growth and development had no effect on the length of metacarpal or metatarsal bones in sows.

Schroeder et al. (1974) reported that the outside diameters of femurs from growing boars increased linearly as dietary Ca level increased from .5 to 1.2% and dietary P increased from .5% to 1.0%. This response was not evident in humeri of growing-finishing barrows when Ca/P levels were elevated from .5/.4 to 1.2/1.0% Ca/P (Forsyth et al., 1972). No increase in the outside diameter of third and fourth metacarpals was observed by Cromwell et al. (1972) when Ca was increased from .50 to .95% of the diet in combination with .50 or .65% P for growing pigs. Arthur et al. (1982b) reported shaft diameters of metacarpals and metatarsals of sows to be unaffected by feeding Ca and P levels 50% above NRC recommendations during growth and development. Similar results were obtained by Kesel et al. (1982) when growing boars were fed Ca and P levels in excess of NRC recommendations. Likewise, Nimmo et al. (1981) observed no effect on the average inside or outside diameters of third and fourth metatarsals from gilts fed elevated Ca/P levels (.65/.50 vs .975/.75%, Ca/P).

Miller et al. (1962) reported that in baby pigs the compact calcified layer thickness of the femur increased with increasing dietary Ca level (0 to 1.6%) while dietary P was maintained at .5%. Schrceder et al. (1974) observed a significant linear increase in femur sidewall thickness resulting from increasing dietary Ca/P levels from .5/.5 to 1.2/1.0% for growing boars. In contrast, femur wall thickness of gilts was not affected by elevating dietary P levels from .40 to .60% when the Ca level in the diet was maintained at .65% (Hsu et al., 1976). Humeri cortical thickness was similarly not influenced by increasing Ca and P levels above NRC recommendations for growing-finishing barrows (Forsyth et al., 1972). Doige et al. (1975) fed growing barrows and gilts Ca and P levels of 50, 100 or 150% of NRC (1968) recommendations. Rib cortical thickness was maximized with the 100% NRC Ca and P level and not significantly reduced by low Ca and P levels provided the Ca:P ratio was maintained near 1.30:1. Raising the level of either mineral above those recommended by the NRC failed to produce a beneficial response. Alternatively, Arthur et al. (1982b) observed increased metacarpal and metatarsal thickness in sows which were fed 150% NRC Ca and P levels during growth and development. Quadratic increases in metacarpal thickness with increasing dietary Ca levels (.50 to .95%) have also been reported in growing pigs (Cromwell et al., 1972). Kesel et al. (1982) reported an increased metacarpal thickness when growing boars were fed Ca and P levels 50% above NRC recommendations.

Ash Content

Increased mean values for humeral (Miller et al., 1962) and femoral (Rutledge et al., 1961) percentage ash in the baby pig have been demonstrated for dietary Ca levels above NRC levels when P level was maintained constant (.5 or .6%). In a later study by Miller et al. (1964), P level varied (.2 to .8%) with Ca level held constant (.8%) in a synthetic milk diet for 1 wk old pigs. Humeral ash concentrations were maximal in pigs receiving .6% dietary P and were significantly reduced in pigs receiving the lowest P level. Combs et al. (1962) reported increasing P levels of .40, .44 and .48% of the diet and Ca:P ratios of .9:1, 1.2:1 and

1.5:1 at each P level produced significant quadratic increases in fibula ash of weaned pigs. Likewise, increasing Ca and P levels in the diet have produced elevated ash content of metatarsal (Zimmerman et al., 1960, 1963) and rib and radius-ulna (Arthur et al., 1980) of young pigs. Mahan et al. (1980) reported that increasing dietary P levels from .50 to .90% at .1% increments with Ca added to maintain a 1.3:1 Ca:P ratio resulted in a non-linear increase in femur and rib ash values for weanling pigs. Percentage ash was maximized at a dietary level of .90% Ca and .70% P which the authors speculated may estimate the animal's Ca and P requirement. Similar results were also obtained using femur, rib, humerus and metacarpal bone (Mahan, 1982).

Harmon et al. (1967) reported that rib and turbinate ash of growing pigs increased curvilinearly with increasing dietary P levels from .34 to .74% with Ca maintained at .85% of the diet. Similarly, Cromwell et al. (1970) observed that increasing P levels from .34 to .56% of the diet with Ca maintained at .65% increased the ash content of metacarpals and turbinates in growing-finishing swine. A subsequent study however, revealed that turbinate ash was not significantly influenced by dietary P level (.45 vs .65%) when Ca level remained at .72% of the diet (Harmon et al., 1974). Increasing the dietary P level in the presence of a constant Ca level has been shown to increase percentage ash of the humerus (Parker et al., 1975a) and of the proximal phalange, metatarsal and humerus (Parker et al., 1979). Chapman et al. (1962) reported that femur ash of growing-finishing pigs increased as the Ca level in the diet was increased from .2 through .6% and as P was increased from .2 through .7%, with a maximum femur ash content observed at .6% Ca and .6% P in the diet. Mahan (1977) observed similar results for both rib and femur ash content. Percentage ash of the scapula (Nielson et al., 1971) and humerus (Forsyth et al., 1972) of growing pigs have also been shown to increase as Ca and P levels were elevated above NRC recommendations. Pond et al. (1975) reported that the ash content of radii-ulnae from growing pigs fed 1.2/1.0% Ca/P tended to be higher than that of radii-ulnae from pigs fed .5/.4% Ca/P. This result was confirmed by van Kempen et al. (1976) utilizing similar dietary Ca and P levels. Peo et al. (1967) reported that increasing Ca and P levels from .40 to .90% or using P levels of .35 or .65% in combination with Ca levels of .65, 1.05 or 1.30% produced no significant differences in percentage ash of the fourth metatarsal from growing-finishing swine. In contrast, Cromwell et al. (1972) observed a significant quadratic increase in the ash content of the second and fifth metacarpals resulting from an increase in the dietary Ca levels by .15% increments from .50 to .95%, with dietary P levels (.50 or .65%) having no apparent effect on the ash content. Ash in the epiphysis of the bone was less than that toward the diaphysis indicating that the epiphysis is more sensitive to low dietary Ca than is the shaft of the metacarpal. Similarly, Scherer et al. (1970) and Stockland and Blaylock (1973) reported that increased dietary P levels (.65%) fed to growing-finishing swine did not effect metacarpal or turbinate ash while elevated Ca level (.90%) resulted in quadratic increases in bone ash. In a study by Fammatre et al. (1977) both Ca and P levels affected bone ash when growing-finishing pigs were fed two levels of dietary Ca and P (.90/.70 or .65/.50%, respectively) up to 52 kg body weight and then continued to market weight on either .50/.40 or .65/.50%, Ca/P. There was a significant increase in bone ash content of the sixth rib, femur, metacarpal and proximal phalanx at the higher mineral level.

Hsu et al. (1976) reported the average percentage ash of the femur in gilts did not differ when P level was increased (.4 to .6%) in the presence of a constant Ca level (.65%). Mahan and Fetter (1982) observed that dietary Ca and P level (.65/.50, .80/.60 or .90/.70%, Ca/P) fed to reproducing sows for three parities failed to alter femur, rib, vertebra or humerus ash values. Doige et al. (1975) fed Ca and P levels of 50, 100 or 150% NRC levels in a 3 x 3 factorial arrangement to growing gilts and noted that low levels of Ca or P did not result in reduced bone ash provided the Ca:P ratio in the diet was maintained near 1.30:1. Reduction in bone ash was observed only in those diets Ca- or P-deficient due to an unbalanced Ca:P ratio. Likewise, no increase in metacarpal or metatarsal ash has been shown either in gilts fed 150% NRC Ca and P recommendations during growth followed by 100% NRC levels for three parities (Arthur et al., 1982b), or for gilts fed elevated Ca and P levels from breeding through five subsequent gestation-lacation cycles (Kornegay et al., 1973). This lack of dietary mineral effect on bone ash later in the life may indicate compensatory bone mineralization with increasing age.

The ash content of the femur and radius from growing boars has been shown to increase as dietary P level was elevated from .35 to .51% in the presence of a constant (.90%) Ca level (Bayley et al., 1975a,b). Schroeder et al. (1974) found that femur and third metacarpal bone ash values were not altered by an increase in the dietary Ca level (.6, .9 or 1.2%) with P maintained at .5%. Kornegay et al.

(1981a) and Kornegay and Thomas (1981) observed that boars fed diets containing Ca and P levels in excess of NRC recommendations produced metacarpal and mandible bone ash values which increased inconsistantly with the magnitude of the increases being small. Nimmo et al. (1980b) reported that percentage ash of femurs and metatarsals of growing boars increased linearly as dietary Ca and P levels increased from 100 to 200% NRC recommendations. Similar results have also been reported by Cromwell et al. (1979). Elevated metacarpal ash resulting from increased Ca and P levels (150% NRC recommendations) was observed by Kesel et al. (1982) to occur only in early growth and to not be evident as the boars approached maturity.

<u>Bone Calcium and Phosphorus Content</u>

Hsu et al. (1976) observed no effect on dry, fat free femur Ca and P levels as a result of increased dietary P (.40 to .60%) with a constant level of Ca (.72%). Conversely, van Kempen et al. (1976) reported increased Ca and P levels of the fat free radius as the dietary mineral level was increased from .53/.43 to 1.26/.70% Ca/P. Cromwell et al. (1970) reported that increased dietary Ca and P levels tended to produce increased percentage Ca and P in dry, fat free turbinates and metacarpals only during the growing phase with no such effects evident during the finishing phase. A similar lack of effect on dry, fat free metacarpal and mandible Ca and P content resulting from elevated dietary Ca and P has been reported in growing-finishing swine (Kornegay and Thomas, 1981). In agreement, Arthur et al. (1982b) observed that Ca and P levels 50% above NRC recommendations fed during the growth phase of gilts had no significant effect on the percentage Ca and P in dried, fat free metacarpals and metatarsals following three parities. Liptrap et al. (1970) reported that increasing dietary Ca levels (.6 to 1.2%) with a constant P level (.5%) for growing boars produced slight increases in the Ca content of the phalanx and no effect on the Ca and P content of the fourth metacarpal on a dry, fat free basis.

Baby pigs fed dietary Ca levels of .4, .6, .8 or 1.0% with P maintained at .6% from 3 to 9 wk of age displayed increased femur ash Ca content as the level of Ca in the diet increased (Rutledge et al., 1961). In contrast, Miller et al. (1962) reported that both the Ca and P content of humerus ash were increased in baby pigs with successive increments of dietary Ca from 0 to 1.2% of the diet with P maintained at .5%. Miller et al. (1964) observed that baby pigs fed a diet containing .8% Ca and varying levels of P (.2 to .8%) had reduced humeral ash Ca and P content on the lowest P level. Humeral ash was maximized at a dietary P level of .6%.

Nielsen et al. (1971) reported that Ca levels ranging from .48 to 1.2% of the diet with a Ca:P ratio maintained at 1.2:1 in growing pigs produced a percentage Ca and P in scapula ash that was fairly constant. Likewise, the percentage Ca and P in the ash of the humerus shaft from growing-finishing pigs was not influenced by elevated dietary Ca and P, however, the percentage Ca in the growth plate did increase with increased Ca and P level fed (Forsyth et al., 1972). Pond et al. (1975, 1978) reported that feeding growing-finishing pigs Ca and P levels above those recommended by the NRC had no effect on the Ca content of radius-ulna ash. Rib and turbinate Ca and P content in growing pigs has been reported to increase curvilinearly with increased dietary P (.34 to .74%) with Ca maintained at .85% (Harmon et al., 1967). A later study by Harmon et al. (1974b) reported no such effect on turbinate Ca and P content. Stockland and Blaylock (1973) similarly observed no effect on Ca and P content of metacarpal and turbinate ash as a result of elevated dietary Ca and P levels in growing-finishing swine.

Harmon et al. (1975) reported that sows fed diets containing .7% Ca and either .33 or .68% P during gestation followed by P levels of .45, .55 or .65% during lactation had non-significant increases in the Ca and P content of the turbinate and tenth rib ash. Kornegay et al. (1973) observed that feeding sows diets containing 10.3 and 11.0 or 15.5 and 15.0 g daily of Ca and total P, respectively, for five gestation-lactation cycles had no effect on sow metacarpal ash Ca and P levels.

Calcium and P content of the ulna of growing boars increased as dietary Ca increased from .55 to .93% with a constant Ca:P ratio of 1.2:1 (Hines et al., 1979). Further increases of dietary Ca to 1.1 or 1.3% produced no additional significant effect. Kesel et al. (1982) reported that growing boars fed 100 or 150% NRC Ca and P recommendations had elevated Ca content of metacarpal ash on the high Ca and P diet in early growth with treatment effects no longer apparent as the animals matured. Bone P was not different between boars fed 100 or 150% NRC Ca and P diets.

Mechanical Characteristics

Scherer et al. (1970) fed growing-finishing swine Ca levels of .50, .65, .80 or .95% in combination with P levels of .50 or .65% to a mean body weight of 45.5 kg after which Ca levels of .35, .50, .65 or .80% in combination with .40 or .50% dietary P were fed. Phosphorus level did not significantly affect metacarpal breaking strength while breaking strength increased linearly as dietary Ca level increased. Cromwell et al. (1972) reported increased breaking strength of the third and fourth metacarpals of growing pigs as dietary Ca level increased (.50 to .95%) with no influence on breaking strength due to increased P levels. Although observing a similar effect of increased breaking strength of metatarsals with elevated dietary Ca level, Libal et al. (1969) also reported an effect due to dietary P level. Metatarsal breaking strength was significantly increased by increasing dietary P in .10% increments from .30 to .70%. Phosphorus had a greater influence on breaking strength than did Ca within adequate levels of Ca. This result is supported by Cromwell et al. (1974) who observed that reducing the P level to growing-finishing swine reduced the force required to break the third and fourth metatarsal. Likewise, several other researchers have demonstrated increased metacarpal and metatarsal breaking strength in growing finishing pigs in response to elevated dietary levels of both Ca and P (Arthur et al., 1980; Crenshaw et al., 1979; Parker et al., 1975b; Peo et al., 1967).

Liptrap et al. (1970) reported that increasing dietary Ca from .6 to 1.2% with P maintained at .5% caused reduced breaking strength of the metacarpal in growing boars. In contrast, elevation of dietary levels of both minerals has been shown to increase metacarpal and metatarsal breaking strength in growing boars (Cromwell et al., 1979; Irlam et al., 1974). However, feeding boars Ca and P levels above those recommended by NRC had no consistent influence on metacarpal breaking strength while breaking strength was reduced when 75% of NRC-recommended P was fed (Kornegay and Thomas, 1981). Nimmo et al. (1980a) reported that peak force and stress required to break metatarsals, and therefore the elasticity of the bone, were higher for bones from growing boars on high Ca and P treatments (1.3/1.0% Ca/P) than for low Ca and P treatments (.65/.50% Ca/P). Similar results were also reported by Nimmo et al. (1980b). In addition to an increased breaking strength, Schroeder et al. (1974) reported no effect on metacarpal flexibility in boars fed varying dietary P level (.50, .75 or 1.00%) or Ca:P ratio (1.1 or 1.2:1). In contrast, Kornegay et al. (1981a) observed increased stiffness and flexural modulus values in conjunction with increased breaking strength and unaltered Young's modulus of elasticity values of metacarpals from growing boars fed 125 and 150% NRC Ca and P recommendations. Increased metacarpal breaking strength, stiffness, Young's modulus of elasticity and flexural modulus for boars fed 150% NRC Ca and P levels as compared with 100% NRC recommendations have been reported by Kesel et al. (1982).

Growing gilts fed diets containing .975/.75% Ca/P to an average weight of 92.8 kg displayed increased metatarsal breaking strength, compared to gilts fed .65/.50 Ca/P similar to reports previously presented (Nimmo et al., 1981). Arthur et al. (1982b) reported no effect on metacarpal or metatarsal breaking strength, stiffness, Young's modulus of elasticity or flexural modulus by the previous feeding of sows either 100 or 150% NRC Ca and P recommendations during growth.

Rutledge et al. (1961) reported that feeding 3 week old pigs dietary levels of .4, .6, .8 or 1.0% Ca with P maintained at .6% resulted in highly significant increases in the breaking strengths of femurs as the level of dietary Ca increased. Similar results in the baby pig have also been reported by Miller et al. (1962). Bayley et al. (1975a) observed increased femur breaking strength of growing boars as dietary P level increased (.35 to .51%) in the presence of a constant (.9%) Ca level. A second experiment showed increased femur breaking strength when a diet containing .8% Ca was fed in combination with .62% P compared with one containing .45% dietary P. Further increases to .75% or .85% P in the diet produced no additional response. This result has also been demonstrated in growing boars by Bayley et al. (1971), in baby pigs by Miller et al. (1964) and in gilts by Hsu et al. (1976). Chapman et al. (1962) reported that femur breaking strength for growing-finishing pigs increased as Ca level was increased from .2 to .8% of the diet and as P level increased from .2 to .7% with peak force maximized at .8% Ca and .6% P. Increased femur breaking strength in response to elevation of both minerals has also been reported by several other investigators (Bayley et al., 1975b; Crenshaw et al., 1979; Nimmo et al., 1980a, b; Schroeder et al., 1974).

Increased bone breaking strength as a result of elevated dietary mineral level has also been observed in the humerus (Crenshaw et al., 1979; Parker et al., 1974; Parker et al., 1975 a, b), ulna (Hines et al., 1979), radius (Bayley et al., 1975b), rib (Harmon et al., 1974a) and proximal phalange (Parker et al., 1974).

EFFECT OF RESTRICTED ENERGY INTAKE ON GROWTH PERFORMANCE

Crampton et al. (1954) fed pigs a 16% protein diet ad libitum during the growing period (16 to 50 kg body weight). During the finishing period (50 to 91 kg body weight) a 13% protein diet was fed either ad libitum or at approximately 75% of ad libitum intake. Average daily gain was lower for the limit-fed pigs, however no difference in feed efficiency was evident. In contrast, Kesel et al. (1982) reported that average daily gain was reduced and feed efficiency improved in growing boars fed 75% of ad libitum energy intake. Comparable results have also been reported in growing gilts fed this same level of energy restriction (Calabotta et al., 1982). Similar effects on feed efficiency as a result of limiting intake have been reported in growing pigs by Frape et al. (1959) and Nielsen (1964).

EFFECT OF RESTRICTED ENERGY INTAKE ON BONE

Grondalen (1974a) reported that sows fed restricted intake (80 to 90% of ad libitum intake) had longer femora and tibiae at 100 kg live weight as compared with sows fed ad libitum. The length of the vertebral column was not influenced by feeding level. Reiland (1978c) similarly observed that pigs on 50 to 60% feed restriction had limb bones which were longer and more slender than those on a higher plane of feeding. In contrast, Furugouri et al. (1981) found that restricting feed intake produced pigs with lighter, shorter and narrower limb bones than those on ad libitum intake. In a study by Arthur et al. (1982b) where gilts were fed ad libitum or 75% of ad libitum intake during growth followed by a similar level during gestation-lactation for three parities, metacarpals and metatarsals were heavier and had greater shaft diameters for previously ad-libitum fed gilts. Kesel et al. (1982) likewise indicated that metacarpal weight, length and shaft diameter were larger for boars fed ad libitum as compared with those fed 75% of ad libitum intake when examined at an equal age. However, examination of these parameters at equal body weight showed no energy level differences. Bone wall thickness was greater for boars on restricted feed intake whether examined on an equal age or body weight basis.

Arthur et al. (1982b) reported that metacarpal breaking strength was greater for sows fed ad libitum during growth as compared with those fed 75% of ad libitum intake while the stiffness, Young's modulus of elasticity and flexural modulus values of metacarpals and metatarsals were not affected by dietary energy level. Kesel et al. (1982) observed greater values for metacarpal breaking strength, stiffness and flexural modulus for boars on ad libitum intake as compared with those on 75% of ad libitum intake when examined at an equal age but not when examined at an equal body weight. Energy level influences were therefore simply reflections of treatment differences in body size.

EFFECT OF AGE ON BONE MINERAL CONTENT

The effect of age on bone mineral content has not been widely examined. In particular, a paucity of data exists concerning aging and bone trace mineral levels. A limited number of studies have been carried out on percentage ash, Ca and P changes over time, however, results are inconclusive at this time.

Early work by Hammett (1925) reported that percentage ash of the humerus and femur of male and female albino rats increased as age increased from 23 to 150 d. Furugouri et al. (1981) observed that the ash content of the mid diaphysis of femurs from Landrace and Yorkshire pigs increased until 150 d of age and then tended to plateau, while the ash content of the head of the femur increased to about 210 d. Similar increases in bone ash have been shown in metacarpals of growing boars (Kesel et al., 1982).

Cervical, thoracic, lumbar and sacral vertebrae, plus rib and femur bones from cattle 89 to 2783 d of age indicated increased Ca and P as a percentage of ash as age increased (Mello et al., 1978). Arthur et al. (1982b) observed similar results in sows carried through three parities. Hansard et al. (1954), using 36 Hereford cattle ranging in age from 10 d to 5700 d, reported that the Ca content of the metatarsal, rib and mandible ash reached a maximum at approximately 540 d and plateaued thereafter. The vertebrae continued to increase over time. Brown et al. (1972) examined Ca and P levels of the turbinates, femur, ulna, radius, humerus, fibula and tibia in growing pigs at 56, 84, 112, and 168 d of age and provided differing results. Mineralization patterns were unique for each bone, but in general, Ca and P concentrations expressed as a percent of bone peaked during the 56 to 84 d period followed by decreased levels. In further contrast, Kesel et al. (1982) reported that Ca, expressed as a percentage of metacarpal ash, increased from 80 to 150 d of age followed by a decrease from 150 to 220 d of age, while P exhibited a linear decrease throughout the study.

ROLE OF TRACE MINERALS AND VITAMINS IN BONE DEVELOPMENT

Copper

Copper effects bone development primarily through its association in the Cu enzyme amine or lysyl oxidase (Underwood, 1977). This enzyme plays an important role in the oxidation of epsilon-amino groups of lysine side chains necessary for cross-linkage of the polypeptide chains of elastin and collagen (Pike and Brown, 1975). A deficiency of Cu therefore results in weak, unstable bone collagen. Underwood (1977) reported thinned cortices, broadened epiphyseal cartilage and a low level of osteoblastic activity in bones from Cu-deficient pigs.

Zinc

Zinc deficiency in young chicks has been shown to produce retarded growth, shortening and thickening of leg bones and enlargement of the hock joints (Scott et al., 1976). Underwood (1977) reported that Zn-deficient chicks and rats develop abnormal epiphyseal plates in growing bones. Chondrocytes near the blood supply were surrounded by more extracellular matrix. Zinc is a component in several metaloenzymes but its functional role in bone development remains unclear (Pike and Brown, 1975).

Manganese

Bone malformations, most evident as crooked legs, have resulted from feeding rabbits diets low in Mn (Maynard and Loosli, 1975). Such effects have also been seen in rats, chicks and swine (Pike and Brown, 1975). Scott et al. (1976) reported perosis to be the most dramatic effect of a Mn deficiency in young chicks. This syndrome is characterized by enlargement and malformation of the tibometatarsal joint, twisting and bending of the distal end of the tibia and the proximal end of the tarsometatarsus, thickening and shortening of the leg bones and slippage of the Achilles tendon from its condyles.

The role of Mn in bone deformation is as an essential component for normal organic matrix development (Scott et al., 1976). Underwood (1977) reported that this fact is due to the ability of Mn to activate the glycosyltransferases. These enzymes are important in polysaccharide and glyoprotein synthesis.

Trace Mineral Interactions

Interactions which involve trace minerals can effect the ability of those minerals to properly perform their functions in bone development.

Hoekstra et al. (1956) reported that addition of Ca to swine diets in the form of 2% bone meal intensified the development of perakeratosis. This condition was largely eliminated by supplementation of 50 ppm Zn. Similar observations were made by Hoefer et al. (1960). This interference in Zn function by Ca was reported by Forbes (1960) to most probably occur at the cellular level. Utilizing ^{65}Zn, Newland et al. (1958) hypothesized that high Ca levels in the diet may promote a higher rate of Zn metabolism in pigs.

Underwood (1977) reported a mutual antagonism to be present between Cu and Zn. High Zn intakes depress Cu absorption while Cu absorption is greatly increased in Zn deficiency. This result is supported by Ritchie et al. (1963) who observed that supplemental Zn offered considerable protection against Cu toxicity in pigs fed a high Cu diet.

A similar antagonism in absorption is present between Cu and Fe (Underwood, 1977). This result has been demonstrated by Hedges and Kornegay (1973) in work feeding growth promoting levels of Cu to swine. Reduced hemoglobin and serum Fe levels resulted from high dietary Cu (257 ppm) and was corrected by supplemental Fe (312 ppm).

Vitamin A

One of the many functions of vitamin A is to ensure proper growth of the cartilage matrix upon which bone is deposited (Scott et al., 1976). This is accomplished through a control over the activity of the osteoclasts and osteoblasts of the epithelial cartilage (Maynard and Loosli, 1975). Vaughan (1975) reported that increased numbers of osteoclasts are associated with areas of resorption. This increase is accomplished by vitamin A stimulating the activity of existing osteoclasts and subsequent stimulation of differentiation of progenitor cells to increase the number of osteoclasts (Vaughan, 1975). Excess vitamin A results in cartilage matrix degredation due to release of cathepsin from lysosomes (Scott et al., 1976). Vitamin A deficiency results in cesation of bone formation and abnormalities in shape due to abnormal growth, maturation and degeneration patterns of the cartilage cells (Pike and Brown, 1975).

<u>Vitamin D</u>

Early workers (Dowdle et al., 1960; Harrison and Harrison, 1960; Schachter and Rosen, 1959) found that ^{45}Ca could be transported across isolated rat intestinal wall against a concentration gradient. This was later shown to be due to the ability of vitamin D to stimulate production of Ca binding protein which facilitates Ca transport across the intestinal mucosa (Corradino and Wasserman, 1970; Mac Gregor et al., 1970; Taylor and Wasserman, 1970; Wasserman and Taylor, 1968). In addition to its role in intestinal Ca absorption, vitamin D, along with parathyroid hormone, functions in the release of Ca^{++} and HPO^{-4} from the bone to the plasma (Scott et al., 1976).

<u>B Vitamins</u>

The B vitamins do not function directly in bone development but do have an indirect effect on skeletal growth. Thiamin, riboflavin, pyridoxine and cyanocobalamin all function in nutrient utilization and energy metabolism pathways which are essential for normal growth processes.

One of the principal functions of thiamin is as the coenzyme thiamin pyrophosphate or cocarboxylase (Maynard and Loosli, 1975). It is the coenzyme for all enzymatic decarboxylations of alpha-keto acids to carboxylic acids such as pyruvic acid to acetyl CoA and alpha-ketoglutarate to succinyl CoA. Thiamin is also involved in a transketolase reaction of the pentose phosphate shunt in which an alpha-keto group is transferred from xyulose-5-phosphate to ribose-5-phosphate to form sedohepulose-7-phosphate and glyceraldehyde-3-phosphate (Pike and Brown, 1975).

Several enzymes have riboflavin as the prosthetic group. These include cytochrome reductase, lipoamide dehydrogenase, xanthine oxidase, l-amino acid oxidase and histaminase which are all involved in oxidation-reduction reactions in cellular respiration (Scott et al., 1976).

These serve as carriers in the electron transport system for the eventual production of the high energy compound adenosine triphosphate.

The function of pyridoxine is primarily as the coenzyme pyridoxal phosphate. Pridoxal phosphate functions in nearly all amino acid metabolism reactions including transamination, desulfhydration, decarboxylation, amine oxidation and deamination (Pike and Brown, 1975). The importance of pyridoxine for proper metabolic utilization of amino acids is therefore quite evident.

Propionyl CoA is an important intermediate in amino acid metabolism and is also produced during the oxidation of odd-numbered fatty acid chains (McGilvery and Goldstein, 1979). Propionyl CoA is converted to methylmalonyl CoA via propionyl CoA carboxylase. Cyanocobalamin is an essential component of the coenzyme methylmalonyl CoA carbonylmutase which is responsible for the conversion of methylmalonyl CoA to succinyl CoA (Scott et al., 1976).

EFFECT OF NUTRITION ON FOOT DEVELOPMENT

Calabotta et al. (1982) reported that feeding of ad libitum or 75% of ad libitum intakes did not affect toe size of gilts during growth when they were examined at similar body weights. Toe size was also not influenced by feeding 150% NRC Ca and P recommendations. Following three parities, Arthur et al. (1982a) reported that the sows which were fed ad libitum during growth had larger front toe than those limit-fed, while those previously fed 150% NRC Ca and P levels had larger hind toes as compared with the 100% NRC Ca and P levels. The combination of ad libitum intake and 150% NRC Ca and P recommendations produced the largest toes.

Kornegay et al. (1982b) reported that boars fed ad libitum had larger toes as compared with boars fed 75% of ad libitum intake, however, when examined at an equal body weight, differences were no longer apparent. Elevated dietary Ca and P levels (150% NRC) had no effect on foot size. Likewise, Kornegay et al. (1981a) observed no influence on toe size of developing boars by feeding varying Ca and P levels (100, 125 or 150% NRC levels) in combination with two dietary protein sequences (16-14% or 18-16%).

USE OF BENDING TESTS ON BONES

In order to perform its role as a load-bearing structural member, bone must possess adequate strength and stiffness. Characterization of the mechanical properties of the bone has therefore become a useful tool for evaluating its structural capabilities.

Flexure or bending tests utilizing a simple three-point loading system have been widely used to examine the mechanical characteristics of bone specimens (Wilson and Baker, 1981). Three-point loading involves placing the bone on two supports and applying a load from above midway between the two supports. The main advantage of this system is the simple methodology allowing for many samples to be analyzed in a short period of time. However, several inherent problems do exist which can lead to erroneous results. Wilson and Baker (1981) have reported that often the cross-sectional area is assumed to be constant over the length of the bone and no variations in elastic properties are considered. This assumption for a biological material will obviously lead to error. As pointed out by Evans (1973), during bending, all the material between the convex surface of the bone and the neutral axis is under tensile stress while the material between the concave surface and the neutral axis is under compressive stress. The central axis is under neither compression nor tension but is subject to shear stress (Evans, 1973). Wilson and Baker (1981) reported that ignoring the shear factor, particularly when the length to diameter ratio of the sample is less than 10, can cause significant discrepancies in the observed results of mechanical tests.

Terms and Definitions

Since the shape of the cross-section of the sample in a bending test will influence its response to a force, this property needs to be considered. The moment of inertia is a calculated estimate of the area over which the force is applied and also the shape over which that area is distributed (Crenshaw et al., 1981a). Crenshaw et al. (1981b) reported that the equation for the moment of inertia of an elipse closely fits the shape of the femur and humerus, while that of an elliptical quadrant more closely fits the metacarpal and metatarsal.

Stress is a measure of the force applied per unit area (Swanson, 1971). The moment of inertia and the test length of the bone (that distance between the supporting fulcra) are used to estimate the surface over which the force is applied (Crenshaw et al., 1981a). Strain is the change in bone length resulting from the application of a force relative to the original bone length (Evans, 1973). Strain is therefore a unitless measure.

The elasticity of the bone, or its ability to return to its original shape after being deformed by a force (Crenshaw et al., 1981a), can be estimated by the modulus of elasticity. The modulus of elasticity is the stress to strain ratio (Crenshaw et al., 1981b) and thus measures the force per unit area required to produce a given deformation per unit bone length. The modulus of elasticity must be determined within the elastic region within which removal of stress is accompanied by disappearance of strain (Swanson, 1971). Beyond the elastic region is the plastic region where removal of stress is accompanied by disappearance of only a portion of the strain, therefore permanant damage has resulted (Swanson, 1971).

Stiffness is defined as the capability to resist bending (Evans, 1973) and can be estimated by the force per unit of deflection in the sample. Flexural modulus is a measure similar to stiffness except bone test length is taken into account. This allows comparison between samples of different test length and structural material.

<u>Effect of Sample Handling and Preparation</u>

Freezing is a common method of sample storage. Swanson (1971) reported that frozen storage for up to 4 wk at -20 C had no effect on the mechanical properties of bone. The temperature at testing does, however, influence the test results. As the temperature increases the total deflection to the failure point increases (Swanson, 1971).

Drying of the bone prior to testing can influence the elasticity, deflection and strength parameters of the sample (Crenshaw et al., 1981a). Miller et al. (1965) reported that wet femurs from young pigs displayed a greater capacity for bending than those which were dried. This result is further supported by Yamada (1973) who reported that the ultimate deflection of air-dried bone is 80% of that for wet bones while the ultimate strength of dried bone is 1.35 times that of wet bone. In contrast, Kornegay et al. (1981a) observed greater breaking load in wet metacarpal as compared to dry metacarpal. In agreement, however, dried metacarpals were found to exhibit greater stiffness, Young's modulus of elasticity and flexural modulus values. Removal of water by drying may decrease the capability of water to act as a lubricant in the bone matrix during deformation (Swanson, 1973).

STRUCTURAL UNSOUNDNESS

Structural unsoundness or leg weakness is a current problem facing the swine industry. It is a condition that is difficult to study owing to its complex etiology. One of the leading causes of unsoundness is currently thought to be osteochondrosis (Grondalen, 1974d; Nakano et al., 1979; Reiland, 1978a). Osteochondrosis has been defined as a non-infectious degenerative condition of cartilage and bone arising from a disturbance of endochondral ossification (Grondalen, 1974d). Several nutritional, genetic, environmental and infectious factors have been implicated as important etiological components of structural unsoundness, a discussion of which is presented.

Nutritional Factors

Vaughan (1971) reported that the relatively common occurance of leg weakness in swine maintained at a high level of nutrition suggests that early maturity and rapid growth are important etiological factors. The author hypothesized that the inability of bone growth to keep pace with body weight thereby places increased stress on the legs. Walker et al. (1966) used the addition of lead saddles or the strapping of one foreleg to the abdomen to study the effect of increased weight load on joint lesions. The severity of lesions of the distal ulnar epiphysis were increased suggesting that physical stress caused by increased weight may be an important etiological factor. With a restricted dietary intake (50 to 60% of ad libitum intake) and reduced growth rate, osteochondrosis was very mild or not evident while rapid growth (ad libitum intake) was associated with increased frequency, severity and clinical signs of osteochondrosis (Reiland, 1978c). Similar results have been presented by Grondalen (1974b) using 20 to 30% feed restriction, and by Walker and Jones (1962) feeding 80 and 60% of ad libitum intake. In contrast, Fell et al. (1970) and Grondalen (1974a) reported no effect of restricted feed intake on the prevalence of bone and joint lesions. Nakano et al. (1979) reported that the feeding of growing-finishing swine ad libitum or 70% of ad libitum intake did not significantly affect visual appraisal of locomatory ability although every pig showed some evidence of disturbed endochondral ossification or cartilage lesion in at least one joint. Similarly, ad libitum and 75% of ad libitum intake had no effect on overall structural soundness of gilts during growth (Calabotta et al., 1982) or on structural soundness, incidence and severity of foot lesions following three parities (Arthur et al., 1982a). Kornegay et al. (1982b), however, reported that ad libitum-fed boars appeared more structurally sound with fewer locomatory anomalies than boars fed 75% of ad libitum intake although pad and horn lesions were not affected.

Dietary levels of Ca and P have been implicated as a potential factor in leg weakness. Storts and Koestner (1965) reported that 1 d old pigs fed a diet deficient in Ca and P (.26 and .14% of the diet, respectively) for 6 wk developed skeletal lesions, multiple bone fractures and thin, soft bones. Elevation of dietary Ca/P levels for gilts from .65/.50 to .975/.75% resulted in higher rear foot and leg soundness scores indicating a reduction in overall soundness with high Ca and P levels (Nimmo et al., 1981). These results conflict with those of Grondalen (1974a) who observed a nonsignificant reduction of incidence and severity of foot lesions with elevated dietary Ca and P levels. The majority of research, however, has indicated no effect of increased Ca and P levels in the diet on overall structural soundness observations or foot lesion development (Arthur et al., 1982a; Calabott et al., 1982; Grondalen, 1976; Kornegay et al., 1981, 1982; Kornegay and Thomas, 1981; Nimmo et al., 1980b; Reiland, 1978b).

Elevated dietary protein level has been reported to have no beneficial effect on reducing the incidence of foot lesions or the degree of leg weakness in pigs (Grondalen, 1974a, b; Reiland, 1978b). Similarly, the feeding of a

16-14 or 18-16% dietary protein sequence to growing boars had no influence on soundness scores or toe lesions (Kornegay et al., 1981a).

Vitamin A, riboflavin, pantothenic acid, biotin and vitamin E have all been incriminated as possible effectors in lameness (Penny et al., 1963). Dobson (1969) produced hypervitaminosis A in growing pigs by oral administration of 344,000 ug of vitamin A between 3 and 7 d of age. Piglets developed weak pasterns along with a significant difference in length between medial and lateral metatarsals. Femur and tibia were reduced to three-quarters and two-thirds of normal length, respectively, with rough, pitted articular surfaces. Pryor et al. (1969) used similar vitamin A levels and observed much the same results. Pigs spent a majority of the time sitting, and when forced to stand assumed a posture with fore and hind feet close together and back arched. In contrast, Reiland (1978b) reported that hyper- or hypovitaminosis A failed to cause a noticeable difference on the incidence or severity of osteochondrosis. Grondalen (1974b) altered total vitamin content of the diet and found no influence on the degree of leg weakness.

Genetic Factors

Early work by Nordby (1939) indicated that toes of uneven size can result in lameness problems due to unequal distribution of weight on the toes. He reported that the frequency and magnitude of the variation in toe size can be reduced by careful selection. Grondalen (1974c) reported that heredity may play a role in joint lesions and subsequent onset of leg weakness partly due to inherited differences in joint shape while poor locomatory ability may be partly due to inherited shape of the hindquarters.

Grondalen (1974d) and Grondalen and Vangen (1974) observed that the degree and incidence of skeletal lesions was higher in Landrace pigs selected for rapid growth rate and thin backfat than for Landrace pigs selected for slow growth and thick backfat. In contrast, Bereskin (1977) reported that pigs with faster early growth, less backfat and larger loin eye areas generally exhibited sounder feet and legs so the selection of leaner and meatier pigs is not necessarily contradictory to selection for improved structural soundness. Bereskin (1977) further noted that unsound feet and legs are moderately heritable, so the condition could be largely eliminated in two to four generations of careful selection. In direct conflict with his earlier work, Bereskin (1979) reported that positive genetic correlations of backfat thickness with improved structural soundness scores, and negative correlations of loin eye area with improved soundness scores will make it difficult to simultaneously select for leaner, more muscular pigs and improved structural soundness. Similarly, Smith (1966) observed rather low (h^2 < .25) heritability of leg weakness based on visual soundness scores and stated that improvement through selection would be a slow and difficult process.

<u>Environmental Considerations</u>

The practice of total confinement has been implicated in the development and intensification of unsoundness. Elliot and Doige (1973) reported that pigs individually penned in an area of insufficient size to allow normal exercise had a higher incidence of lameness or posterior weakness. The authors hypothesized that this could in part be a result of a lack of intermittent compression of articular cartilage which is important for the diffusion of nutrients from the synovial fluid into the cartilage. Significant degree of osteoporosis was also noted in the cortical bone. Likewise, Fredeen and Sather (1978) reported up to 50% of boars, barrows and gilts raised in total confinement on concrete display moderate to severe articular cartilage damage with the degree of damage directly related to the duration of the total confinement.

Perrin et al. (1978) observed no differences in the incidence or severity or cartilage lesions between boars housed on concrete floors with wood shavings as bedding or on dirt with cereal straw bedding. In contrast, a greater number of crippled sows were noted in sows housed in dirt lots as compared with sows housed in confinement on concrete (Kornegay et al., 1973). Rough floor surfaces have been shown to produce the highest incidence of foot lesions and lameness (Penny et al., 1965). Smith and Mitchell (1976) reported that slippery and abrasive concrete floors in farrowing pens produced piglets with bruising of the sole, swellings of one or more of the digits, or the hock or knee joints and necrosis of the skin over the knee joints. Smith (1981) observed that mild bruising of the sole usually occurs in 100% of piglets within 24 hr of birth and may lead to erosion of both the soft tissue and horny region of the sole. Bruising and erosion may also occur on the lateral and medial aspects of the ball of the heel. In addition, damp, dirty conditions may aggravate erosive-type lesions by softening the horn and predisposing the foot to bruising, minor injury and excessive wear on hard surfaces such as concrete (Penny et al., 1963).

Slatted floors with sharp edges and wide gaps (2.5 to 3.2 cm) have been shown to produce foot and leg injuries leading to partial or complete posterior paralysis in sows (Smith and Robertson, 1971). Fritschen et al. (1972)

reported that pigs housed on 100% slatted floors displayed increased wear on the foot compared with pigs on 25% slatted floors as indicated by shorter claws. This wear resulted in more foot injuries on the 100% slatted floors. Newton et al. (1980) reported that hoof and sole length of pigs housed on concrete slats were shortest followed by those on steel, aluminum and plastic slats in order of increasing length. The investigators speculated that the degree of traction, roughness and abrasiveness of flooring may be the main factors involved in foot injury with slat width having little effect. Floors that provide low levels of traction along with uneven surfaces produce the greatest degree of lesions to the volar surface of the foot while those providing higher traction levels produce more hoof cracks and less severe pad lesions (Newton et al., 1980).

Infectious Agents

Duthie and Lancaster (1964) concluded from field studies and feeding experiments that leg weakness is not primarily of genetic or nutritional origin but more likely due to an infectious agent. Apparently normal animals were found to have joint lesions similar to animals displaying mild leg weakness leading the authors to hypothesize that some predisposing factor may be involved which changes an incipient condition to a clinical one. Penny et al. (1963)

reported that chronic arthritis can be caused by Erysipelothrix rhusiopathae or less commonly by Mycobacterium tuberculosis, polyserostitis by Haemophilus suis and pleuropneumonia-like organisms, and paraplegic-type lameness by Corynebacterium pyogenes, streptocci and Fusiformis necrophorus. Reiland (1978a) observed that Erysipelothrix insidiosa was a common infectious agent associated with chronic arthritis in skeletons of breeding pigs slaughtered because of leg weakness.

Chapter III

THE EFFECT OF RESTRICTED ENERGY INTAKE AND ELEVATED MINERALS AND VITAMINS ON GROWTH PERFORMANCE, FOOT AND LEG MEASUREMENTS AND SOUNDNESS SCORES OF GROWING BOARS

Summary

The effects of dietary energy level (ad libitum and 75% of ad libitum) and mineral-vitamin intake (100 and 150% of the National Research Council recommendations) on foot and leg development, incidence and severity of foot lesions and structural soundness scores were studied utilizing a 2 x 2 factorial arrangement of treatments. Twenty boars were assigned to each treatment at 5 wk of age. Fifteen of the 20 boars in each group were necropsied at 15 d intervals beginning at 120 d of age (85 d on test), while five boars from each group were continued on test to 330 d of age (295 d on test) before necropsy. Foot and leg measurements were taken and pad and horn lesions were characterized at 0 (initially), 87, 174 and 255 d on test and at necropsy. Structural soundness scores were assigned at 87 and 255 d on test. Toe measurements increased over time with little effect of elevated mineral-vitamin levels. At an equal age,

ad libitum-fed boars had larger foot measurements; however, weight-correction often reversed this effect producing larger values for limit-fed boars relative to body weight at 85 and 190 d on test. Outside toe measurements were larger than inside toe measurements. The hind outside horn length, toe length and horn height exhibited a faster growth rate relative to the other toes, particularly beyond 190 d on test. Incidence and severity of pad and horn lesions were generally not affected by the dietary treatments. The incidence of lesion was generally greatest for the hind outside toe. Limit-fed boars had significantly better soundness scores compared to ad libitum-fed boars while dietary mineral-vitamin level had no effect. The findings of this study indicate that elevating mineral and vitamin levels above those recommended by the NRC has no effect on foot and leg development or the resulting structural soundness. Restricting feed intake similarly has little effect on foot and leg development but did produce boars that were more structurally sound in appearance.

Introduction

Structural unsoundness or leg weakness is a condition difficult to study due to its complex etiology. Vaughan (1971) suggested that early maturity and rapid growth rate may be important etiological factors in the development of unsoundness. This hypothesis was supported by the work of Grondalen (1974b), Reiland (1978c) and Walker and Jones (1962) who fed restricted intakes to growing swine and observed reduced evidence of lameness. In contrast, several other workers have reported no beneficial effect of such an energy restriction (Arthur et al., 1982; Calabotta et al., 1982; Fell et al., 1970; Kornegay et al., 1982b; Nakano et al., 1979) which raises doubt as to the validity of reduced growth resulting in improved structural soundness at maturity.

Nordby (1939) reported that toes of unequal size can result in lameness due to unequal distribution of weight on the toes. This fact may account for the greater injury which is observed on the pad and horn of the outside toe (Fritschen et al., 1972; Penny et al., 1963).

The present study was undertaken to study the effects of reduced growth rate and elevated dietary mineral and vitamin levels (150% NRC recommendations) on foot and leg development, incidence and severity of foot lesions and overall structural soundness of growing boars raised in total confinement.

Experimental Procedures

Eighty crossbred boars weaned at 4 wk of age were assigned (20/treatment) at 5 wk of age to a 2 x 2 factorial arrangement of treatments (ad libitum vs 75% of ad libitum and 100 vs 150% NRC recommended daily minerals and vitamins). Boars were randomly assigned to dietary treatments from outcome groups based on weight and litter. A feed intake curve obtained in a previous study (Calabotta et al., 1982) under similar conditions was used to predict the intake of the ad libitum-fed boars. Limit-fed boars were allowed 75% of the predicted ad libitum intake. Adjustments to feed intake were made every 2 wk. Energy was made the sole limiting nutrient by elevating the levels of all other nutrients in the diet of the limit-fed boars thus assuring a constant daily intake of these dietary components. Diet composition and feeding schedules are indicated in table 1. Water was provided ad libitum. Boars were vaccinated against erysipelas at approximately 4 wk of age. Boars were housed on expanded metal floors to approximately 25 kg and subsequently on solid concrete.

Fifteen of the 20 boars in each group were necropsied at 15 d intervals beginning at 120 d of age (85 d on test). Five boars from each group were fed to 330 d of age (295 d on test) before necropsy. Each boar was randomly assigned

TABLE 1. COMPOSITION OF DIETS

Ingredients	100% NRC										150% NRC									
	Ad libitum					75% of ad libitum					Ad libitum					75% of ad libitum				
Phase[a]	I	II	III	IV	V	I	II	III	IV	V	I	II	III	IV	V	I	II	III	IV	V
Corn (4-02-931)	59.64	73.91	79.28	79.52	84.78	41.92	57.91	65.01	65.35	72.43	57.65	72.27	72.72	78.05	83.45	39.21	55.47	62.94	63.40	70.68
Soybean meal (5-04-612)	27.93	23.70	18.62	18.56	13.47	44.74	38.94	32.14	32.06	25.21	28.30	24.00	18.89	18.82	13.73	45.26	39.42	32 49	32.41	25.52
Dried whole whey (4-01-182)	10.00					10.00					10.00					10.00				
Defluorinated phosphate (6-01-780)	1.03	1.09	.90	.62	.44	1.83	1.81	1.61	1.20	.95	2.72	2.66	2.30	1.91	1.56	4.07	3.87	3.45	2.89	2.46
Limestone (6-02-632)	.75	.58	.64	.75	.81	.65	.43	.49	.65	.74	.36	.13	.25	.40	.52	.18			.20	.34
Salt (6-14-013)	.30	.30	.30	.30	.30	.40	.40	.40	.40	.40	.45	.45	.45	.45	.45	.60	.60	.60	.60	.60
Trace mineral premix[b]	.10	.08	.06	.05	.05	.13	.10	.08	.07	.07	.15	.12	.09	.07	.07	.19	.15	.12	.10	.10
Vitamin-Selenium premix[c]	.25	.25	.20	.20	.15	.33	.33	.27	.27	.20	.37	.37	.30	.30	.22	.49	.49	.40	.40	.30
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Calculated																				
Protein, %	20.0	18.0	16.0	16.0	14.0	26.6	24.0	21.3	21.3	18.6	20.0	18.0	16.0	16.0	14.0	26.6	24.0	21.3	21.3	18.6
Calcium, %	.80	.65	.60	.55	.50	1.06	.86	.80	.73	.67	1.20	.98	.90	.83	.75	1.60	1.30	1.20	1.10	1.00
Phosphorus, %	.60	.55	.50	.45	.40	.80	.73	.67	.60	.53	.90	.83	.75	.68	.60	1.20	1.10	1.00	.90	.80
Magnesium, %	.159	.153	.145	.145	.138	.184	.175	.164	.164	.155	.159	.151	.138	.144	.137	.182	.173	.163	.163	.154
Copper, ppm	27.17	19.92	16.05	14.96	13.27	35.97	27.11	22.68	21.56	19.31	28.73	24.37	19.23	17.19	15.52	42.66	32.70	27.13	24.92	24.37
Zinc, ppm	218.5	178.1	136.3	116.3	114.5	284.3	223.3	181.0	161.0	158.6	318.5	258.0	195.8	156.3	154.5	404.3	323.3	260.9	220.9	218.6
Iron, ppm	167.4	134.3	110.1	100.1	95.8	211.4	167.0	141.3	131.3	125.6	217.1	174.1	138.1	119.9	115.7	271.0	216.7	181.0	161.1	155.4
Manganese, ppm	66.3	54.2	42.1	36.6	35.4	86.5	68.6	56.1	50.6	49.1	93.2	76.2	58.3	47.6	46.4	119.5	96.1	78.1	67.1	65.6
Analyzed																				
Protein, %	19.1	17.4	15.2	15.6	13.6	23.0	22.6	19.8	20.7	18.4	19.6	16.9	15.1	15.4	13.4	24.5	22.8	20.1	20.2	18.1
Calcium, %	.69	.70	.63	.62	.54	.88	.90	.79	.75	.77	1.05	.93	.88	.86	.76	1.52	1.35	1.08	1.13	1.00
Phosphorus, %	.45	.52	.50	.50	.39	.68	.73	.65	.62	.54	.80	.77	.71	.64	.58	1.20	1.00	.88	.82	.76
Magnesium, %	.157	.165	.136	.140	.133	.175	.187	.164	.160	.156	.163	.160	.143	.139	.136	.201	.188	.154	.164	.158
Copper, ppm	17.34	15.69	12.16	15.32	10.50	24.11	19.37	19.69	14.42	18.00	23.31	19.02	18.11	16.01	14.38	32.61	24.67	19.07	22.00	19.63
Zinc, ppm	177.8	197.2	168.7	145.5	148.7	292.3	248.3	180.7	146.8	197.5	305.6	252.4	185.3	159.7	187.5	421.6	310.3	232.7	308.4	251.2
Iron, ppm	178.9	129.9	114.1	109.1	125.0	198.2	178.9	194.4	160.9	235.0	214.3	219.4	178.3	137.0	250.0	301.2	384.9	236.1	297.2	169.9
Manganese, ppm	70.2	59.9	52.6	49.9	44.4	83.7	82.5	67.6	47.4	63.7	97.0	87.2	59.5	49.9	57.6	135.5	107.4	78.7	72.2	74.5

[a] Phase I, initial to 10 kg; Phase II, 10 to 20 kg; Phase III, 20 to 35 kg; Phase IV, 35 to 60 kg; Phase V, 60 kg to termination of experiment.
[b] Content (%): 20 Zn, 10 Fe, 5.5 Mn, 1.1 Cu and .15 I.
[c] Supplied (per kilogram of premix): 1.76 g riboflavin, 8.8 g pantothenic acid, 8.8 g niacin, 8.8 mg vitamin B_{12}, 176 g choline chloride, 1,760,000 IU vitamin A, 176,000 IU vitamin D_3, 4,400 IU vitamin E, 440 mg menadione dimethylprimidinol bisulfite (MPB) and 40 mg Se.

to have either the right front and left rear feet or the left front and right rear feet measured and characterized at initiation of dietary treatments, three intervals thereafter (87, 174 and 255 d on test) and at necropsy. Foot and leg measurements and characterization of pad and horn lesions were conducted as described by Calabotta et al. (1982) (appendix figure 1; appendix tables 1 and 2.) Three animal scientists, unaware of dietary treatment, scored each boar for overall structural soundness at approximately 87 and 255 d on test. Scores were assigned on a scale of 1 to 15 with 1 indicating very good overall soundness and 15 indicating severe structural unsoundness. Individual soundness scores for each period were then averaged to obtain an average committee score for each boar.

The micro Kjeldahl method of nitrogen determination was used to determine the protein content of the feed. Following wet-ashing of the diets, mineral content, with the exception of P, was analyzed using a Perkin-Elmer 403 atomic absorption spectrophotometer. Inorganic P was determined by a colorimetric procedure (Fiske and Subbarow, 1925).

Changes in dependent variables over the course of the study were evaluated by linear and quadratic regression on days on test. Treatment effects were evaluated by testing the homogenity of the regression equations across energy levels (E), mineral-vitamin levels (M) and E x M subclasses (Snedecor and Cochran, 1967). Calculations were performed with the general linear models procedure of the Statistical Analysis System (Barr et al., 1979). For traits measured only at necropsy the specific statistical model was:

$$Y_{ijk} = b_o + (\bar{b}_1 + b_{1i} + b_{1j} + b_{1ij})T_{ijk} + (\bar{b}_2 + b_{2i} + b_{2j} + b_{2ij})T^2_{ijk} + e_{ijk} \quad (1)$$

where Y_{ijk} is the value observed for the kth pig fed the ith energy level and the jth mineral-vitamin level; T_{ijk} is days on test; b_o is the regression intercept and is the same for all treatments; $\bar{b}_1$ and $\bar{b}_2$ are average linear and quadratic regression coefficients relating Y and T; the remaining b values are subclass regression constants corresponding to specific treatments; and e_{ijk} is a random, residual deviation from the regression equation. In addition to testing the homogeneity of the curves, differences between energy levels and between mineral-vitamin levels were estimated from the regression equations at 85, 190 and 295 d on test and were tested by t-tests.

Differences among treatments in the pattern of change in measured variables over time will often correspond to differences in the pattern of body weight change over time. This result is especially prevalent when treatment effects involve differences in rate of energy intake. Thus, the observed differences in measured variables may simply reflect differences in body weight at a given age. In general, differences in measured variables at a constant age can be partitioned, conceptually at least, into a component that is attributable to treatment differences in body weight and a component that is independent of weight.

To attempt such a partition, the overall relationship between each dependent variable and body weight was first defined using the model:

$$Y_i = C_o + C_1W_i + C_2W_i^2 + e_i$$

where Y_i is the value for the ith pig; W_i is the weight of that pig at necropsy; C_o, C_1 and C_2 are regression constants; and e is a random, residual deviation from the regression line. Predicted values $(\hat{Y})$, for dependent variables were calculated for each pig based on the weight of that pig, and all observations were subsequently expressed as deviations from predicted values $(Y-\hat{Y})$. The deviations were then analyzed using model (1), and the resulting regression equations were used to predict the extent by which observed treatment differences at 85, 190 and 295 d differed from those expected from body weight differences at those ages. Weight-corrected treatment differences are reported mathematically as $(\overline{Y}_1 - \overline{Y}_2) - (\hat{Y}_1 - \hat{Y}_2)$, or as the deviation of the observed treatment differences from the expected treatment difference based on weight. For example, boars fed ad libitum for 190 d had front inside toes which tended to be .58 mm wider than the toes of limit-fed boars (table 3); however, this difference was 1.23 mm less ($P<.05$) than would be expected based on the 22.1 kg difference in body weight of these boars.

Effects of time for variable measured on the same pig at several ages were analyzed by nested analysis of variance and were adjusted for individual pig differences by including an intercept term specific to the individual pigs in model (1). Differences between inside and outside and front and hind legs were also analyzed in a nested analysis.

Pad and horn scores of each toe were supplementally analyzed to describe the incidence and severity of lesions. The incidence of lesions was defined as the percentage of the total number of boars characterized that exhibited lesions. Severity of pad and horn lesions was evaluated after the elimination of observations with a score of zero. Main effects and the interaction of energy x mineral-vitamin levels were tested at each time period by analysis of variance, and least squares means were calculated. Pad and horn variables and soundness score least squares means were adjusted for age or body weight. With the exception of soundness scores, age and weight adjustment did not affect the results. Therefore unadjusted means are presented.

Results and Discussion

Growth performance.

The growth performance data is presented in table 2. Since boars within a treatment were group fed the values represent pen means and are therefore not statistically analyzed. As a result, conclusions drawn from this data must be general in nature.

Average daily gain was greater for the ad libitum-fed boars at each phase and overall, while mineral-vitamin level had little effect on average daily gain. Overall average daily feed intake of the limit-fed boars was approximately 77% that of the ad libitum-fed boars which is very close to the desired 25% feed restriction. Average daily feed intake did not differ between mineral-vitamin levels. Feed efficiency appeared to favor the limit-fed boars at phases I, II and III and the ad libitum-fed boars at phases IV and V resulting in little difference in overall feed efficiency. A slight improvement in feed efficiency was evident for the 150% mineral-vitamin level at period II, but during periods III, IV and V, feed efficiency was better for the 100% mineral-vitamin level with little overall effect.

Elevated Ca and P levels above NRC recommendations have been reported to have no effect on average daily feed intake, average daily gain or feed efficiency of growing

TABLE 2. PERFORMANCE DATA FOR BOARS FED TWO LEVELS OF ENERGY AND TWO LEVELS OF MINERALS AND VITAMINS[a]

	Energy		Mineral and Vitamin	
	Ad libitum	75% Ad libitum	100%	150%
Beginning body wt, (kg)				
Phase I	6.5	6.5	6.5	6.5
II	11.7	10.1	10.9	10.9
III	22.9	20.5	20.4	22.9
IV	49.0	52.0	49.4	51.6
V	61.1	60.8	60.3	61.6
Average daily gain (kg)				
Phase I	.25	.17	.21	.21
II	.53	.51	.45	.59
I and II	.39	.33	.33	.39
III	.60	.55	.58	.57
I-III	.49	.45	.46	.48
IV	.87	.62	.76	.72
I-IV	.54	.47	.50	.51
V	.63	.42	.56	.50
I-V	.59	.45	.53	.51
Average daily feed intake (kg)				
Phase I	.36	.24	.30	.30
II	.93	.72	.82	.83
I and II	.64	.48	.56	.56
III	1.56	1.32	1.44	1.44
I-III	1.09	.95	1.02	1.02
IV	2.16	1.89	2.00	2.04
I-IV	1.23	1.06	1.15	1.15
V	2.67	2.03	2.40	2.31
I-V	2.01	1.55	1.79	1.77
Feed to gain ratio				
Phase I	1.49	1.41	1.44	1.45
II	1.76	1.44	1.80	1.40
I and II	1.67	1.42	1.69	1.44
III	2.61	2.42	2.49	2.53
I-III	2.22	2.10	2.21	2.11
IV	2.50	3.06	2.68	2.88
I-IV	2.28	2.25	2.29	2.24
V	4.22	4.76	4.34	4.64
I-V	3.41	3.45	3.38	3.47

[a]Number of pigs per mean was 20, 20, 18, 18 and 18 respectively, for the beginning of phases I, II, III, IV and V.

boars (Hines et al., 1979; Nimmo et al., 1980a, b). In contrast, Kornegay et al. (1981a) and Kesel et al. (1982) have observed improved average daily gain and feed efficiency resulting from feeding growing boars Ca and P levels in excess of NRC recommendations. A moderately restricted feed intake (65 to 75% of ad libitum) has been demonstrated to result in improved feed efficiency (Frape et al., 1959; Nielsen, 1964; Calabotta et al., 1982; Kesel et al., 1982).

Toe measurements.

Data concerning mineral-vitamin levels have not been presented as few significant (P<.10) effects were evident. Toe measurements increased both linearly and quadratically with increasing age (tables 3 and 4; appendix figures 2, 3, 4 and 5). Horn length and height of horn tended to be greater for limit-fed boars at 85 d on test while horn length, toe width and height of horn were significantly (P<.10 to .001) greater for ad libitum-fed boars by 295 d on test. Toe width appears to display less response to energy level than does horn length. Toe length tended to be greater for the ad libitum-fed boars; however, the magnitude of the response was not as great as for the other toe measurements. Correction for the expected body weight differences resulting from unequal energy intakes produced

TABLE 3. PREDICTED MEANS AND ACTUAL AND WEIGHT-CORRECTED MEAN DIFFERENCE AT 85, 190 AND 295 DAYS ON TEST FOR HORN LENGTH AND TOE WIDTH OF INSIDE AND OUTSIDE TOES ON FRONT AND HIND FEET OF BOARS AD LIBITUM OR LIMIT-FED

Item	Days on test[a]		
	85	190	295
Length of horn, mm			
Front inside[bcde]	15.58 ± .36	20.91 ± .44	23.20 ± .56
Actual difference[f]	-.66 ± .42	.05 ± .55	2.47 ± .74**
Weight-corrected difference[f]	-1.68 ± .36***	-1.63 ± .48***	.77 ± .64
Front outside[bcghi]	16.62 ± .36	22.64 ± .44	25.06 ± .57
Actual difference	-.07 ± .43	.67 ± .56	2.34 ± .75**
Weight-corrected difference	-1.22 ± .41**	-1.09 ± .54*	.83 ± .72
Hind inside[bci]	15.06 ± .37	20.27 ± .45	22.86 ± .57
Actual difference	-.10 ± .43	.31 ± .57	1.30 ± .76†
Weight-corrected difference	-1.07 ± .44*	-1.20 ± .57*	.01 ± .76
Hind outside[bcjk]	16.35 ± .39	22.97 ± .48	26.91 ± .61
Actual difference	.24 ± .46	.44 ± .60	.54 ± .81
Weight-corrected difference	-.98 ± .45*	-1.52 ± .59**	-1.31 ± .79†
Width of toe, mm			
Front inside[bcdl]	18.52 ± .31	25.44 ± .38	28.32 ± .48
Actual difference	.03 ± .37	.58 ± .48	1.71 ± .64**
Weight-corrected difference	-1.27 ± .37***	-1.23 ± .49*	.60 ± .65
Front outside[bcd]	20.28 ± .35	28.13 ± .43	31.43 ± .55
Actual difference	.56 ± .41	.97 ± .54†	1.08 ± .72
Weight-corrected difference	-.92 ± .43*	-1.10 ± .57†	-.20 ± .76
Hind inside[bcg]	16.70 ± .32	22.52 ± .39	25.38 ± .49
Actual difference	.64 ± .37†	1.22 ± .49*	1.58 ± .65*
Weight-corrected difference	-.46 ± .38	-.38 ± .50	.43 ± .66
Hind outside[bcd]	19.55 ± .26	26.78 ± .32	29.55 ± .40
Actual difference	.58 ± .31†	.91 ± .40*	.80 ± .54
Weight-corrected difference	-.78 ± .35*	-.86 ± .46†	.05 ± .61

†, *, **, ***Energy effect (P<.10, .05, .01 and .001, respectively).
[a]Mean body weight (kg) was 58.9 and 49.3 (P<.05) at 85 d; 115.8 and 93.7 (P<.001) at 190 d; 160.6 and 125.6 (P<.001) at 295 d, respectively, for ad libitum- and limit-fed boars (linear age effect, P<.001; quadratic age effect, P<.001; energy x linear age effect, P<.001).
[b]Linear age effect (P<.001).
[c]Quadratic age effect (P<.001).
[d]Energy x linear age effect (P<.05).
[e]Energy x quadratic age effect (P<.01).
[f]Differences are expressed as ad libitum-fed minus limit-fed. Actual differences are unadjusted for body weight differences; whereas, the weight-corrected differences measure the deviation of the actual treatment difference from that which would have been expected from treatment differences in body weight.
[g]Energy x linear age effect (P<.01).
[h]Energy x quadratic age effect (P<.10).
[i]Energy x mineral-vitamin x linear age effect (P<.1).
[j]Energy x mineral-vitamin x linear age effect (P<.001).
[k]Energy x mineral-vitamin x quadratic age effect (P<.01).
[l]Energy x mineral-vitamin x quadratic age effect (P<.05).
[m]Energy x mineral-vitamin x linear age effect (P<.05).

TABLE 4. PREDICTED MEANS AND ACTUAL AND WEIGHT-CORRECTED MEAN DIFFERENCE AT 85, 190 AND 295 DAYS ON TEST FOR HORN HEIGHT AND TOE LENGTH OF INSIDE AND OUTSIDE TOES ON FRONT AND HIND FEET OF BOARS AD LIBITUM OR LIMIT-FED

Item	Days on test[a]		
	85	190	295
Height of horn, mm			
Front inside[bcde]	27.82 ± .42	35.80 ± .52	36.53 ± .66
Actual difference[f]	-.22 ± .50	.63 ± .65	2.72 ± .87**
Weight-corrected difference[f]	-1.78 ± .50***	-.96 ± .65	3.21 ± .87***
Front outside[bcdg]	29.07 ± .44	37.07 ± .54	37.97 ± .69
Actual difference	-.37 ± .52	.61 ± .68	3.16 ± .91***
Weight-corrected difference	-2.03 ± .51***	-1.10 ± .67†	3.62 ± .89***
Hind inside[bcehi]	27.63 ± .45	36.66 ± .55	39.10 ± .70
Actual difference	-.46 ± .53	.28 ± .69	2.44 ± .92**
Weight-corrected difference	-2.17 ± .57***	-1.71 ± .74*	2.20 ± .99*
Hind outside[bcej]	28.66 ± .48	38.34 ± .59	41.58 ± .75
Actual difference	-.46 ± .57	.22 ± .74	2.28 ± .99*
Weight-corrected difference	-2.27 ± .60***	-1.94 ± .78*	1.84 ± 1.05†
Length of toe, mm			
Front inside[bck]	36.43 ± .63	46.95 ± .78	48.41 ± .99
Actual difference	1.01 ± .75	1.49 ± .98	1.13 ± 1.31
Weight-corrected difference	-1.04 ± .73	-1.01 ± .96	.47 ± 1.28
Front outside[bci]	38.02 ± .57	49.70 ± .69	52.27 ± .88
Actual difference	.77 ± .67	1.10 ± .87	.74 ± 1.17
Weight-corrected difference	-1.48 ± .66*	-1.69 ± .86†	-.09 ± 1.15
Hind inside[bcjk]	34.65 ± .56	46.74 ± .69	51.87 ± .88
Actual difference	.52 ± .66	1.18 ± .87	1.85 ± 1.16
Weight-corrected difference	-1.73 ± .69*	-1.97 ± .90*	-.11 ± 1.20
Hind outside[bck]	36.62 ± .63	50.20 ± .77	57.22 ± .98
Actual difference	.22 ± .74	.56 ± .97	.99 ± 1.30
Weight-corrected difference	-2.27 ± .80**	-3.06 ± 1.04**	-1.60 ± 1.40

†, *, **, *** Energy effect (P<.10, .05, .01 and .001, respectively).

[a] Mean body weight (kg) was 58.9 and 49.3 (P<.05) at 85 d; 115.8 and 93.7 (P<.001) at 190 d; 160.6 and 125.6 (P<.001) at 295 d, respectively, for ad libitum- and limit-fed boars (linear age effect, P<.001; quadratic age effect, P .001; energy x linear age effect, P<.001).

[b] Linear age effect (P<.001).

[c] Quadratic age effect (P<.001).

[d] Energy x linear age effect (P<.01).

[e] Energy x quadratic age effect (P<.01).

[f] Differences are expressed as ad libitum-fed minus limit-fed. Actual differences are unadjusted for body weight differences; whereas, the weight-corrected differences measure the deviation of the actual treatment difference from that which would have been expected from treatment differences in body weight.

[g] Energy x quadratic age effect (P<.05).

[h] Energy x linear age effect (P<.05).

[i] Energy x mineral-vitamin x quadratic age effect (P<.1).

[j] Energy x linear age effect (P<.10).

[k] Energy x mineral-vitamin x quadratic age effect (P<.05).

longer and wider toes and longer horns for the limit-fed boars. This difference was prominent ($P<.10$ to .001) at 85 and 190 d on test and non-significant by 295 d weight correction. Horn height displayed a similar early response due to weight-correction but also exhibited larger values for ad libitum-fed boars by 295 days. This demonstrates a true effect of the high energy intake in producing a greater height of horn. Ad libitum intake in combination with the 150% mineral-vitamin level generally produced the largest foot measurements. Calabotta et al. (1982) and Kornegay et al. (1982b) have similarly reported larger foot measurements for swine fed ad libitum as compared with those fed 75% of ad libitum intake when examined at an equal age. Differences were not apparent when examined at a similar body weight. Dietary Ca and P level has likewise been shown to have little effect on foot size of developing boars (Kornegay et al., 1981a; 1982b).

Toe base area and toe volume responded as would be expected based on the observations of the individual measurements from which they are calculated. Both toe area and volume increased over time with the ad libitum intake promoting significantly ($P<.1$ to .001) larger values at 190 and 295 d on test (table 5; appendix figures 6 and 7). Weight-correction removed the differences instituted by

TABLE 5. PREDICTED MEANS AND ACTUAL AND WEIGHT-CORRECTED MEAN DIFFERENCE AT 85, 190 AND 295 DAYS ON TEST FOR VOLUME AND AREA OF INSIDE AND OUTSIDE TOES ON FRONT AND HIND FEET OF BOARS AD LIBITUM OR LIMIT-FED

Item	Days on test[a]		
	85	190	295
Volume of toe, cm^3[b]			
Front inside[cdefg]	21.60 ± 1.19	40.41 ± 1.45	53.80 ± 1.85
Actual difference[h]	.32 ± 1.40	3.17 ± 1.83†	8.73 ± 2.45***
Weight-corrected difference[h]	-3.15 ± 1.29*	-3.27 ± 1.68†	.76 ± 2.25
Front outside[cdi]	25.48 ± 1.43	49.04 ± 1.75	67.31 ± 2.23
Actual difference	1.14 ± 1.69	4.22 ± 2.20†	9.14 ± 2.94**
Weight-corrected difference	-3.16 ± 1.57*	-3.87 ± 2.05†	-1.06 ± 2.74
Hind inside[ce]	18.12 ± 1.11	36.85 ± 1.35	54.60 ± 1.72
Actual difference	.96 ± 1.30	4.20 ± 1.70*	9.71 ± 2.28***
Weight-corrected difference	-2.36 ± 1.32†	-2.59 ± 1.72	.17 ± 2.30
Hind outside[ce]	23.36 ± 1.38	48.95 ± 1.69	74.48 ± 2.15
Actual difference	1.16 ± 1.63	4.89 ± 2.13*	11.16 ± 2.84***
Weight-corrected difference	-3.33 ± 1.77†	-4.29 ± 2.31†	-1.75 ± 3.09
Area of toe, cm^2[j]			
Front inside[cdik]	7.11 ± .25	11.63 ± .30	14.14 ± .39
Actual difference	.23 ± .29	.64 ± .38†	1.18 ± .51*
Weight-corrected difference	-.61 ± .26*	-.77 ± .34*	-.28 ± .46
Front outside[cdgl]	8.14 ± .29	13.63 ± .35	17.03 ± .45
Actual difference	.47 ± .34	.85 ± .44†	.98 ± .59†
Weight-corrected difference	-.54 ± .32†	-.87 ± .41*	-.82 ± .55
Hind inside[cdi]	6.05 ± .22	10.30 ± .27	13.53 ± .35
Actual difference	.37 ± .26	.87 ± .35*	1.41 ± .46**
Weight-corrected difference	-.40 ± .26	-.52 ± .34	-.24 ± .45
Hind outside[cdimn]	7.54 ± .24	13.12 ± .29	17.38 ± .37
Actual difference	.40 ± .28	.84 ± .37*	1.22 ± .49*
Weight-corrected difference	-.60 ± .31†	-.93 ± .41*	-.78 ± .54

†, *, **, ***Energy effect (P<.10, .05, .01 and .001, respectively).
[a]Mean body weight (kg) was 58.9 and 49.3 (P<.05) at 85 d; 115.8 and 93.7 (P<.001) at 190 d; 160.6 and 125.6 (P<.001) at 295 d, respectively, for ad libitum- and limit-fed boars (linear age effect, P<.001; quadratic age effect, P<.001; energy x linear age effect, P<.001).
[b]Length of toe x width of toe x height of horn.
[c]Linear age effect (P<.001).
[d]Quadratic age effect (P<.001).
[e]Energy x linear age effect (P<.001).
[f]Energy x quadratic age effect (P<.10).
[g]Energy x mineral-vitamin x quadratic age effect (P<.05).
[h]Differences are expressed as ad libitum-fed minus limit-fed. Actual differences are unadjusted for body weight differences; whereas, the weight-corrected differences measure the deviation of the actual treatment difference from that which would have been expected from treatment differences in body weight.
[i]Energy x linear age effect (P<.01).
[j]Length of toe x width of toe.
[k]Energy x mineral-vitamin x quadratic age effect (P<.01).
[l]Energy x linear age effect (P<.05).
[m]Energy x mineral-vitamin x linear age effect (P<.1).
[n]Energy x mineral-vitamin x quadratic age effect (P<.1).

energy level at 295 d and reversed the energy level effects seen at 85 and 190 d on test as had similarly been observed with the individual foot measurements. Ad libitum intake with elevated mineral-vitamin levels generally exhibited the largest measures.

Percentage horn is, by its very nature, a characteristic that is difficult to interpret. Since it is a ratio of horn length to toe length, small changes in these measurements lead to dramatic changes in percentage horn. Percentage horn generally increased over time indicating that the pad and horn may be developing at different rates (table 6; appendix figure 8). Horn growth may be more rapid than pad growth particularly as the animals mature. This hypothesis is supported by a longer term study conducted by Arthur et al. (1982a) in which percentage horn values increased linearly by about .02% per parity as sows were carried through three parities. Kornegay et al. (1982b) reported that percentage horn for growing boars decreased to about 135 d of age but then subsequently increased. The lack of such a response in the present study is likely due to the increased age of the boars on test as compared to those of Kornegay et al. (1982b). Any decline in percentage horn would have presumably occured prior to the first tested time point (85 d on test). In the present study, percentage

TABLE 6. PREDICTED MEANS AND ACTUAL DIFFERENCE AT 85, 190 AND 295 DAYS ON TEST FOR PERCENTAGE HORN OF INSIDE AND OUTSIDE TOES ON FRONT AND HIND FEET OF BOARS FED TWO LEVELS OF ENERGY AND TWO LEVELS OF MINERALS AND VITAMINS[a]

Item	Days on test[b]		
	85	190	295
Percentage horn			
Front inside toe[cdef]	42.9 ± 1.0	44.4 ± 1.2	48.3 ± 1.5
Energy difference	-2.8 ± 1.2*	-1.9 ± 1.5	3.9 ± 2.0†
Mineral-vitamin difference	-1.2 ± 1.2	-.3 ± 1.5	3.3 ± 2.0
Front outside toe[cghi]	43.7 ± .8	45.6 ± 1.0	47.6 ± 1.2
Energy difference	-.9 ± .9	.5 ± 1.2	4.5 ± 1.7**
Mineral-vitamin difference	-1.0 ± .9	-1.0 ± 1.2	.3 ± 1.7
Hind inside toe[jkl]	43.6 ± .9	43.0 ± 1.1	44.7 ± 1.4
Energy difference	-.6 ± 1.1	-.3 ± 1.4	1.3 ± 1.9
Mineral-vitamin difference	-2.6 ± 1.1*	-2.8 ± 1.4†	.7 ± 1.9
Hind outside toe[clm]	44.6 ± .8	45.7 ± 1.0	47.2 ± 1.3
Energy difference	.8 ± 1.0	1.2 ± 1.3	.8 ± 1.7
Mineral-vitamin difference	-1.6 ± 1.0†	-1.1 ± 1.3	2.3 ± 1.7

†, *, ** Energy or mineral-vitamin effect (P<.10, .05 and .01, respectively).
[a] Length of horn ÷ length of toe x 100.
[b] Actual differences are expressed as ad libitum-fed minus limit-fed or as 100% minus 150% minerals and vitamins.
[c] Linear age effect (P<.001).
[d] Quadratic age effect (P<.05).
[e] Energy x quadratic age effect (P<.01).
[f] Energy x mineral-vitamin x quadratic age effect (P<.10).
[g] Energy x linear age effect (P<.05).
[h] Energy x quadratic age effect (P<.05).
[i] Energy x mineral-vitamin x linear age effect (P<.10).
[j] Linear age effect (P<.01).
[k] Quadratic age effect (P<.01).
[l] Mineral-vitamin x quadratic age effect (P<.05).
[m] Energy x mineral-vitamin x linear age effect (P<.05).

horn tended to be greater for the limit-fed boars at 85 d on test with this trend beginning to diminish by 190 d. By 295 d on test percentage horn was greater for the ad libitum-fed boars with the difference significant (P<.10 to .01) for the front foot. The 150% mineral-vitamin level produced greater percentage horn at 85 d on test which was significant for the hind inside (P<.05) and hind outside (P<.10) toes. This difference was reduced to a trend in favor of the elevated mineral-vitamin level by 190 d and reversed to a trend in favor of the 100% mineral-vitamin level by 295 d. Correction for body weight differences had little effect on percentage horn. In general agreement, Kornegay et al. (1982b) reported that percentage horn for all toes tended to be larger for limit-fed vs ad libitum-fed boars at 80 and 150 d of age. In contrast, however, larger percentage horn values were observed for 100 vs 150% dietary Ca and P at 80, 150 and 220 d of age. Calabotta et al. (1982) reported no dietary energy or Ca and P level effect on percentage horn for inside and outside toes of front and hind legs of growing gilts.

Outside toe measurements were larger (P<.01) than inside toe measurements (table 7). This has also been observed in early work by Nordby (1939) and more recently by Arthur et al. (1982a), Calabotta et al. (1982) and Kornegay

TABLE 7. MEASUREMENTS FOR FRONT AND HIND FEET, AND INSIDE AND OUTSIDE TOES OF BOARS

Item	Period 1[abc]		Period 2[abc]		Period 3[abc]		Period 4[abc]		Period 5[abc]	
	Inside	Outside	Inside	Outside	Inside	Outside	Inside	Outside	Inside	Outside
Length of horn, mm										
Front[defg]	9.33	9.41	16.08	17.28	20.89	22.26	22.05	24.53	23.93	25.71
Hind	9.26	9.32	15.40	17.06	20.30	22.50	22.65	25.58	22.79	28.93
Width of toe, mm										
Front[efgh]	10.23	10.81	19.44	21.42	24.76	27.29	27.93	30.50	28.71	33.36
Hind	9.95	10.69	17.65	20.55	21.50	25.90	24.93	29.18	25.71	30.57
Height of horn, mm										
Front[efh]	16.39	16.42	28.74	29.70	35.73	36.81	36.90	38.08	37.21	39.00
Hind	15.84	16.34	28.81	30.20	35.97	37.17	39.50	40.68	39.14	42.50
Length of toe, mm										
Front[efh]	21.49	22.23	38.16	39.74	46.38	48.63	47.03	51.70	51.43	54.14
Hind	20.05	21.06	36.60	38.94	45.54	48.57	50.48	55.30	54.14	60.07

[a] Means at the end of each period (88, 86, 70, 40 and 14 observations for periods 1, 2, 3, 4 and 5, respectively). Average age (d) on test were 0, 87, 174, 255 and 297, and average body weight (kg) was 6.6, 55.8, 107.0, 143.6 and 157.5, respectively, for periods 1, 2, 3, 4 and 5.

[b] All measurements increased (P<.001) over time.

[c] Inside toe measurements were smaller (P<.001) than outside toe measurements.

[d] Significant (P<.10) differences between front and hind feet.

[e] Significant (P<.001) period x toe interactions.

[f] Significant (P<.001) period x foot interactions.

[g] Significant (P<.001) period x toe x foot interactions.

[h] Significant (P<.10) differences between front and hind feet.

et al. (1982b). Front foot horn length and toe length was greater than hind foot horn length and toe length through the second measurement period with little difference evident in period three (table 7). Horn length and toe length were greater for the hind foot during the final two periods. The hind outside toe exhibits a growth pattern different from that of the other toes. Horn and toe lengths of all four toes increased at approximately the same rate through period three at which point the hind outside horn and toe grow at a relatively faster rate. In general agreement, the magnitude of the difference between inside and outside toes in horn length and toe length has been reported to be greater on the hind foot than the front foot (Arthur et al., 1982a; Calabotta et al., 1982). Front foot toe width was greater than hind foot toe width for all five measurement periods (table 7). The hind inside toe is consistantly narrowest and displayed a slower growth rate relative to the other toes. The increase in the width of the front outside toe was greater than for the other toes and produced the largest value at period five. Horn height was greater for hind feet than for front feet. The rate of increase in horn height was approximately equal for all four toes with the exception of a greater growth rate of the hind outside horn height from period four to period five. These findings support those of Calabotta et al. (1982) and Kornegay et al. (1982b) who reported wider front toes than hind toes and taller hind toe horns than front toe horns. The present study also supports the possibility of a differential growth rate among toes with a faster growth of hind outside horn length, toe length and horn height which is particularly evident as the boar matures. Toe volume was greater for front feet than hind feet during the first three measurement periods and was reversed for the final two periods (table 8). Outside toe volume was consistantly larger than inside toe volume. Likewise, toe base area was generally greater for front toes than for hind toes, and for outside toes than inside toes. Toe volume and area increases were most dramatic for the hind outside toe during periods four and five which is a reflection of a similar effect on horn length and height during these periods. With the exception of period one, outside percentage horn was greater than inside percentage horn. Few other consistant patterns were evident for percentage horn.

Leg measurements.

Forelimb and hindlimb circumference increased with age (table 9; appendix figure 9). Ulna, tibia, metacarpal and metatarsal length increased to 190 d on test and subsequently declined (appendix figure 10). This is most

TABLE 8. PERCENT HORN, TOE BASE AREA AND TOE VOLUME FOR FRONT AND HIND FEET, AND INSIDE AND OUTSIDE TOES OF BOARS

Item	Period 1[abc]		Period 2[abc]		Period 3[abc]		Period 4[abc]		Period 5[abc]	
	Inside	Outside	Inside	Outside	Inside	Outside	Inside	Outside	Inside	Outside
Percent horn										
Front[def]	42.6	42.5	42.2	43.6	45.0	45.8	47.7	47.5	46.6	47.5
Hind	46.4	44.5	42.1	43.9	44.6	46.3	44.9	46.4	42.1	48.1
Volume of toe, cm^3										
Front[degh]	3.6	4.0	21.5	25.4	41.5	49.6	48.7	60.6	55.2	70.7
Hind	3.2	3.7	18.7	24.3	35.7	47.4	50.0	66.3	54.8	78.3
Area of toe, cm^2										
Front[degh]	2.2	2.4	7.4	8.5	11.5	13.3	13.1	15.8	14.8	18.1
Hind	2.0	2.3	6.5	8.0	9.9	12.7	12.6	16.2	14.0	18.4

[a]Means at the end of each period (88, 86, 70, 40 and 14 observations for periods 1, 2, 3, 4 and 5, respectively). Average age (d) on test was 0, 87, 174, 255 and 297, and average body weight (kg) was 6.6, 55.8, 107.0, 143.6 and 157.5, respectively, for periods 1, 2, 3, 4 and 5.

[b]All values with the exception of percent horn increased (P<.001).

[c]Inside toe values were smaller (P<.001) than outside toe values.

[d]Significant (P<.001) period x toe interactions.

[e]Significant (P<.001) period x foot interactions.

[f]Significant (P<.10) period x toe x foot interactions.

[g]Significant (P<.001) period x toe x foot interactions.

[h]Significnat (P<.001) difference between front and hind feet.

TABLE 9. PREDICTED MEANS AND ACTUAL AND WEIGHT-CORRECTED MEAN DIFFERENCE AT 85, 190 AND 295 DAYS ON TEST FOR CIRCUMFERENCE OF THE FORELIMB AND THE HINDLIMB AND LENGTH OF THE ULNA, TIBIA, METACARPAL AND METATARSAL OF BOARS AD LIBITUM OR LIMIT-FED

	Days on test[a]		
Item	85	190	295
Circumference, cm			
Forelimb[bc]	14.61 ± .15	19.32 ± .18	21.19 ± .44
Actual difference[d]	.29 ± .18	.41 ± .23†	.39 ± .31
Weight-corrected difference[d]	-.59 ± .21**	-.73 ± .27**	-.21 ± .36
Hindlimb[bce]	15.25 ± .18	20.15 ± .22	21.57 ± .27
Actual difference	.31 ± .21	.66 ± .27*	.97 ± .36**
Weight-corrected difference	-.61 ± .25*	-.49 ± .32	.60 ± .43
Length, cm			
Ulna[bc]	18.71 ± .24	23.24 ± .29	23.28 ± .38
Actual difference	.31 ± .28	.45 ± .37	.35 ± .51
Weight-corrected difference	-.58 ± .31†	-.36 ± .40	.90 ± .55†
Tibia, cm[bc]	19.76 ± .32	23.82 ± .39	22.13 ± .51
Actual difference	.14 ± .38	.20 ± .49	.13 ± .67
Weight-corrected difference	-.67 ± .38†	-.19 ± .50	1.73 ± .68*
Metacarpal, cm[bcf]	7.43 ± .13	9.05 ± .16	8.60 ± .21
Actual difference	.24 ± .16	.44 ± .20*	.54 ± .27*
Weight-corrected difference	-.09 ± .16	.22 ± .21	1.01 ± .29***
Metatarsal, cm[bc]	8.42 ± .15	10.53 ± .18	10.22 ± .23
Actual difference	.06 ± .17	.19 ± .22	.37 ± .30
Weight-corrected difference	-.36 ± .19†	-.17 ± .24	.72 ± .32*

†, *, **, ***Energy effect ($P<.10$, .05, .01 and .001, respectively).

[a]Mean body weight (kg) was 58.9 and 49.3 ($P<.05$) at 85 d; 115.8 and 93.7 ($P<.001$) at 190 d; 160.6 and 125.6 ($P<.001$) at 295 d, respectively for ad libitum- and limit-fed boars (linear age effect, $P<.001$; quadratic age effect, $P<.001$; energy x linear age effect, $P<.001$).

[b]Linear age effect ($P<.001$).

[c]Quadratic age effect ($P<.001$).

[d]Differences are expressed as ad libitum-fed minus limit-fed. Actual differences are unadjusted for body weight differences; whereas, the weight-corrected differences measure the deviation of the actual treatment difference from that which would have been expected from treatment differences in body weight.

[e]Energy x linear age effect ($P<.01$).

[f]Energy x linear age effect ($P<.05$).

likely a function of measurement error rather than a true age effect. Palpation of the joints of the leg was used to determine bone length and this leads to difficulty in obtaining accurate measurements. Actual metacarpal and metatarsal lengths obtained at necropsy are presented in Chapter IV.

Mineral-vitamin level had little effect on circumference of the forelimb or hindlimb, or on length of the ulna, tibia, metacarpal or metatarsal when examined either as actual or weight-corrected differences. Kornegay et al. (1982b) and Calabotta et al. (1982) similarly found no effect of elevated dietary Ca and P levels (150% NRC) on these same leg characteristics. Bone length has also been shown to not be responsive to Ca and P levels above those recommended by NRC (Forsyth et al., 1972; Kornegay et al., 1981a; Nimmo et al., 1980b; van Kempen et al., 1976).

Circumference of the leg was greater for boars on ad libitum intake with this effect particularly evident in the hindlimb. Bone length tended to be greater with ad libitum feeding, however, only metacarpal length response was significant ($P<.05$). Correction for body weight differences reversed the energy level effects seen in circumference measurements at all time points with the exception of the hindlimb circumference at 295 d on test and also reversed energy level effects seen in bone lengths at 85 and 190 d on test. By 295 d on test weight-corrected ulna, tibia, metacarpal and metatarsal lengths were greater ($P<.10$ to .001) for boars on ad libitum intake. Grondalen (1974a) reported that restricting the feed intake (80 to 90% of ad libitum) of sows produced longer femora and tibiae at 100 kg body weight. Kornegay et al. (1982b) likewise reported trends towards increased weight-corrected ulna, tibia, metacarpal and metatarsal lengths of growing boars fed 75% of ad libitum intake up to 220 d of age. The present study indicates that if the boars are taken beyond this point bone lengths become greater for ad libitum-fed boars. Age and dietary treatments had little effect on the ratio of the length of metacarpal to ulna (.39) and metatarsal to tibia (.43). Similar observations have been made by Calabotta et al. (1982) and Kornegay et al. (1982b).

Pad and horn lesions.

Incidence and severity of pad and horn lesions are shown in tables 10 and 11. The values were not affected by adjustment to a constant age or weight, therefore, unadjusted means are presented.

Energy or mineral-vitamin level effects on incidence and severity of pad lesions were few and inconsistant (table 10). In agreement with the present study, Kornegay and

TABLE 10. LEAST SQUARES MEANS OF INCIDENCE AND SEVERITY OF PAD LESIONS FOR FRONT, HIND, INSIDE AND OUTSIDE TOES FOR BOARS FED TWO LEVELS OF ENERGY AND TWO LEVELS OF MINERALS AND VITAMINS[b]

Item	Period[a]	Energy		Mineral-vitamin		SE
		Ad libitum	75% Ad libitum	100%	150%	
Front inside	1	15.9 (1.4)	6.8 (-)[c]	15.9 (1.4)	6.8 (-)[c]	4.8
	2	2.4 (-)[c]	0 (0)	2.4 (-)[c]	0 (0)	1.6
	3	12.1 (1.0)	15.9 (1.0)	8.7 (1.0)	19.4 (1.0)	5.9
	4	0 (0)	5.6 (-)[c]	5.6 (-)[c]	0 (0)	3.5
	5	0 (0)	0 (0)	0 (0)	0 (0)	0
Front outside	1	15.9[d] (1.1)	4.5 (-)[c]	13.6 (1.1)	6.8 (-)[c]	4.6
	2	23.8 (1.6)	11.4 (1.0)	21.1 (1.3)	14.1 (1.3)	5.8
	3	33.5 (1.1)	35.1 (1.1)	31.4 (1.0)	37.2 (1.2)	8.3
	4	12.5 (-)[c]	25.6 (1.4)	5.6[e] (-)[c]	32.5 (1.5)	8.8
	5	20.0 (-)[c]	0 (0)	0 (0)	20.0 (-)[c]	13.8
Hind inside	1	13.6 (1.2)	9.1 (1.5)	11.4 (1.3)	11.4 (1.4)	4.9
	2	4.8 (-)[c]	2.3 (-)[c]	7.0[d] (1.3)	0 (0)	2.8
	3	8.8 (-)[c]	24.0 (1.1)	14.4 (1.0)	18.4 (-)[c]	6.1
	4	13.9 (-)[c]	0 (0)	5.6 (-)[c]	8.3 (-)[c]	6.0
	5	0 (0)	16.7 (-)[c]	0 (0)	16.7 (-)[c]	10.3
Hind outside	1	15.9 (1.5)	9.1 (1.2)	15.9 (1.3)	9.1 (1.3)	5.0
	2	21.4 (1.7)	18.2 (1.3)	11.6[d] (1.7)	28.0 (1.3)	6.1
	3	48.7[e] (1.3)	21.5 (1.0)	28.9 (1.1)	41.3 (1.2)	7.9
	4	23.6 (2.1)	36.1 (1.9)	22.2 (1.8)	37.5 (2.2)	10.5
	5	30.0 (-)[c]	12.5 (-)[c]	12.5 (-)[c]	30.0 (-)[c]	17.6

[a]Average d on test were 0, 87, 174, 255 and 297 for periods 1, 2, 3, 4 and 5, respectively. Average body weight (kg) was 6.6 and 6.6 for period 1; 61.2 and 51.9 for period 2; 117.7 and 97.3 for period 3; 167.0 and 120.3 for period 4; 180.0 and 131.6 for period 5, respectively, for ad libitum- and limit-fed boars.
[b]Scores were assigned on a scale of 0 to 3, where 0 = no lesion and 3 = severe lesion. Mean is incidence with severity in parenthesis.
[c]Severity unable to be determined due to low incidence.
[d]Energy or mineral-vitamin effect (P<.10).
[e]Energy or mineral-vitamin effect (P<.05).

TABLE 11. LEAST SQUARES MEANS OF INCIDENCE AND SEVERITY OF HORN LESIONS FOR FRONT, HIND, INSIDE AND OUTSIDE TOES FOR BOARS FED TWO LEVELS OF ENERGY AND TWO LEVELS OF MINERALS AND VITAMINS[b]

Item	Period[a]	Energy: Ad libitum	Energy: 75% Ad libitum	Mineral-vitamin: 100%	Mineral-vitamin: 150%	SE
Front inside	1	4.5 (-)[c]	6.8 (1.0)	0[d] (0)	11.4 (1.3)	3.5
	2	0 (-)[c]	4.5 (-)[c]	4.5 (-)[c]	0 (-)[c]	2.3
	3	0 (0)	0 (0)	0 (0)	0 (0)	0
	4	0 (0)	0 (0)	0 (0)	0 (0)	0
	5	0 (0)	0 (0)	0 (0)	0 (0)	0
Front outside	1[e]	0[f] (0)	13.7 (1.2)	2.3[g](-)[c]	11.4 (1.4)	3.6
	2	19.0 (1.7)	15.9 (1.2)	18.5 (1.5)	16.5 (1.4)	5.9
	3	2.9 (-)[c]	2.6 (-)[c]	2.9 (-)[c]	2.6 (-)[c]	2.9
	4	5.6 (-)[c]	10.0 (-)[c]	5.6 (-)[c]	10.0 (-)[c]	5.9
	5	25.0[g](2.0)	0	25.0[g](2.0)	0	8.9
Hind inside	1	34.1 (2.0)	20.5 (1.8)	38.6[d](2.1)	15.9 (1.7)	6.6
	2	2.4 (-)[c]	0 (-)[c]	2.4 (-)[c]	0 (0)	1.6
	3	0 (0)	5.4 (-)[c]	2.8 (-)[c]	2.6 (-)[c]	2.9
	4	0 (0)	0 (0)	0 (0)	0 (0)	0
	5	0 (0)	0 (0)	0 (0)	0 (0)	0
Hind outside	1	15.9 (2.3)	11.4 (2.0)	18.2 (1.8)	9.1 (2.5)	5.2
	2	14.3 (2.4)	13.6 (1.2)	9.2 (2.0)	18.7 (1.6)	5.3
	3	2.9 (-)[c]	2.6 (-)[c]	2.9 (-)[c]	2.6 (-)[c]	2.9
	4	4.2 (-)[c]	15.6 (2.0)	5.6 (-)[c]	14.2 (2.0)	6.9
	5	0 (0)	0 (0)	0 (0)	0 (0)	0

[a]Average d on test were 0, 87, 174, 255 and 297 for periods 1, 2, 3, 4 and 5, respectively. Average body weight (kg) was 6.6 and 6.6 for period 1; 61.2 and 51.9 for period 2; 117.7 and 97.3 for period 3; 167.0 and 120.3 for period 4; 180.0 and 131.6 for period 5, respectively, for ad libitum- and limit-fed boars.

[b]Scores were assigned on a scale of 0 to 3, where 0 = no lesion and 3 = severe lesion. Mean is incidence with severity in parenthesis.

[c]Severity unable to be determined due to low incidence.

[d]Mineral-vitamin effect (P<.05).

[e]Energy x mineral-vitamin effect (P<.10).

[f]Energy effect (P<.01).

[g]Energy or mineral-vitamin effect (P<.10).

Thomas (1981) and Kornegay et al., (1981a) reported that foot and toe lesions of growing boars were unaffected when 125% NRC Ca and P levels were fed. Likewise, Ca and P levels 50% above NRC recommendations had no effect on incidence or severity of toe lesions of gilts during growth (Calabotta et al., 1982) or following three parities (Arthur et al., 1982a). Dietary Ca and P levels 50% above NRC recommendations, however, have been reported to decrease pad and horn lesion incidence in growing boars while not affecting lesion severity (Kornegay et al., 1982b).

Restricted feed intake similar to the level used in the present study was shown by Kornegay et al., (1982b) to have little consistant effect on the incidence or severity of foot lesions. In contrast, Calabotta et al. (1982) reported that gilts fed ad libitum had a higher incidence of front inside and outside pad lesions than did limit-fed gilts with little difference in lesion severity, while horn lesion incidence was greater for limit-fed gilts. Calabotta et al. (1982) further noted that dietary energy level had little effect on lesions of the hind inside and outside pad and horn. No affect of dietary energy level on lesion incidence or severity was observed as the gilts were subsequently taken through three parities (Arthur et al., 1982b).

An increase in incidence of pad lesions was observed through period three (174 d on test) with a decline thereafter. Such observations on lesion severity were not possible due to low incidence which prevented estimation of lesion severity in several cases. However, where severity could be determined, the values were often higher for outside pads during period four (255 d on test). This may be a result of healing of the less severe lesions prior to period four leaving only the more serious lesions for characterization. The incidence of pad lesions did not differ significantly ($P>.10$) between front and hind feet. The difference in the incidence of inside and outside toe pad lesions was significant ($P<.001$) with outside pads having consistantly greater lesion incidence. Although the foot x toe interaction was not significant ($P>.10$) the hind toe appears to have a greater incidence of pad lesions as compared with the other toes.

Horn lesions were less pronounced than pad lesions with few energy or mineral-vitamin level effects (table 11). Outside horns had greater ($P<.05$) lesion incidence than did inside horns while front and hind foot horns were not significantly ($P>.10$) different. The front inside horn displayed a very low incidence and severity of lesion. Likewise, lesions of the hind inside horn were not evident with the exception of period one (0 d on test). The incidence of outside horn lesions was very low at period three (174 d on test) and subsequently increased to period four (255 d on test). The explanation of this observation is not clear at this time. Several previous studies have likewise demonstrated greater incidence of lesions on the outside toe than the inside toe (Calabotta et al., 1982; Fritschen et al., 1972; Kornegay et al., 1981a; Penny et al., 1963). This result may possibly be due to a greater weight load borne by the outside toe thus subjecting it to greater wear and abrasion.

Soundness scores.

Soundness scores were greater for ad libitum-fed boars indicating that limit-feeding produced a more structurally sound appearance (table 12). This was apparent at both periods (87 and 255 d on test) and was true regardless of whether the values were corrected for age or body weight differences. The present study supports the hypothesis of Vaughan (1971) who suggested that rapid growth may predispose an animal to leg weakness problems. In contrast, Kornegay et al. (1982b) reported that soundness favored ad libitum-fed boars when the scores were corrected for body weight. Furthermore, studies by Calabotta et al. (1982), Fell et al. (1970) and Nakano et al. (1979) reported no relationship between reduced growth rate and the development

TABLE 12. LEAST SQUARES MEANS OF AVERAGE STRUCTURAL SOUNDNESS SCORE FOR BOARS FED TWO LEVELS OF ENERGY AND TWO LEVELS OF MINERALS AND VITAMINS[a]

		Energy		Min-vit		
Period[b]		Ad libitum	75% Ad libitum	100%	150%	SE
1	Age adjustment	9.1[c]	8.1	8.7	8.4	.4
	Weight adjustment	9.5[d]	7.7	8.7	8.5	.4
2	Age adjustment	10.2[e]	8.7	9.4	9.5	.5
	Weight adjustment	11.1[d]	8.0	9.6	9.5	.5

[a]Scores were assigned on a scale of 1 to 15, where 1 = very good overall soundness and 15 = severe structural unsoundness.

[b]Average days on test were 87 and 255 for periods 1 and 2, respectively. Average body weight (kg) was 61.2 and 51.9 for period 1; 167.0 and 120.3 for period 2, respectively, for ad libitum- and limit-fed boars.

[c]Energy effect (P<.10).

[d]Energy effect (P<.01).

[e]Energy effect (P<.05).

of unsoundness.

The present study supports the results of Calabotta et al. (1982), Kornegay et al. (1981a), Kornegay et al. (1982b) and Nimmo et al. (1980a,b) in finding no improvement in structural soundness scores as a result of dietary mineral levels in excess of NRC recommendations.

Chapter IV

THE EFFECT OF RESTRICTED ENERGY INTAKE AND ELEVATED MINERALS AND VITAMINS ON METACARPAL AND METATARSAL CHARACTERISTICS OF GROWING BOARS

Summary

The effects of dietary energy level (ad libitum and 75% of ad libitum) and mineral-vitamin intake (100 and 150% of the National Research Council recommendations) on metacarpal and metatarsal dimensional and mechanical characteristics and chemical composition were studied utilizing a 2 x 2 factorial arrangement of treatments. Fifteen of the 20 boars assigned to each treatment at 5 wk of age were necropsied at 15 d intervals beginning at 120 d of age (85 d on test), while five boars from each group were fed to 330 d of age before necropsy. At necropsy, two metacarpals and two metatarsals were removed from each boar for analysis. Bone weight, length, shaft diameter and wall thickness increased with age, while bone ether extract decreased and ash content increased. As age increased, Ca content of bone ash increased, P level remained unchanged and Mg, Cu, Zn, Fe and Mn levels decreased. At an equal age, bone weight, length, shaft diameters and mechanical characteristics were greater for ad libitum-fed boars, however, weight-correction produced trends in favor of the limit-fed boars. Although mineral-vitamin level had no effect on the weight, length or diameter of bones, the 150% NRC mineral-vitamin level resulted in increased bone wall thickness. The elevated dietary mineral-vitamin level increased bone mechanical characteristics with these effects more prominent in the metatarsals than the metacarpals. Metatarsals were heavier and longer than metacarpals, while shaft diameters and wall thicknesses displayed less consistent results. Percentage of ether extract increased with ad libitum feeding and elevated dietary mineral-vitamin levels resulted in increased percentage of ash. The 150% NRC mineral-vitamin level resulted in increased bone ash Ca level, while dietary energy or mineral-vitamin levels failed to effect the bone content of any of the other minerals examined. The results of this study indicate that changes in bone characteristics resulting from ad libitum feeding are due to a larger body size at a given age while greater values for mechanical characteristics can be obtained by elevation of dietary mineral-vitamin levels.

Introduction

Structural unsoundness, or leg weakness, continues to be of economic importance to the swine industry, with the causative factors uncertain, but most likely nutrition, genetics and environment all playing a role in predisposing an animal to a lameness problem. Altering dietary mineral level can affect bone mineralization and may thus alter its capacity to perform as a structural member. Nimmo et al. (1981) reported that elevation of dietary Ca and P levels for gilts resulted in a reduction in overall soundness scores for the rear foot and leg. In contrast, however, several studies have indicated no effect of dietary Ca and P in excess of NRC recommendations on overall structural soundness observations (Arthur et al., 1982a; Calabotta et al., 1982; Grondalen, 1976; Kornegay et al., 1981a, 1982b; Kornegay and Thomas, 1981; Nimmo et al., 1980b; Reiland, 1978c).

The relatively common occurrence of leg weakness in swine maintained at a high level of nutrition suggests that rapid growth rate may be an important factor in the development of unsoundness (Vaughan, 1971). Grondalen (1974b), Reiland (1978c) and Walker and Jones (1962) have presented results indicating improved soundness with restricted feed intake. No such influence of restricted feed intake was observed in the work of Arthur et al. (1982a), Calabotta et al. (1982) or Nakano et al. (1979).

The present study was designed to examine the effects of restricted growth rate and elevated mineral and vitamin levels on skeletal changes of growing boars. Additionally, the effect of aging on bone characteristics was examined.

Experimental Procedures

Details of dietary treatments, management and housing of boars were as previously described (Chapter III).

Fifteen of the 20 boars in each treatment group were necropsied at 15 d intervals beginning at 120 d of age (85 d on test). Five boars from each group were carried through to 330 d of age (295 d on test) before necropsy. Each boar was assigned to have the third and fourth metacarpals and metatarsals of either right front and left rear feet or the left front and right rear feet removed at necropsy. Following removal from the animal, the metacarpals and metatarsals were freed of all extraneous tissue in preparation for analysis. Each bone was then weighed and measured. Bone length and three shaft diameters were measured using dial calipers as described by Arthur et al. (1982b) (appendix figure 11). A force-deformation curve was generated via a three-point bending test using an Instron Universal Testing Machine (appendix figures 12 and 13). Following breaking, bone wall thicknesses corresponding to the external shaft diameters were measured. To describe the mechanical characteristics of the metacarpals and metatarsals, breaking strength, stiffness, Young's modulus of elasticity and flexural modulus were derived utilizing the force deformation curves and bone measurements as described by Baker (1974) and Arthur et al. (1982b) (appendix table 3).

The proximal half of each bone was crushed and dried in a 70 C forced air oven for 4 d. Reagent grade anhydrous ethyl ether was refluxed over the crushed, dried bone for 5 h to determine percent ether extract. Percent ash was determined by placing the dried fat-free bone in a 600 C muffle furnace for 5 h. One-half gram ash samples were suspended in reagent grade hydrochloric acid over heat until disolved and then quantitatively transfered to volumetric flasks for mineral analysis. A Perkin-Elmer 403 atomic absorption spectrophotometer was used to determine Ca, Mg, Cu, Zn, Fe and Mn content of the bone. Phosphorus content of the bone was determined using the colorimetric procedure of Fiske and Subbarrow (1925).

Horn samples were obtained at necropsy from those feet designated for metacarpal or metatarsal removal. Percent dry matter was determined for all horns by drying in a 70 C forced air oven for 4 d. Ether extract and ash determinations were made on horns of boars necropsied at

120, 150, 180, 210, 240, 270 and 300 d on test, while horn mineral analysis was carried out on boars 135, 165, 195, 225, 255, 285, 315 and 330 d on test at necropsy. This provided 120 samples for ether extract and ash determination and 188 samples for mineral analysis; however, due to difficulties in the analytical procedures results on 115, 48 and 156 samples for ether extract, ash and mineral content, respectively, are reported. Percent ether extract was determined by refluxing petroleum ether over the dried horn for 6 h using a Soxhlet apparatus. Percent ash was determined as previously described for the bone samples. Horn samples were prepared for mineral analysis by wet ashing in concentrated nitric acid and concentrated perchloric acid. Calcium, P, Mg, Cu, Zn, Fe and Mn were then determined as described for bone mineral analysis.

Statistical analysis of the data was as previously described for the feet and leg characteristics (Chapter III).

Results and Discussion

Bone dimensional characteristics.

Metacarpal and metatarsal fresh weight, length, shaft diameters and wall thicknesses increased with age (tables 13 to 16; appendix figures 14 to 21). The only exception was

TABLE 13. PREDICTED MEANS AND ACTUAL AND WEIGHT-CORRECTED MEAN DIFFERENCE AT 85, 190 AND 295 DAYS ON TEST FOR THIRD METACARPAL WEIGHT AND SIZE PARAMETERS OF BOARS AD-LIBITUM OR LIMIT-FED

	Days on test[a]		
Item	85	190	295
Weight, g[bcd]	14.40 ± 2.05	32.24 ± 1.19	42.50 ± 1.22
Actual difference[e]	.63 ± 1.33	2.32 ± 1.45	5.03 ± 1.68**
Weight-corrected difference[e]	-.63 ± 1.01	-1.35 ± 1.11	-2.00 ± 1.28
Length, cm[bfg]	6.54 ± .19	8.42 ± .11	9.20 ± .11
Actual difference	.06 ± .12	.14 ± .13	.22 ± .15
Weight-corrected difference	-.09 ± .11	-.17 ± .12	-.23 ± .13†
Palmar dimension, cm[b]	1.32 ± .05	1.62 ± .03	1.81 ± .03
Actual difference	.02 ± .03	.03 ± .04	.04 ± .04
Weight-corrected difference	-.01 ± .03	-.03 ± .03	-.05 ± .04
Axial dorsopalmar dimension, cm[bdh]	1.46 ± .05	1.88 ± .03	2.08 ± .03
Actual difference	.01 ± .03	.04 ± .03	.11 ± .04**
Weight-corrected difference	-.02 ± .03	-.03 ± .03	-.02 ± .03
Abaxial dorsopalmar dimension, cm[bgh]	1.66 ± .07	2.15 ± .04	2.34 ± .04
Actual difference	.01 ± .04	.04 ± .05	.11 ± .06†
Weight-corrected difference	-.03 ± .04	-.04 ± .04	-.02 ± .05
Palmar thickness, mm[bi]	1.65 ± .23	2.43 ± .13	2.65 ± .13
Actual difference	-.12 ± .15	-.02 ± .16	.36 ± .19†
Weight-corrected difference	-.16 ± .14	-.16 ± .15	.03 ± .18
Axial dorsopalmar thickness, mm[c]	1.48 ± .19	2.06 ± .11	1.91 ± .11
Actual difference	.06 ± .13	.01 ± .14	-.18 ± .16
Weight-corrected difference	-.01 ± .12	-.02 ± .13	-.05 ± .15
Abaxial dorsopalmar thickness, mm[b]	1.44 ± .15	1.66 ± .09	2.00 ± .09
Actual difference	.06 ± .01	-.01 ± .11	-.24 ± .12†
Weight-corrected difference	.02 ± .10	-.07 ± .11	-.29 ± .12*

†,*,** Energy effect (P<.10, .05 and .01, respectively).

[a] Mean body weight (kg): 43.4 and 41.7 at 85 d; 122.1 and 104.5 at (P<.01) 190 d; 180.2 and 131.7 at (P<.001) 295 d, respectively for ad libitum- and limit-fed boars (linear age effect, P<.001; quadratic age effect, P<.05; energy x linear age effect, P<.001; energy x quadratic age effect, P<.05).

[b] Linear age effect (P<.001).

[c] Quadratic age effect (P<.05).

[d] Energy x linear age effect (P<.01).

[e] Differences are expressed as ad libitum-fed minus limit-fed. Actual differences are unadjusted for body weight differences; whereas, the weight-corrected differences measure the deviation of the actual treatment difference from that which would have been expected from treatment differences in body weight.

[f] Quadratic age effect (P<.001).

[g] Energy x linear age effect (P<.10).

[h] Quadratic age effect (P<.01).

[i] Mineral-vitamin x linear age effect (P<.05).

TABLE 14. PREDICTED MEANS AND ACTUAL AND WEIGHT-CORRECTED MEAN DIFFERENCE AT 85, 190 AND 295 DAYS ON TEST FOR FOURTH METACARPAL WEIGHT AND SIZE PARAMETERS OF BOARS AD-LIBITUM OR LIMIT-FED

Item	Days on test[a]		
	85	190	295
Weight, g[bcd]	12.25 ± 2.00	32.69 ± 1.10	42.54 ± 1.12
Actual difference[e]	1.14 ± 1.26	3.00 ± 1.38*	5.37 ± 1.57***
Weight-corrected difference[e]	-.66 ± .98	-1.50 ± 1.07	-2.36 ± 1.22*
Length, cm[bcf]	6.53 ± .18	8.58 ± .10	9.31 ± .10
Actual difference	.03 ± .11	.13 ± .12	.29 ± .14*
Weight-corrected difference	-.13 ± .10	-.20 ± .10+	.17 ± .12
Palmar dimension, cm[bg]	1.35 ± .05	1.76 ± .03	1.94 ± .03
Actual difference	-.01 ± .04	.02 ± .04	.08 ± .04+
Weight-corrected difference	-.04 ± .03	-.05 ± .03	-.02 ± .04
Axial dorsopalmar dimension, cm[bfh]	1.36 ± .05	1.79 ± .03	2.03 ± .03
Actual difference	.01 ± .03	.04 ± .04	.09 ± .04*
Weight-corrected difference	-.02 ± .03	-.04 ± .03	-.06 ± .04+
Abaxial dorsopalmar dimension, cm[bfg]	1.48 ± .06	1.97 ± .03	2.19 ± .03
Actual difference	.02 ± .04	.06 ± .04	.10 ± .05+
Weight-corrected difference	-.02 ± .03	-.03 ± .03	-.03 ± .04
Palmar thickness, mm[ij]	1.92 ± .20	2.61 ± .11	2.59 ± .12
Actual difference	.08 ± .13	.12 ± .14	.08 ± .16
Weight-corrected difference	.01 ± .11	.02 ± .12	.04 ± .14
Axial dorsopalmar thickness, mm[i]	1.92 ± .20	2.16 ± .11	2.30 ± .12
Actual difference	-.04 ± .13	-.06 ± .14	-.03 ± .16
Weight-corrected difference	-.08 ± .12	-.13 ± .13	-.12 ± .15
Abaxial dorsopalmar thickness, mm[bj]	1.31 ± .20	2.07 ± .11	2.19 ± .11
Actual difference	.09 ± .13	0 ± .14	-.33 ± .16*
Weight-corrected difference	0 ± .13	-.07 ± .14	-.22 ± .16

+,*,*** Energy effect (P<.10, .05 and .001, respectively).

[a] Mean body weight (kg): 43.4 and 41.7 at 85 d; 122.1 and 104.5 at (P<.01) 190 d; 180.2 and 131.7 at P<.001) 295 d, respectively for ad libitum - and limit-fed boars (linear age effect, P<.001; quadratic age effect, P<.05; energy x linear age effect, P<.001; energy x quadratic age effect, P<.05).

[b] Linear age effect (P<.001).

[c] Quadratic age effect (P<.001).

[d] Energy x linear age effect (P<.001).

[e] Differences are expressed as ad-libitum minus limit-fed. Actual differences are unadjusted for body weight differences; deviation of the actual treatment difference from that which would have been expected from treatment differences in body weight.

[f] Energy x linear age effect (P<.05).

[g] Energy x quadratic age effect (P<.01).

[h] Energy x quadratic age effect (P<.05).

[i] Linear age effect (P<.05).

[j] Quadratic age effect (P<.05).

TABLE 15. PREDICTED MEANS AND ACTUAL AND WEIGHT-CORRECTED MEAN DIFFERENCE AT 85, 190 AND 295 DAYS ON TEST FOR THIRD METATARSAL WEIGHT AND SIZE PARAMETERS OF BOARS AD-LIBITUM OR LIMIT-FED

Item	Days on test[a]		
	85	190	295
Weight, g[bcd]	15.72 ± 1.73	35.13 ± 1.01	44.51 ± 1.00
Actual difference[e]	1.32 ± 1.15	3.07 ± 1.26*	4.95 ± 1.40***
Weight-corrected difference[e]	-1.03 ± .99	-1.74 ± 1.09	-1.82 ± 1.22
Length, cm[bc]	7.04 ± .18	9.19 ± .10	9.93 ± .10
Actual difference	-.02 ± .12	.06 ± .13	.25 ± .15+
Weight-corrected difference	-.25 ± .11*	-.33 ± .12**	-.15 ± .13
Palmar dimension, cm[bf]	1.35 ± .07	1.62 ± .04	1.83 ± .04
Actual difference	-.01 ± .04	.03 ± .05	.12 ± .05*
Weight-corrected difference	-.03 ± .04	-.03 ± .04	-.02 ± .05
Axial dorsopalmar dimension, cm[bgh]	1.51 ± .05	1.92 ± .03	2.12 ± .03
Actual difference	.03 ± .03	.06 ± .04+	.11 ± .04**
Weight-corrected difference	-.01 ± .03	-.01 ± .03	-.02 ± .03
Abaxial dorsopalmar dimension, cm[bhg]	1.64 ± .06	2.05 ± .03	2.25 ± .03
Actual difference	.02 ± .04	.07 ± .04	.12 ± .05*
Weight-corrected difference	-.01 ± .03	-.01 ± .03	0 ± .04
Palmar thickness, mm[ij]	1.73 ± .18	2.52 ± .11	2.50 ± .11
Actual difference	-.15 ± .12	-.15 ± .13	.07 ± .15
Weight-corrected difference	-.22 ± .11*	-.24 ± .12*	.01 ± .13
Axial dorsopalmar thickness, mm[ik]	1.56 ± .16	2.00 ± .09	2.10 ± .10
Actual difference	.12 ± .11	.09 ± .12	-.13 ± .13
Weight-corrected difference	.05 ± .10	.02 ± .11	-.09 ± .12
Abaxial dorsopalmar thickness, mm[l]	1.50 ± .17	1.81 ± .10	1.86 ± .10
Actual difference	.05 ± .11	.07 ± .12	.05 ± .14
Weight-corrected difference	.01 ± .10	.02 ± .11	.03 ± .13

+,*,**,***Energy effect (P<.10, .05, .01 and .001, respectively)

[a]Mean body weight (kg): 43.4 and 41.7 at 85 d; 122.1 and 104.5 at (P<.01) 190 d; 180.2 and 131.7 at (P<.001) 295 d, respectively for ad libitum- and limit-fed boars (linear age effect, P<.001; quadratic age effect, P<.05; energy x linear age effect, P<.001; energy x quadratic age effect, P<.05).

[b]Linear age effect (P<.001).

[c]Quadratic age effect (P<.001).

[d]Energy x linear age effect (P<.001).

[e]Differences are expressed as ad libitum-fed minus limit-fed. Actual differences are unadjusted for body weight differences; whereas, the weight-corrected differences measure the deviation of the actual treatment difference from that which would have been expected from treatment differences in body weight.

[f]Energy x linear age effect (P<.05).

[g]Quadratic age effect (P<.05).

[h]Energy x linear age effect (P<.01).

[i]Linear age effect (P<.01).

[j]Quadratic age effect (P<.01).

[k]Mineral-vitamin x linear age effect (P<.10).

[l]Linear age effect (P<.05).

TABLE 16. PREDICTED MEANS AND ACTUAL AND WEIGHT-CORRECTED MEAN DIFFERENCE AT 85, 190 AND 295 DAYS ON TEST FOR FOURTH METATARSAL WEIGHT AND SIZE PARAMETERS OF BOARS AD-LIBITUM OR LIMIT-FED

Item	Days on test[a]		
	85	190	295
Weight, g[bcd]	16.04 ± 1.86	38.12 ± 1.11	48.41 ± 1.10
Actual difference[e]	1.04 ± 1.24	3.14 ± 1.37*	6.16 ± 1.55***
Weight-corrected difference[e]	-1.39 ± 1.02	-2.18 ± 1.12†	-1.92 ± 1.26
Length, cm[bcf]	7.61 ± .22	9.74 ± .13	10.66 ± .13
Actual difference	.07 ± .14	.21 ± .16	.41 ± .18*
Weight-corrected difference	-.13 ± .12	-.20 ± .13	-.18 ± .15
Palmar dimension, cm[bgh]	1.34 ± .05	1.64 ± .03	1.77 ± .03
Actual difference	0 ± .03	.02 ± .04	.08 ± .04†
Weight-corrected difference	-.03 ± .03	-.03 ± .03	.01 ± .04
Axial dorsopalmar dimension, cm[bcf]	1.44 ± .05	1.92 ± .03	2.11 ± .03
Actual difference	.01 ± .03	.04 ± .03	.08 ± .04
Weight-corrected difference	-.04 ± .02	-.04 ± .03	-.01 ± .03
Abaxial dorsopalmar dimension, cm[bhi]	1.54 ± .06	2.03 ± .03	2.24 ± .03
Actual difference	-.01 ± .04	.03 ± .04	.08 ± .05†
Weight-corrected difference	-.04 ± .03	-.05 ± .03	-.03 ± .04
Palmar thickness, mm[bj]	2.13 ± .20	2.80 ± .11	3.03 ± .11
Actual difference	-.11 ± .13	-.08 ± .14	.13 ± .16
Weight-corrected difference	-.17 ± .11	-.21 ± .12†	-.03 ± .14
Axial dorsopalmar thickness, mm[bg]	1.14 ± .13	1.76 ± .07	1.93 ± .08
Actual difference	-.03 ± .08	00 ± .09	.11 ± .10
Weight-corrected difference	-.08 ± .07	-.10 ± .08	-.04 ± .09
Abaxial dorsopalmar thickness, mm[k]	1.55 ± .14	1.83 ± .08	1.79 ± .08
Actual difference	-.03 ± .09	-.07 ± .10	-.09 ± .11
Weight-corrected difference	-.08 ± .08	-.10 ± .09	-.04 ± .11

†,*,***Energy effect (P<.10, .05 and .001, respectively).

[a]Mean body weight (kg): 43.4 and 41.7 at 85 d: 122.1 and 104.5 at (P<.01) 190 d; 180.2 and 131.7 at (P<.001) 295 d, respectively for ad libitum - and limit-fed boars (linear age effect, P<.001; quadratic age effect, P<.05; energy x linear age effect, P<.001; energy x quadratic age effect, P<.05).

[b]Linear age effect (P<.001).

[c]Quadratic age effect (P<.001).

[d]Energy x linear age effect (P<.001).

[e]Differences are expressed as ad libitum-fed minus limit-fed. Actual differences are unadjusted for body weight differences; whereas, the weight-corrected differences measure the deviation of the actual treatment difference from that which would have been expected from treatment differences in body weight.

[f]Energy x linear age effect (P<.05).

[g]Quadratic age effect (P<.05).

[h]Energy x linear age effect (P<.1).

[i]Quadratic age effect (P<.01).

[j]Mineral-vitamin x linear age effect (P<.05).

[k]Mineral-vitamin x quadratic age effect (P<.10).

the fourth metatarsal abaxial dorsopalmar thickness which tended to increase to 190 d on test but failed to display an overall age effect.

At an equal age, bone weight was greater for ad libitum-fed boars than for limit-fed boars (tables 13 to 16; appendix figure 14) with the difference significant by 295 d ($P < .01$) on test for the third metacarpal and at 190 d ($P < .05$) and 295 d ($P < .001$) for the fourth metacarpal and the third and fourth metatarsal. Metacarpals and metatarsals tended to be longer for ad libitum-fed boars when examined at a constant age although the energy difference for the third metacarpal was not significant ($P > .10$) and the energy level effects were more pronounced for the fourth metacarpal and metatarsal (tables 13 to 16; appendix figure 15). Correction for body weight differences reversed the energy level effects and produced consistent non-significant trends toward heavier and longer metacarpals and metatarsals for limit-fed boars. Mineral-vitamin level effects were not observed for bone weight and length. Grondalen (1974a) reported that sows fed restricted intake (80 to 90% of ad libitum) had longer femurs and tibias at 100 kg live weight as compared to sows fed ad libitum. Similar results have also been observed using 50 to 60% feed restriction (Reiland, 1978c). In general agreement with the present study, Kesel et al. (1982) reported heavier and longer metacarpals for boars fed ad libitum intake as compared with those fed 75% ad libitum intake when examined at a constant age; however, no significant energy level differences were evident when corrections were made for body weight. Also in agreement, elevation of dietary Ca and P levels above those recommended by NRC have been shown to have no effect on bone length (Nimmo et al., 1980b; Kornegay et al., 1981a; Arthur et al., 1982b). However, in contrast, Kornegay et al. (1981a) and Kesel et al. (1982) reported heavier metacarpals for growing boars when elevated Ca and P levels above NRC recommendations were fed. Several other studies have observed no affect of elevated Ca and P levels on bone weight (Doige et al., 1975; Nimmo et al., 1980b; Kornegay and Thomas, 1981; Arthur et al., 1982b).

When examined at an equal age, all shaft diameters, with the exception of the third metacarpal palmar dimension, were larger for ad libitum-fed boars with the difference significant ($P < .01$ to .10) by 295 d on test (tables 13 to 16; appendix figures 16 to 18). Correction for body weight differences reversed the energy level effects and produced trends in favor of the limit-fed boars. Mineral-vitamin level had no affect on shaft diameters.

Linear and quadratic regression coefficients did not differ with energy level ($P > .10$) for any of the thickness measurements (tables 13 to 16; appendix figures 19 to 21). However, palmar thickness of the third metacarpal and third and fourth metatarsal tended to be greater for the limit-fed boars until approximately 200 to 250 d on test after which the trend favored ad libitum-fed boars. The reverse of this was observed for the axial dorsopalmar thickness of the third metacarpal and third metatarsal and for the abaxial dorsopalmar thickness of the third and fourth metacarpal. Correction for body weight differences generally reduced the magnitude of bone wall thickness differences when the actual difference favored ad libitum-fed boars and often produced trends in favor of limit-fed boars. When the actual difference favored limit-fed boars, weight-correction increased the magnitude of the energy level difference.

With a few exceptions the elevated mineral-vitamin level had little affect on bone thicknesses. Palmar thickness of the third metacarpal ($P < .05$) and fourth metatarsal ($P < .05$) and axial dorsopalmar thickness of the third metatarsal ($P < .10$) were larger for boars fed 150% NRC mineral and vitamin recommendations. At a constant age, differences (100% minus 150% NRC minerals and vitamins) were .002, -.011 and .042 for third metacarpal palmar thickness; -.008, -.018 and -.028 for fourth metatarsal palmar thickness; -.005, -.013 and -.023 for third metatarsal axial dorsopalmar thickness, respectively for 85, 190 and 295 d on test. Little effect was observed as a result of body weight correction, as body weights were similar.

A comparison between third and fourth metacarpal and metatarsal weight, length, shaft diameter and wall thickness is presented in table 17. Bone weight and length was greater ($P < .001$) for metatarsals than for metacarpals. Likewise, outside bones (fourth metacarpals and metatarsals) were heavier and longer than inside bones (third metacarpals and metatarsals). The magnitude of the difference, however, was much greater between metacarpals and metatarsals than between inside and outside bones. The palmar dimension was greater for metacarpals than metatarsals and greater for outside bones than inside bones, while the reverse was true for the axial dorsopalmar dimension. These effects appeared to be solely due to the fourth metacarpal which displayed a greater palmar dimension and a smaller axial dorsopalmar dimension as compared with the other bones. No difference was apparent between metacarpal and metatarsal abaxial dorsopalmar dimension, while this diameter was greater ($P < .001$) for inside bones than for outside bones. Palmar thickness was greater ($P < .001$) for outside bones than for inside bones. Although palmar thickness was greater for

TABLE 17. WEIGHT, LENGTH, SHAFT DIAMETERS AND WALL THICKNESSES FOR THIRD AND FOURTH METACARPALS (MC) AND THIRD AND FOURTH METATARSALS (MT) OF BOARS[a]

Item	3rd MC	4th MC	3rd MT	4th MT
Weight, g[bcd]	34.01	34.10	36.43	39.07
Length, cm[bcd]	8.48	8.60	9.19	9.82
Palmar dimension, cm[bcd]	1.65	1.78	1.67	1.65
Axial dorsopalmar dimension, cm[bcd]	1.91	1.83	1.95	1.93
Abaxial dorsopalmar dimension, cm[cd]	2.16	1.99	2.08	2.05
Palmar thickness, mm[bcd]	2.42	2.51	2.40	2.81
Axial dorsopalmar thickness, mm[bd]	1.92	2.19	1.98	1.75
Abaxial dorsopalmar thickness, mm[def]	1.76	2.01	1.79	1.78

[a]Values are overall means.
[b]Metacarpal values differed from metatarsal values (P<.001).
[c]Inside (3rd MC and MT) bones differed from outside (4th MC and MT) bones (P<.001).
[d]Significant bone interaction (P<.001).
[e]Metacarpal values differed from metatarsal values (P<.01).
[f]Inside (3rd MC and MT) bones differed from outside (4th MC and MT) bones (P<.05).

metatarsals than metacarpals, this result was primarily due to the difference between the fourth metacarpal and fourth metatarsal. The fourth metacarpal exhibited a thicker bone wall at the axial dorsopalmar and the abaxial dorsopalmar positions as compared with the other bones.

Mechanical characteristics.

Metacarpal and metatarsal breaking strength, stiffness and flexural modulus increased with age while Young's modulus of elasticity exhibited a linear decrease with age (tables 18 to 21; appendix figures 22 to 25).

Ad libitum feeding tended to produce greater bone breaking strength, stiffness and flexural modulus values at 295 d on test with no consistent affect at 85 and 190 d and with the difference significant ($P < .10$ or $.05$) for the fourth metacarpal and the third metatarsal (tables 18 to 21). Young's modulus of elasticity was not significantly influenced by energy level. Weight-correction reversed the energy level effects and produced a consistent trend in favor of limit-fed boars for breaking strength, stiffness and flexural modulus while reducing the magnitude of the difference between energy levels for Young's modulus of elasticity. In general agreement with the present study, Kesel et al. (1982) observed greater values for boars on ad libitum intake as compared with those on 75% of ad libitum

TABLE 18. PREDICTED MEANS AND ACTUAL AND WEIGHT-CORRECTED MEAN DIFFERENCE AT 85, 190 AND 295 DAYS ON TEST FOR THIRD METACARPAL MECHANICAL PARAMETERS OF BOARS AD LIBITUM- OR LIMIT-FED

	Days on test[a]		
Item	85	190	295
Breaking strength, N[bc]	879 ± 209	2064 ± 118	2656 ± 121
Actual difference[d]	-31 ± 135	42 ± 148	241 ± 170
Weight-corrected difference[d]	-98 ± 123	-182 ± 135	-226 ± 156
Stiffness, N/m $(\times 10^4)$[be]	34.0 ± 9.7	91.5 ± 5.5	108.3 ± 5.6
Actual difference	-3.1 ± 6.3	-1.8 ± 6.9	5.2 ± 7.9
Weight-corrected difference	-6.2 ± 6.2	-9.8 ± 6.8	-9.0 ± 7.8
YME, Pa $(\times 10^6)$[b]	393 ± 40	325 ± 22	263 ± 23
Actual difference	-25 ± 26	-37 ± 28	-27 ± 32
Weight-corrected difference	-14 ± 24	-16 ± 26	.8 ± 30
Flexural modulus, Nm^2 $(\times 10^{-2})$[bef]	29.1 ± 8.3	78.4 ± 4.7	92.7 ± 4.8
Actual difference	-2.6 ± 5.4	-1.5 ± 5.9	4.4 ± 6.8
Weight-corrected difference	-5.3 ± 5.3	-8.4 ± 5.8	-7.7 ± 6.7

[a]Mean body weight (kg): 43.4 and 41.7 at 85 d; 122.1 and 104.5 at (P<.01) 190 d; 180.2 and 131.7 at (P<.001) 295 d, respectively for ad libitum- and limit-fed boars (linear age effect, P<.001; quadratic age effect, P<.05; energy x linear age effect, P<.001; energy x quadratic age effect, P<.05).

[b]Linear age effect (P<.001). N = Newtons. Pa = Pascals.

[c]Quadratic age effect (P<.10).

[d]Differences are expressed as ad libitum-fed minus limit-fed. Actual differences are unadjusted for body weight differences; whereas, the weight-corrected differences measure the deviation of the actual treatment difference from that which would have been expected from treatment differences in body weight.

[e]Quadratic age effect (P<.01).

[f]Energy x quadratic age effect (P<.10).

TABLE 19. PREDICTED MEANS AND ACTUAL AND WEIGHT-CORRECTED MEAN DIFFERENCE AT 85, 190 AND 295 DAYS ON TEST FOR FOURTH METACARPAL MECHANICAL PARAMETERS OF BOARS AD LIBITUM- OR LIMIT-FED

Item	Days on test[a]		
	85	190	295
Breaking strength, N[bc]	655 ± 207	1771 ± 114	2445 ± 115
Actual difference[d]	80 ± 131	183 ± 143	289 ± 162†
Weight-corrected difference[d]	3 ± 115	-95 ± 127	-306 ± 144*
Stiffness, N/m ($x10^4$)[bc]	49.1 ± 6.5	76.4 ± 3.7	107.8 ± 3.8
Actual difference	-.1 ± 4.2	3.6 ± 4.6	11.5 ± 5.3*
Weight-corrected difference	-2.1 ± 4.0	-6.1 ± 4.4	-11.6 ± 5.1*
YME, Pa ($x10^6$)[bc]	371 ± 31	276 ± 17	253 ± 18
Actual difference	-10 ± 20	-13 ± 22	-6 ± 25
Weight-corrected difference	3 ± 17	3 ± 19	-2 ± 22
Flexural modulus, Nm^2 ($x10^{-2}$)[bc]	28.0 ± 5.6	68.2 ± 3.2	92.2 ± 3.2
Actual difference	-.1 ± 3.6	3.1 ± 3.9	9.9 ± 4.6*
Weight-corrected difference	-1.8 ± 3.4	-5.2 ± 3.8	-9.9 ± 4.3*

†,*Energy effect ($P<.10$ and .05, respectively).

[a]Mean body weight (kg): 43.4 and 41.7 at 85 d; 122.1 and 104.5 at ($P<.01$) 190 d; 180.2 and 131.7 at ($P<.001$) 295 d, respectively for ad libitum- and limit-fed boars (linear age effect, $P<.001$; quadratic age effect $P<.05$; energy x linear age effect, $P<.001$; energy x quadratic age effect, $P<.05$).

[b]Linear age effect ($P<.001$). N = Newtons. Pa = Pascals.

[c]Energy x linear age effect ($P<.05$).

[d]Differences are expressed as ad libitum-fed minus limit-fed. Actual differences are unadjusted for body weight differences; whereas, the weight-corrected differences measure the deviation of the actual treatment difference from that which would have been expected from treatment differences in body weight.

TABLE 20. PREDICTED MEANS AND ACTUAL AND WEIGHT-CORRECTED MEAN DIFFERENCE AT 85, 190 AND 295 DAYS ON TEST FOR THIRD METATARSAL MECHANICAL PROPERTIES OF BOARS AD LIBITUM- OR LIMIT-FED

	Days on test[a]		
Item	85	190	295
Breaking strength, N[bcd]	550 ± 195	1868 ± 116	2439 ± 113
Actual difference[e]	128 ± 130	217 ± 143	229 ± 159
Weight-corrected difference[e]	-27 ± 125	-107 ± 138	-240 ± 153
Stiffness, N/m $(x10^4)$[bf]	41.6 ± 8.6	80.1 ± 4.9	110.0 ± 5.0
Actual difference	3.9 ± 5.6	7.3 ± 6.1	9.3 ± 7.0
Weight-corrected difference	1.0 ± 5.0	-2.0 ± 5.5	-9.5 ± 6.3
YME, Pa $(x10^6)$[g]	357 ± 36	261 ± 20	253 ± 21
Actual difference	-3 ± 23	-15 ± 25	-35 ± 29
Weight-corrected difference	7 ± 22	-1 ± 24	-26 ± 27
Flexural modulus, Nm^2 $(x10^{-2})$[bf]	29.5 ± 11.5	73.8 ± 6.5	94.4 ± 6.7
Actual difference	7.7 ± 7.4	11.9 ± 8.1	10.3 ± 9.4
Weight-corrected difference	4.4 ± 7.0	3.5 ± 7.7	-4.4 ± 8.9

[a]Mean body weight (kg): 43.4 and 41.7 at 85 d; 122.1 and 104.5 at (P<.01) 190 d; 180.2 and 131.7 at (P<.001) 295 d, respectively for ad libitum- and limit-fed boars (linear age effect, P<.001; quadratic age effect, P<.05; energy x linear age effect, P<.001; energy x quadratic age effect, P<.05).

[b]Linear age effect (P<.001). N = Newtons.

[c]Quadratic age effect (P<.05).

[d]Energy x linear age effect (P<.05).

[e]Differences are expressed as ad libitum-fed minus limit-fed. Actual differences are unadjusted for body weight differences; whereas, the weight-corrected differences measure the deviation of the actual treatment difference from that which would have been expected from treatment differences in body weight.

[f]Energy x linear age effect (P<.10).

[g]Linear age effect (P<.05). Pa = Pascals.

TABLE 21. PREDICTED MEANS AND ACTUAL WEIGHT-CORRECTED MEAN DIFFERENCE AT 85, 190 AND 295 DAYS ON TEST FOR FOURTH METATARSAL MECHANICAL PROPERTIES OF BOARS AD LIBITUM- OR LIMIT-FED

Item	Days on test[a] 85	190	295
Breaking strength, N[bc]	387 ± 192	1747 ± 117	2071 ± 109
Actual difference[d]	-32 ± 132	4 ± 145	123 ± 154
Weight-corrected difference[d]	-115 ± 144	-170 ± 141	-212 ± 125†
Stiffness, N/m ($x10^4$)[be]	34.1 ± 8.9	78.5 ± 5.1	97.4 ± 5.2
Actual difference	-4.1 ± 5.8	-4.2 ± 6.3	1.1 ± 7.3
Weight-corrected difference	-8.0 ± 5.7	-11.0 ± 6.2†	-6.3 ± 7.2
YME, Pa ($x10^6$)[fg]	299 ± 34	274 ± 19	232 ± 20
Actual difference	-12 ± 22	-20 ± 24	-19 ± 28
Weight-corrected difference	-4 ± 21	-6 ± 23	-5 ± 26
Flexural modulus, Nm^2 ($x10^{-2}$)[bc]	23.2 ± 7.2	71.6 ± 4.1	84.7 ± 4.2
Actual difference	-.6 ± 4.6	.8 ± 5.1	4.8 ± 5.9
Weight-corrected difference	-4.3 ± 4.5	-5.8 ± 4.9	-3.0 ± 5.6

†Energy effect (P<.10).

[a]Mean body weight (kg): 43.4 and 41.7 at 85 d; 122.1 and 104.5 at (P<.01) 190 d; 180.2 and 131.7 at (P<.001) 295 d, respectively for ad libitum- and limit-fed boars (linear age effect, P<.001; quadratic age effect, P<.05; energy x linear age effect, P<.001; energy x quadratic age effect, P<.05).

[b]Linear age effect (P<.001). N = Newtons.

[c]Quadratic age effect (P<.01).

[d]Differences are expressed as ad libitum-fed minus limit-fed. Actual differences are unadjusted for body weight differences; whereas, the weight-corrected differences measure the deviation of the actual treatment difference from that which would have been expected from treatment differences in body weight.

[e]Quadratic age effect (P<.10).

[f]Linear age effect (P<.01). Pa = Pascals.

[g]Energy x mineral-vitamin x quadratic age effect (P<.05).

intake when examined at an equal age but not when examined at an equal body weight.

Elevated mineral-vitamin levels generally increased metacarpal and metatarsal breaking strength, Young's modulus of elasticity, stiffness and flexural modulus (tables 22 to 25). The fourth metacarpal appeared to be less responsive than the third metacarpal. Metatarsals appeared to be more responsive to elevated mineral-vitamin level than metacarpals. Weight-correction increased the magnitude of the mineral-vitamin level differences for breaking strength, stiffness and flexural modulus but had little effect on Young's modulus of elasticity. The present study indicates that the response of metacarpals to mineral and vitamin levels above NRC recommendations is less dramatic than that of metatarsals. This is generally supported by the findings of Kornegay and Thomas (1981) who reported that Ca/P levels above NRC recommendations had no consistent effect on metacarpal breaking strength of growing boars, and that of Nimmo et al. (1980a) who reported that elevated mineral levels produced increased metatarsal breaking strength. In contrast, Kornegay et al. (1981a) and Kesel et al. (1982) reported increased metacarpal breaking strength resulting from 150% NRC Ca and P recommendations. The lack of a strong mineral-vitamin level affect on metacarpal or

TABLE 22. ACTUAL AND WEIGHT-CORRECTED MEAN DIFFERENCES AT 85, 190 AND 295 DAYS ON TEST FOR THIRD METACARPAL MECHANICAL PARAMETERS OF BOARS FED 100 OR 150% NRC MINERAL AND VITAMIN LEVELS

	Days on test[a]		
Item	85	190	295
Breaking strength, N			
Actual difference[b]	37 ± 135	-33 ± 148	-229 ± 171
Weight-corrected difference[b]	-3 ± 124	-90 ± 135	-269 ± 156†
Stiffness, N/m ($x10^4$)[c]			
Actual difference	-3.5 ± 6.3	-7.9 ± 6.9	-12.5 ± 7.9
Weight-corrected difference	-5.0 ± 6.2	-10.0 ± 6.8	-13.8 ± 7.8†
YME, Pa ($x10^6$)			
Actual difference	-24 ± 26	-35 ± 28	-26 ± 32
Weight-corrected difference	-19 ± 24	-29 ± 26	-23 ± 30
Flexural modulus, Nm^2 ($x10^{-2}$)[c]			
Actual difference	-2.9 ± 5.4	-6.7 ± 5.9	-10.7 ± 6.8
Weight-corrected difference	-4.3 ± 5.3	-8.6 ± 5.8	-11.8 ± 6.7†

† Mineral-vitamin effect (P<.10).
[a] Mean body weight (Kg): 43.8 and 41.3 at 85 d; 115.2 and 111.3 at 190 d; 157.7 and 154.2 at 295 d, respectively for boars fed 100 vs 150% mineral and vitamin levels.
[b] Differences are expressed as 100% minus 150% mineral and vitamin level. Actual differences are unadjusted for body weight; whereas, the weight-corrected differences measure the deviation of the actual treatment differences from that which would have been expected from treatment differences in body weight.
[c] Mineral-vitamin x linear age effect (P<.10). N = Newtons. Pa = Pascals.

TABLE 23. ACTUAL AND WEIGHT-CORRECTED MEAN DIFFERENCES AT 85, 190 AND 295 DAYS ON TEST FOR FOURTH METACARPAL MECHANICAL PARAMETERS OF BOARS FED 100 OR 150% NRC MINERAL AND VITAMIN LEVELS

	Days on test[a]		
Item	85	190	295
Breaking strength, N			
Actual difference[b]	7 ± 29	.3 ± 32	-24 ± 36
Weight-corrected difference[b]	-9 ± 26	-23 ± 28	-38 ± 32
Stiffness, N/m ($x10^4$)			
Actual difference	-3.7 ± 4.2	-4.0 ± 4.6	.6 ± 5.3
Weight-corrected difference	-5.3 ± 4.0	-6.3 ± 4.4	-1.2 ± 5.1
YME, Pa ($x10^6$)			
Actual difference	-9 ± 20	-8 ± 22	8 ± 25
Weight-corrected difference	-5 ± 17	-2 ± 19	10 ± 22
Flexural modulus, Nm^2 ($x10^{-2}$)			
Actual difference	-3.1 ± 3.6	-3.4 ± 3.9	.5 ± 4.6
Weight-corrected difference	-4.5 ± 3.4	-5.4 ± 3.8	-1.0 ± 4.3

[a]Mean body weight (kg): 43.8 and 41.3 at 85 d; 115.2 and 111.3 at 190 d; 157.7 and 154.2 at 295 d, respectively for boars fed 100 vs 150% mineral and vitamin levels.

[b]Differences are expressed as 100% minus 150% mineral and vitamin level. Actual differences are unadjusted for body weight; whereas, the weight-corrected differences measure the deviation of the actual treatment differences from that which would have been expected from treatment differences in body weight. N = Newtons. Pa = Pascals.

TABLE 24. ACTUAL AND WEIGHT-CORRECTED MEAN DIFFERENCES AT 85, 190 AND 295 DAYS ON TEST FOR THIRD METATARSAL MECHANICAL PARAMETERS OF BOARS FED 100 OR 150% NRC MINERAL AND VITAMIN LEVELS

Item	Days on test[a]		
	85	190	295
Breaking strength, N[b]			
Actual difference[c]	-11 ± 29	-38 ± 32	-79 ± 36*
Weight-corrected difference[c]	-19 ± 28	-48 ± 31	-82 ± 34*
Stiffness, N/m ($x10^4$)[b]			
Actual difference	-3.6 ± 5.6	-8.0 ± 6.1	-12.4 ± 7.0†
Weight-corrected difference	-5.3 ± 5.0	-10.4 ± 5.5†	-14.0 ± 6.3*
YME, Pa ($x10^6$)[d]			
Actual difference	7 ± 23	-4 ± 25	-37 ± 29
Weight-corrected difference	10 ± 22	0 ± 24	-35 ± 28
Flexural modulus, Nm^2 ($x10^{-2}$)[e]			
Actual difference	-7.7 ± 7.4	-12.8 ± 8.1	-13.0 ± 9.4
Weight-corrected difference	-9.3 ± 7.0	-15.0 ± 7.7†	-14.4 ± 8.9

†,*Mineral-vitamin effect (P<.10 or .05, respectively).
[a]Mean body weight (kg): 43.8 and 41.3 at 85 d; 115.2 and 111.3 at 190 d; 157.7 and 154.2 at 295 d respectively for boars fed 100 vs 150% mineral and vitamin levels.
[b]Mineral-vitamin x linear age effect (P<.05). N = Newtons.
[c]Differences are expressed as 100% minus 150% mineral and vitamin level. Actual differences are unadjusted for body weight; whereas, the weight-corrected differences measure the deviation of the actual treatment differences from that which would have been expected from treatment differences in body weight.
[d]Pa = Pascals.
[e]Mineral-vitamin x linear age effect (P<.10).

TABLE 25. ACTUAL AND WEIGHT-CORRECTED MEAN DIFFERENCES AT 85, 190 AND 295 DAYS ON TEST FOR FOURTH METATARSAL MECHANICAL PARAMETERS OF BOARS FED 100 OR 150% NRC MINERAL AND VITAMIN LEVELS

	Days on test[a]		
Item	85	190	295
Breaking strength, N[b]			
Actual difference[c]	-7 ± 30	-25 ± 32	-55 ± 35
Weight-corrected difference[c]	-23 ± 27	-46 ± 29	-66 ± 31*
Stiffness, N/m $(x10^4)$[d]			
Actual difference	3.0 ± 5.8	-2.5 ± 6.3	-18.1 ± 7.3*
Weight-corrected difference	1.5 ± 5.7	-4.5 ± 6.2	-19.1 ± 7.2**
YME, Pa $(x10^6)$[e]			
Actual difference	14 ± 22	-1 ± 24	-50 ± 28†
Weight-corrected difference	17 ± 21	3 ± 23	-48 ± 26†
Flexural modulus, Nm^2 $(x10^{-2})$[f]			
Actual difference	-.5 ± 4.6	-6.8 ± 5.1	-19.5 ± 5.9**
Weight-corrected difference	-1.9 ± 4.5	-8.7 ± 4.9†	-20.4 ± 5.6***

†,*,**,*** Mineral-vitamin effect (P<.10, .05, .01 and .001, respectively).

[a] Mean body weight (kg): 43.8 and 41.3 at 85 d; 115.2 and 111.3 at 190 d; 157.7 and 154.2 at 295 d, respectively for boars fed 100 vs 150% mineral and vitamin levels.

[b] Mineral-vitamin x linear age effect (P<.10). N = Newtons.

[c] Differences are expressed as 100% minus 150% mineral and vitamin level. Actual differences are unadjusted for body weight; whereas, the weight-corrected differences measure the deviation of the actual treatment differences from that which would have been expected from treatment differences in body weight.

[d] Mineral-vitamin x linear age effect (P<.05).

[e] Energy x mineral-vitamin x quadratic age effect (P<.05). Pa = Pascals.

[f] Mineral-vitamin x linear age effect (P<.01).

metatarsal elasticity in the present study agrees with the findings of Kornegay et al. (1981a) but disagrees with those of Kesel et al. (1982) who observed increased metacarpal elasticity with elevated (150% NRC) Ca and P levels.

Metacarpal breaking strength was greater ($P < .001$) than metatarsal breaking strength, while that of the inside bones (third metacarpals and metatarsals) was greater ($P < .001$) than for the outside bones (fourth metacarpals and metatarsals) (table 26). The results for Young's modulus of elasticity followed a pattern similar to that observed for breaking strength. Stiffness and flexural modulus values did not differ when metacarpals were compared to metatarsals, however, values for inside bones were consistently greater ($P < .001$) than those for outside bones.

<u>Bone chemical composition</u>.

Third metacarpal and metatarsal ether extract (27.85%) and ash (62.16%) when examined across treatments were found to not differ ($P > .10$) from fourth metacarpal and metatarsal ether extract (28.31%) and ash (61.91%) values. Therefore graphic representation of ether extract and ash values are by metacarpal and metatarsal only (appendix figure 26).

Percentage ether extract displayed a linear ($P < .01$)

TABLE 26. BREAKING STRENGTH, YOUNG'S MODULUS OF ELASTICITY, STIFFNESS AND FLEXURAL MODULUS FOR THIRD AND FOURTH METACARPALS (MC) AND THIRD AND FOURTH METATARSALS (MT) OF BOARS[a]

Item	3rd MC	4th MC	3rd MT	4th MT
Breaking strength, N[bc]	2145	1908	1921	1708
Young's modulus of elasticity, Pa ($\times 10^{6}$)[bc]	309	208	270	260
Stiffness, N/m ($\times 10^{4}$)[c]	90.5	83.3	87.1	80.0
Flexural modulus, Nm^2 ($\times 10^{-2}$)[c]	77.5	71.3	76.5	70.4

[a]Values are overall means.

[b]Metacarpal values differed from metatarsal values ($P<.001$). N = Newtons. Pa = Pascals.

[c]Inside (3rd MC and MT) bones differed from outside (4th MC and MT) bones ($P<.001$).

decrease over time (table 27; appendix figure 26). Metacarpal ether extract was lower (P < .001) than that of the metatarsal (25.00 vs 31.09%). Dietary mineral-vitamin level did not affect the metacarpal and metatarsal ether extract content. At a constant age, metacarpals and metatarsals from ad libitum-fed boars tended to have greater ether extract content as compared with limit-fed boars with the difference becoming significant (P < .05) by 295 d on test for the fourth metacarpal and fourth metatarsal. Correction for body weight differences had little affect on the energy level differences. Kesel et al. (1982) reported that metacarpal ether extract values were higher for ad libitum-fed boars at 80 and 150 d of age and higher for limit-fed (75% of ad libitum) boars at 220 d of age. In further contrast to the present study, Kesel et al. (1982) observed greater metacarpal ether extract content of boars fed 100% NRC Ca and P levels as compared with boars fed 150% NRC recommendations. Arthur et al. (1982b), however, reported that feeding of restricted energy intake (75% of ad libitum) or elevated Ca and P (150% NRC) during growth had no effect on ether extract content of metacarpals or metatarsals of sows following three parities.

Metacarpal and metatarsal ash content increased (P < .05) over time (table 28; appendix figure 26). Ash content

TABLE 27. PREDICTED MEANS AND ACTUAL AND WEIGHT-CORRECTED MEAN DIFFERENCES AT 85, 190 AND 295 DAYS ON TEST FOR METACARPAL AND METATARSAL PERCENT ETHER EXTRACT OF BOARS AD LIBITUM- OR LIMIT-FED

Item	Days on test[a]		
	85	190	295
Third metacarpal[b]	27.64 ± 2.08	25.96 ± 1.18	23.14 ± 1.23
Actual difference[c]	.36 ± 1.35	1.16 ± 1.47	2.34 ± 1.72
Weight-corrected difference[c]	.62 ± 1.34	1.72 ± 1.46	3.18 ± 1.71†
Fourth metacarpal[d]	26.50 ± 2.01	24.92 ± 1.16	23.75 ± 1.18
Actual difference	.75 ± 1.31	2.00 ± 1.44	3.62 ± 1.66*
Weight-corrected difference	.95 ± 1.32	2.12 ± 1.44	3.29 ± 1.67†
Third metatarsal[e]	31.41 ± 2.03	31.33 ± 1.16	29.60 ± 1.17
Actual difference	.28 ± 1.32	.94 ± 1.44	1.95 ± 1.65
Weight-corrected difference	.40 ± 1.31	1.25 ± 1.43	2.46 ± 1.64
Fourth metatarsal[bd]	34.53 ± 2.17	32.02 ± 1.23	29.94 ± 1.26
Actual difference	.05 ± 1.41	1.37 ± 1.53	4.08 ± 1.77*
Weight-corrected difference	.63 ± 1.36	1.97 ± 1.49	3.95 ± 1.72*

[†,*]Energy effect (P<.10 and .05, respectively).

[a]Mean body weight (kg): 43.4 and 41.7 at 85 d; 122.1 and 104.5 at (P<.01) 190 d; 180.2 and 131.7 at (P<.001) d, respectively for ad libitum- and limit-fed boars (linear age effect, P<.001; quadratic age effect, P<.05; energy x linear age effect, P<.001; energy x quadratic age effect, P<.05).

[b]Linear age effect (P<.01).

[c]Differences are expressed as ad libitum-fed minus limit-fed. Actual differences are unadjusted for body weight differences; whereas, the weight-corrected differences measure the deviation of the actual treatment difference from that which would have been expected from treatment differences in body weight.

[d]Energy x linear age effect (P<.05).

[e]Linear age effect (P<.10).

TABLE 28. PREDICTED MEANS AND ACTUAL AND WEIGHT-CORRECTED MEAN DIFFERENCES AT 85, 190 AND 295 DAYS ON TEST FOR METACARPAL AND METATARSAL PERCENT ASH FOR BOARS FED 100 OR 150% NRC MINERAL AND VITAMIN LEVELS

Item	Days on test[a]		
	85	190	295
Third metacarpal[bc]	59.57 ± .64	62.14 ± .36	62.29 ± .37
Actual difference[d]	-.51 ± .41	-.58 ± .45	-.03 ± .52
Weight-corrected difference[d]	-.59 ± .42	-.66 ± .45	-.05 ± .52
Fourth metacarpal[be]	59.57 ± .66	61.37 ± .38	62.04 ± .38
Actual difference	-.80 ± .43†	-1.03 ± .47*	-.41 ± .54
Weight-corrected difference	-.84 ± .44†	-1.08 ± .48*	-.45 ± .55
Third metatarsal[bcf]	59.78 ± .76	62.71 ± .43	63.07 ± .44
Actual difference	-.08 ± .49	-.54 ± .53	-1.39 ± .62*
Weight-corrected difference	-.15 ± .50	-.63 ± .55	-1.43 ± .63*
Fourth metatarsal[b]	60.95 ± .78	62.08 ± .45	63.29 ± .46
Actual difference	-.21 ± .52	-.25 ± .56	-.05 ± .64
Weight-corrected difference	-.25 ± .52	-.31 ± .56	-.10 ± .64

†,* Mineral-vitamin effect (.10 and .05, respectively).

[a] Mean body weight (kg): 43.8 and 41.3 at 85 d; 115.2 and 111.3 at 190 d; 157.7 and 154.2 at 295 d, respectively for boars fed 100 vs 150% mineral and vitamin levels.

[b] Linear age effect (P<.001).

[c] Quadratic age effect (P<.05).

[d] Differences are expressed as 100% minus 150% mineral and vitamin level. Actual differences are unadjusted for body weight; whereas, the weight-corrected differences measure the deviation of the actual treatment differences from that which would have been expected from treatment differences in body weight.

[e] Mineral-vitamin x linear age effect (P<.10).

[f] Mineral-vitamin x linear age effect (P<.05).

of the metacarpal was consistently lower ($P < .001$) than that of the metatarsal (61.63 vs 62.44%). Dietary energy level had no significant ($P > .10$) effect on metacarpal or metatarsal ash content, therefore only values for dietary mineral-vitamin level are presented (table 28). Ash content was greater for the 150% NRC mineral-vitamin level as compared with 100% NRC recommendations. The difference between dietary mineral-vitamin levels for the third and fourth metacarpals and fourth metatarsal tended to increase from 85 to 190 d on test and then decline to 295 d on test. These mineral-vitamin level differences, however, were only significant for the fourth metacarpal at 85 ($P < .10$) and 190 ($P < .05$) d on test. In contrast, the mineral-vitamin level difference for the third metatarsal displayed a consistent increase over time becoming significant ($P < .05$) by 295 d on test. Weight-correction failed to affect mineral-vitamin level differences. Kornegay et al. (1981a) and Kornegay and Thomas (1981) observed that boars fed diets containing Ca and P levels in excess of NRC recommendations produced metacarpal and mandible bone ash values which increased inconsistently with the magnitude of the increases being small. In contrast, linear increases in percentage ash of femurs and metatarsals of growing boars has been reported by Nimmo et al. (1980b) as dietary Ca and P levels were increased from 100 to 200% NRC recommendations. Kesel et al. (1982) reported that elevation of Ca and P levels (150% NRC) produced increased metacarpal ash only in the early growth of the boar.

The effects of dietary energy and mineral-vitamin levels on the mineral composition of the third and fourth metacarpals and metatarsals are presented in appendix tables 4 to 11. Statistical analysis revealed no significant ($P > .10$) difference between third or fourth metacarpal or metatarsal mineral values and few effects due to dietary treatment, therefore overall ash mineral content has been represented graphically (figures 1 and 2). Calcium content of bone ash generally increased with age. With the exception of the fourth metacarpal, ash Ca content tended to be higher for the 150% NRC mineral-vitamin level as compared with 100% NRC levels, however, this difference was significant ($P < .01$) only for the third metatarsal at 85 and 190 d on test. Phosphorus, as a percentage of bone ash, did not significantly change as age increased. Additionally, no consistent dietary energy or mineral-vitamin trends were apparent for bone P. This resulted in a bone ash Ca:P ratio which tended to increased with age.

The bone ash content of Mg, Cu, Zn, Fe and Mn decreased with age and may in part result from a dilution effect

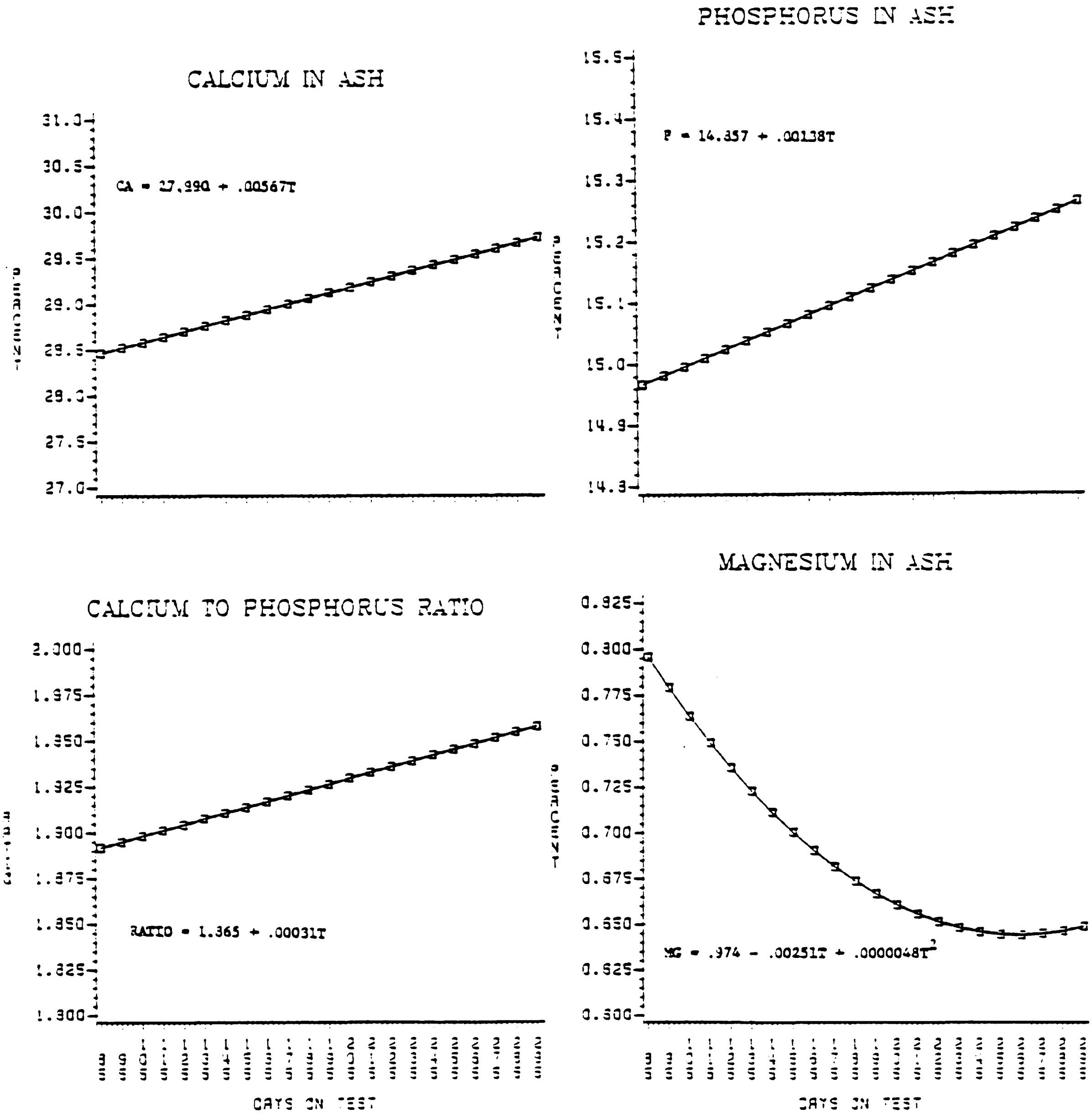

Figure 1. Metacarpal and metatarsal calcium, phosphorus, magnesium and calcium to phosphorus ratio for boars fed two energy levels (ad libitum vs limit) and two mineral and vitamin levels (100 vs 150% NRC). Overall means and prediction equations are presented.

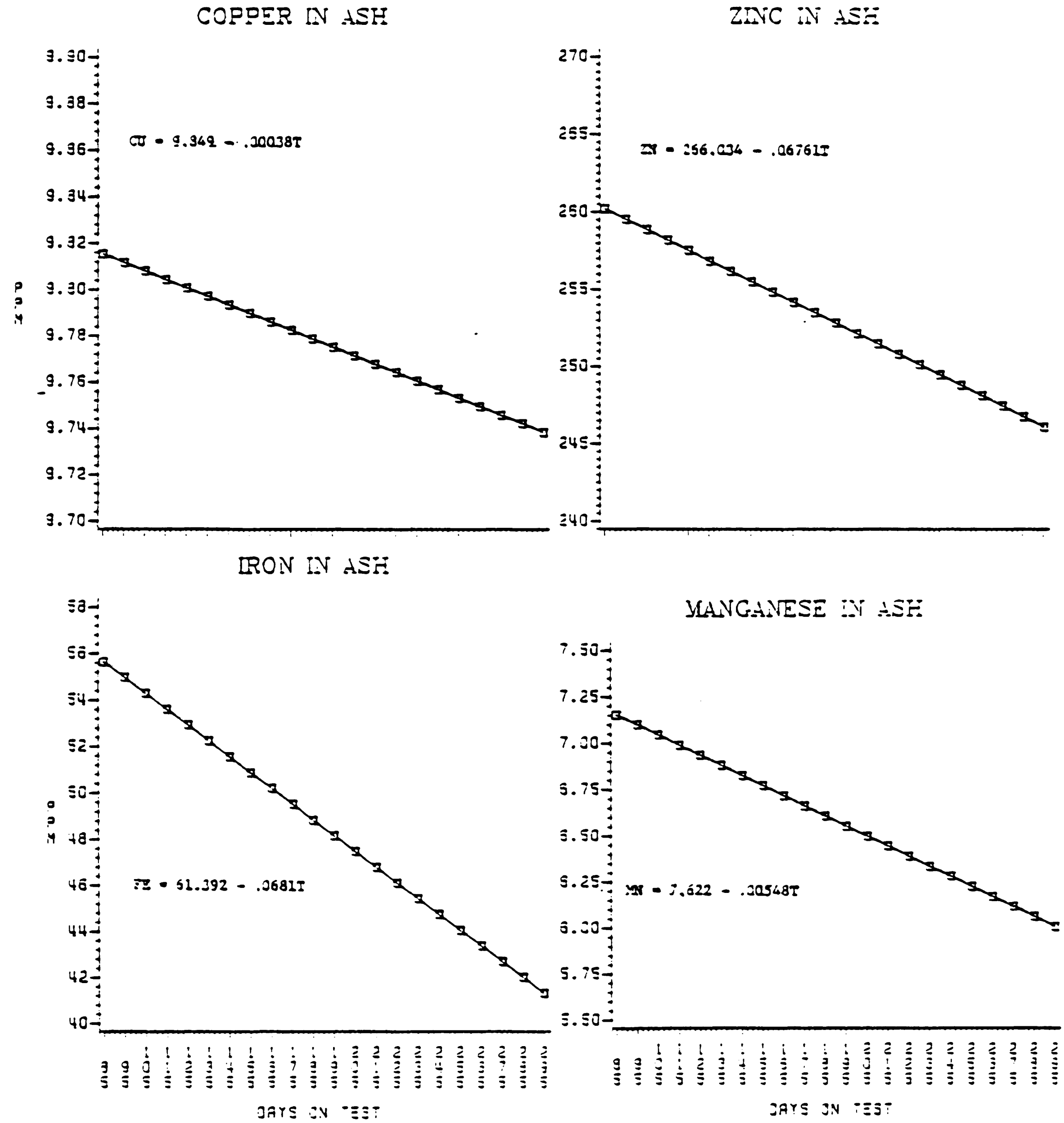

Figure 2. Metacarpal and metatarsal copper, zinc, iron and manganese for boars fed two energy levels (ad libitum vs limit) and two mineral and vitamin levels (100 vs 150% NRC). Overall means and prediction equations are presented.

caused by the increasing Ca content of bone ash. Several of the trace minerals are involved in enzyme systems essential for bone growth and development (Maynard and Loosli, 1975; Pike and Brown, 1975; Scott et al., 1976; Underwood, 1977). The reduced trace mineral content of bone ash may therefore reflect a reduced need for these minerals as the bone matures and growth rate decreases.

In agreement with the present study, Pond et al. (1975, 1978) reported that feeding growing-finishing pigs Ca and P levels above those recommended by the NRC had no effect on the Ca content of radius-ulna ash. Stockland and Blaylock (1973) similarly observed no effect on Ca and P content of metacarpal and turbinate ash as a result of elevated dietary Ca/P levels. Kesel et al. (1982) reported that growing boars fed 100 or 150% NRC Ca and P recommendations had elevated Ca content of metacarpal ash on the high Ca/P diet in early growth with effects no longer apparent as the boars matured. Kesel et al. (1982) further observed no effect of dietary mineral level on bone P content.

Horn chemical composition.

Dietary mineral and vitamin level had no effect on horn composition. The effect of energy intake is presented in table 29 and appendix figures 27 and 28.

Horn dry matter increased both linearly ($P < .001$) and

TABLE 29. PREDICTED MEANS AND ACTUAL AND WEIGHT-CORRECTED MEAN DIFFERENCES AT 85 190 AND 295 DAYS ON TEST FOR HORN CHEMICAL COMPOSITION OF BOARS AD LIBITUM OR LIMIT-FED

Item	Days on test[a]		
	85	190	295
Dry matter, %[bcd]	70.33 ± .46	74.91 ± .26	75.74 ± .27
Actual difference[e]	.46 ± .30	.64 ± .32*	.39 ± .37
Weight-corrected difference[e]	.18 ± .30	.09 ± .33	-.33 ± .38
Ether extract, %[f]	.61 ± .45	1.70 ± .12	1.73 ± .13
Actual difference	-.07 ± .16	-.03 ± .17	.16 ± .18
Weight-corrected difference	-.06 ± .16	-.02 ± .17	.17 ± .18
Ash, %[fg]	3.44 ± .60	1.34 ± .17	1.83 ± .29
Actual difference	.03 ± .20	.05 ± .19	.08 ± .28
Weight-corrected difference	-.04 ± .18	.01 ± .16	.16 ± .24
Calcium, %[hij]	.167 ± .010	.160 ± .005	.169 ± .005
Actual difference	-.016 ± .006**	-.021 ± .007**	-.012 ± .007*
Weight-corrected difference	-.016 ± .006**	-.020 ± .007**	-.006 ± .007
Phosphorus, %[bcdh]	.118 ± .006	.061 ± .003	.105 ± .003
Actual difference	.002 ± .003	-.001 ± .004	-.008 ± .004†
Weight-corrected difference	.002 ± .004	-.003 ± .004	-.016 ± .004***
Magnesium, %[hi]	.023 ± .001	.022 ± .001	.022 ± .001
Actual difference	-.001 ± .001	-.002 ± .001*	-.002 ± .001†
Weight-corrected difference	-.001 ± .001	-.002 ± .001†	0 ± .001
Copper, ppm[ghj]	5.36 ± .27	4.62 ± .14	4.51 ± .13
Actual difference	.05 ± .16	-.05 ± .17	-.32 ± .18 †
Weight-corrected difference	.08 ± .16	.10 ± .17	.02 ± .18
Zinc, ppm[bh]	128.10 ± 9.01	144.13 ± 4.54	158.95 ± 4.22
Actual difference	.31 ± 5.91	2.05 ± 5.72	5.28 ± 5.96
Weight-corrected difference	-2.88 ± 5.27	-3.62 ± 5.81	-1.25 ± 6.05
Iron, ppm[bfhk]	198.91 ± 17.25	107.49 ± 8.73	73.39 ± 8.02
Actual difference	20.70 ± 9.98*	15.86 ± 11.00	-22.58 ± 11.33 *
Weight-corrected difference	36.25 ± 9.61***	40.04 ± 10.59 ***	-1.48 ± 10.91
Manganese, ppm[bhi]	2.38 ± .34	2.49 ± .17	1.74 ± .16
Actual difference	.03 ± .19	-.17 ± .21	-.65 ± .22 **
Weight-corrected difference	.10 ± .19	.12 ± .21	.01 ± .22

†,*,**,***Energy effect (P<.05, .01 and .001, respectively).
[a]Mean body weight (kg) was 43.4 and 41.7 at 85 d; 122.1 and 104.5 (P<.001) at 190 d; 180.2 and 131.7 (P<.001) at 295 d, respectively for ad libitum and limit-fed boars (linear age effect, P<.001; quadratic age effect, P<.001; energy x linear age effect, P<.001; energy x quadratic age effect, P<.001).
[b]Linear age effect (P<.001).
[c]Quadratic age effect (P<.001).
[d]Energy x linear age effect (P<.10).
[e]Differences are expressed as ad libitum-fed minus limit-fed. Actual differences are unadjusted for body weight differences; whereas, the weight-corrected differences measure the deviation of the actual treatment difference from that which would have been expected from treatment differences in body weight.
[f]Quadratic age effect (P<.05).
[g]Linear age effect (P<.01).
[h]Percent of ppm of dry matter.
[i]Energy x linear age effect (P.<01).
[j]Energy x quadratic age effect (P<.10).
[k]Energy x quadratic age effect (P<.05).

quadratically ($P < .001$) over time. Percentage dry matter was greater for ad libitum-fed boars than for limit-fed boars with this difference most prominent ($P < .05$) at 190 d on test. Weight-correction tended to reduce the energy level differences at 85 and 190 d on test and reverse the direction of the effect at 295 d on test. Ether extract content of the horn increased quadratically ($P < .05$) over time with a large increase from 85 to 190 d on test and much less increased from 190 to 295 d on test. Examination of actual or weight-corrected differences yielded no significant energy level effects.

Horn ash content displayed both linear ($P < .01$) and quadratic ($P < .05$) age effects. Ash content was greatest at 85 d on test with a dramatic decrease by 190 d on test followed by a small increase to 295 d on test. Dietary energy level failed to alter percentage ash content of the horn.

Mineral content, expressed as percentage or ppm of dry matter, differed for each mineral examined. Horn Ca and Mg content did not change over time while linear decreases were noted for Cu ($P < .01$) and Mn ($P < .001$) content and a linear increase was noted for Zn ($P<.001$). Linear and quadratic changes over time were evident for P and Fe content. Phosphorus content decreased from 85 to 190 d on test followed by an increase to 295 d on test, while Fe decreased throughout the study. With the exception of Zn, limit feeding tended to increase the mineral content of the horn dry matter with this effect generally significant by 295 d on test. Ad libitum feeding tended to produce greater Zn values, however large variation prevented significant effects from being observed. Weight-correction generally reduced the magnitude of the energy level differences removing the significant differences seen at 295 d on test for Mg, Cu, Fe and Mn. Weight-correction had less of an effect on Ca and P content indicating that restricting energy intake can truly result in increased Ca and P content of the horn.

With the exception of Ca content, the mineral content of the horn obtained in the present study is in close agreement with that reported by Kovacs and Szilagyi (1973). The Ca level observed in the present study was substantially higher (.165 vs .100%) than determined by Kovacs and Szilagyi (1973).

Chapter V

INTERRELATIONSHIPS OF VARIOUS FOOT AND LEG MEASUREMENTS AND BONE CHARACTERISTICS OF GROWING BOARS FED TWO LEVELS OF ENERGY AND TWO LEVELS OF MINERALS AND VITAMINS

Summary

The results of a study to examine the effects of dietary energy level (ad libitum and 75% of ad libitum) and mineral-vitamin intake (100 and 150% of the National Research Council recommendations) on foot and leg development, incidence and severity of foot lesions, structural soundness scores and metacarpal and metatarsal characteristics were used to determine correlation coefficients for these various characteristics. Correlation coefficients for foot and leg characteristics were determined at 35 (0 d on test), 122 (87 d on test), 209 (174 d on test), 290 (255 d on test) and 330 (297 d on test) d of age to examine changes which occur over time. Foot and leg measurements were positively correlated to each other initially (0 d on test) with the correlation coefficients and significance levels increasing by 87 and 174 d on test. Examination of values at 255 and 295 d on test revealed a dramatic decrease in the magnitude and significance of

correlation coefficients and the presence of several negative values. This result is indicative of a similar growth pattern for foot and leg charactistics early in growth which becomes more divergent as the boar matures. Structural soundness scores taken at 87 and 255 d on test indicate trends towards improved structural soundness with longer limb bones and larger foot measurements. Little relationship was evident between toe area or volume and the incidence of foot lesions particularly as the boar matures. The Ca content of bone ash was generally positively correlated to bone dimensions while P content of bone ash had little effect. The Mg and trace mineral (Cu, Zn, Fe and Mn) content of bone ash were negatively correlated to bone size. Metacarpal and metatarsal dimensional characteristics exhibited strong positive correlation to bone breaking strength, stiffness, and flexural modulus and consistent negative correlation to Young's modulus of elasticity (YME). Negative correlations were evident between bone ash and YME while all other mechanical characteristics were positively correlated to bone ash. The results indicate that increased Ca content of bone ash results in a larger bone and greater breaking strength. Strong positive correlations between breaking strength and stiffness and flexural modulus, however, indicate a reduced ability of the bone to bend as breaking strength is increased which may not be advantageous under normal environmental conditions.

Introduction

In order to better understand the effects of altering dietary intake on growing boars it is essential to study the interrelationships among the various characteristics examined. This provides the opportunity to determine if alteration of a given characteristic through dietary intervention may result in desirable or undesirable changes in other related characteristics.

Arthur et al. (1982b) reported that foot and leg measurements of sows were generally positively correlated to one another, but were generally unrelated to the incidence of foot lesions. In contrast, Penny et al. (1963) and Newton et al. (1978) demonstrated a positive relationship between the size of the toe and the development of foot lesions, indicating the possibility of a larger toe being more prone to lesion development.

Cromwell et al. (1972) observed a positive correlation between metacarpal breaking strength and bone weight, but found no relationship between metacarpal ash content and bone breaking strength. Similar results have been reported in metacarpals by Kornegay et al. (1981b) and in the femur by Schroeder et al. (1974). Arthur et al. (1982b) reported that metacarpal and metatarsal weight was negatively correlated to bone elasticity while a positive relationship existed between bone breaking strength, stiffness and flexural modulus.

The objective of the research reported herein was to determine the interrelationships between various foot and leg characteristics, to examine changes in the relationships over time and to examine the interrelationships between bone measurements, mechanical characteristics and chemical composition.

Experimental Procedures

Data on foot and leg characteristics and metacarpal and metatarsal characteristics were obtained by the experimental procedures previously described (Chapters III and IV). Residual correlation coefficients were determined for these parameters after adjusting for treatment effects. Correlation coefficients among foot and leg means were determined at each of the four live animal measurement periods (0, 87, 174 and 255 d on test) and at the final necropsy period (297 d on test) to examine changes in correlation coefficients over time. Necropsy values occurring between 131 and 174 d on test or between 215 and

255 d on test were included with the live animal values at 174 and 255 d on test, respectively. Correlations among bone characteristics at necropsy were calculated separately for each bone.

Results and Discussion

Foot and leg correlations.

During period one (0 d on test) foot measurements were generally positively correlated ($P < .05$ to .01) to one another (table 30). Hind foot toe width appeared less highly correlated to front and hind horn height and toe length than was apparent for the other toe measurements. Metacarpal length was not significantly correlated to toe width or horn length while metatarsal length displayed consistent correlation with toe width but not with other toe measurements. The length of the ulna and tibia and circumference of the front and hind limbs were positively correlated to the foot measurements. Significant ($P < .05$) positive correlations were evident for metacarpal and ulna lengths and for metatarsal and tibia lengths. Similarly, metacarpal, metatarsal, ulna and tibia lengths were positively correlated to circumference of the front and hind limbs.

Changes occuring during period two (87 d on test) were

TABLE 30. PERIOD ONE CORRELATION COEFFICIENTS FOR FOOT AND LEG MEASUREMENTS OF BOARS FED TWO LEVELS OF ENERGY AND TWO LEVELS OF MINERALS AND VITAMINS[ab]

	F1I	F1O	H1I	H1O	F2I	F2O	H2I	H2O	F3I	F3O	H3I	H3O	F4I	F4O	H4I	H4O	MC	MT	Ulna	Tibia	CIRCF	CIRCH
F1I	1.0	.53**	.21	.25*	.29**	.22*	.23*	.21	.29**	.24*	.22*	.30**	.23*	.27*	.20	.34**	.08	.06	.28**	.30**	.34**	.24*
F1O		1.0	.24*	.36**	.28**	.31**	.22*	.24*	.26*	.16	.20	.37**	.21	.33**	.25*	.28**	.03	.07	.39**	.34**	.31**	.41**
H1I			1.0	.68**	.24*	.23*	.30**	.03	.47**	.49**	.36**	.38**	.49**	.41**	.27**	.22*	.08	0	.26*	.41**	.16	.20
H1O				1.0	.35**	.44**	.32**	.16	.52**	.54**	.46**	.55**	.62**	.55**	.47**	.42**	.20	.21	.49**	.50**	.29**	.40**
F2I					1.0	.56**	.45**	.26*	.40**	.41**	.49**	.47**	.32**	.34**	.39**	.31**	.09	.35**	.50**	.31**	.36**	.40**
F2O						1.0	.42**	.50**	.37**	.52**	.48**	.59**	.27*	.38**	.52**	.56**	.20	.31**	.50**	.40**	.41**	.50**
H2I							1.0	.29**	.17	.30**	.21	.24*	.15	.20	.24*	.20	.07	.24*	.37**	.31**	.49**	.48**
H2O								1.0	.12	.21	.05	.35**	.19	.18	.20	.42**	.16	.33**	.33**	.28**	.33**	.42**
F3I									1.0	.79**	.64**	.69**	.59**	.63**	.65**	.56**	.26*	.14	.60**	.39**	.40**	.46**
F3O										1.0	.63**	.73**	.52**	.60**	.60**	.60**	.29**	.18	.52**	.40**	.35*	.48**
H3I											1.0	.74**	.48**	.54**	.63**	.55**	.16	.14	.48**	.27*	.20	.36**
H3O												1.0	.55**	.66**	.65**	.71**	.20	.23*	.60**	.36**	.39**	.45**
F4I													1.0	.78**	.63**	.56**	.28*	.15	.46**	.31**	.33**	.44**
F4O														1.0	.69**	.62**	.29**	.14	.53**	.30**	.51**	.53**
H4I															1.0	.74**	.24*	.18	.52**	.33**	.41**	.43**
H4O																1.0	.17	.17	.52**	.27*	.46**	.50**
MC																	1.0	.28**	.24*	.20	.25*	.40**
MT																		1.0	.43**	.23*	.36**	.39**
Ulna																			1.0	.47**	.50**	.67**
Tibia																				1.0	.22*	.47**
CIRCF																					1.0	.58**
CIRCH																						1.0

[a]Measurements taken at initiation of dietary treatments.
[b]Values for front and hind inside and outside horn length (F1I, F1O, H1I and H1O), front and hind inside and outside toe width (F2I, F2O, H2I and H2O), front and hind inside and outside horn height (F3I, F3O, H3I and H3O), front and hind inside and outside toe length (F4I, F4O, H4I and H4O), metacarpal (MC) and metatarsal (MT) length and front and hind limb circumference (CIRCF and CIRCH).
*(P<.05).
**(P<.01).

not pronounced although correlation coefficients and significance levels increased in several cases (table 31). Little correlation was seen between hind outside horn height or hind inside toe length and any of the toe width measurements. Metacarpal correlation coefficients increased at period two becoming significant ($P < .01$) for all toe measurements. Metatarsal length correlation coefficients were significant ($P < .05$ to .01) for all toe measurements with the exception of front outside horn length, hind outside horn length and hind outside horn height. Correlations between ulna and tibia length and toe measurements remained relatively unchanged from periods one to two although individual values increased or decreased slightly. Correlations between front limb circumference and foot measurements increased ($P < .01$ in most cases). This was not true for hind limb circumference for which correlation coefficients were reduced dramatically. This effect was particularly evident for horn length and horn height. Correlations between bone lengths were generally increased by period two. Correlation of bone lengths to front limb circumference increased while those for hind limb circumference were less affected and in some cases decreased.

By period three (174 d on test) correlations between

TABLE 31. PERIOD TWO CORRELATION COEFFICIENTS FOR FOOT AND LEG MEASUREMENTS AND SOUNDNESS SCORES OF BOARS FED TWO LEVELS OF ENERGY AND TWO LEVELS OF MINERALS AND VITAMINS[ab]

	F1I	F1O	H1I	H1O	F2I	F2O	H2I	H2O	F3I	F3O	H3I	H3O	F4I	F4O	H4I	H4O	MC	MT	Ulna	Tibia	CIRCF	CIRCH	CS
F1I	1.0	.61**	.59**	.47**	.48**	.36**	.34**	.35**	.52**	.52**	.36**	.31**	.61**	.49**	.40**	.36**	.33**	.30**	.28**	.36**	.45**	.24*	-.29*
F1O		1.0	.52**	.43**	.36**	.35**	.41**	.26**	.42**	.41**	.32**	.30**	.42**	.35**	.23*	.21	.42**	.18	.24*	.17	.30**	.21	-.18
H1I			1.0	.54**	.26*	.21	.34**	.30**	.38**	.37**	.33**	.32**	.48**	.39**	.44**	.34**	.36**	.38**	.18	.21	.37**	.08	-.14
H1O				1.0	.20	.24*	.20	.45**	.27*	.24*	.40*	.24*	.37**	.43**	.32**	.44**	.24*	.21	.25*	.22*	.27*	.09	-.09
F2I					1.0	.66**	.57**	.45**	.37**	.36**	.28**	.14	.47**	.37**	.10	.10	.50**	.43**	.41**	.55**	.56**	.26*	-.43**
F2O						1.0	.57**	.61**	.34**	.37**	.17*	.07	.43**	.41**	.12	.27*	.53**	.45**	.52**	.50**	.57**	.19	-.33**
H2I							1.0	.47**	.28**	.26*	.17	.10	.47**	.37**	.10	.10	.42**	.40**	.45**	.53**	.56**	.26*	-.34**
H2O								1.0	.33**	.24*	.19	.05	.47**	.54**	.18	.34**	.52**	.59**	.54**	.49**	.61**	.31**	-.45*
F3I									1.0	.76**	.49**	.55**	.59**	.49**	.28*	.28**	.40**	.33**	.42**	.37**	.32**	.14	-.25*
F3O										1.0	.63**	.62**	.63**	.51**	.43**	.47**	.45**	.22*	.34**	.41**	.40**	.17	-.11
H3I											1.0	.75**	.40**	.47**	.41**	.50**	.40**	.33**	.42**	.37**	.32**	.14	.15
H3O												1.0	.35**	.31**	.34**	.40**	.29**	.07	.26*	.16	.24*	.25*	.10
F4I													1.0	.79**	.49**	.45**	.50**	.47**	.39**	.50**	.55**	.23*	-.40**
F4O														1.0	.45**	.54**	.48**	.49**	.42**	.40**	.51**	.23*	-.28*
H4I															1.0	.65**	.37**	.22*	.25*	.15	.35**	.26*	-.05
H4O																1.0	.34**	.25*	.28*	.15	.36**	.17	.01
MC																	1.0	.42**	.48**	.44**	.63**	.32**	-.36**
MT																		1.0	.41**	.34**	.50**	.18	-.15
Ulna																			1.0	.52**	.54**	.33**	-.31**
Tibia																				1.0	.61**	.20	-.35**
CIRCF																					1.00	.50**	-.41**
CIRCH																						1.0	-.07
CS																							1.0

[a]Measurements taken and structural soundness scores assigned at an average of 87 d on test.

[b]Values for front and hind inside and outside horn length (F1I, F1O, H1I and H1O), front and hind inside and outside toe width (F2I, F2O, H2I and H2O), front and hind inside and outside horn height (F3I, F3O, H3I and H3O), front and hind inside and outside toe length (F4I, F4O, H4I and H4O), metacarpal (MC) and metatarsal (MT) length, front and hind limb circumference (CIRCF and CIRCH) and average committee score (CS).

*(P<.05).

**(P<.01).

all foot measurements, bone lengths and limb circumferences increased so as to produce highly significant ($P < .01$) values (table 32).

Correlations which were prevalent during the first three periods were radically reduced by period four (255 d on test; table 33). Several negative values were evident particularly for correlations of horn length or toe width with horn height. Correlations between bone length and foot measurements were generally reduced to non-significant levels with only horn height displaying significant positive correlations with metatarsal, tibia and ulna length. Relatively consistent negative correlations can be noted for horn length and tibia length, and for horn height and metatarsal length. Metacarpal and metatarsal lengths were significantly ($P < .05$) correlated to front and hind limb circumference, respectively although no such effect was evident for ulna and tibia length with leg circumference.

By period five (297 d on test), correlation coefficients and significance level had reduced even further (table 34). Few significant correlations between foot measurements were seen with no consistent pattern evident. Likewise, correlations between bone lengths and foot measurements were low with several negative values evident particularly between bone length and horn height or toe

TABLE 32. PERIOD THREE CORRELATION COEFFICIENTS FOR FOOT AND LEG MEASUREMENTS OF BOARS FED TWO LEVELS OF ENERGY AND TWO LEVELS OF MINERALS AND VITAMINS[a,b]

	F1I	F1O	H1I	H1O	F2I	F2O	H2I	H2O	F3I	F3O	H3I	H3O	F4I	F4O	H4I	H4O	MC	MT	Ulna	Tibia	CIRCF	CIRCH
F1I	1.0	.81**	.69**	.63**	.54**	.64**	.59**	.45**	.56**	.58**	.60**	.60**	.74**	.71**	.67**	.60**	.53**	.51**	.43**	.52**	.57**	.62**
F1O		1.0	.67**	.60**	.50**	.63**	.59**	.52**	.63**	.65**	.53**	.54**	.71**	.78**	.66**	.60**	.52**	.48**	.41**	.54**	.51**	.47**
H1I			1.0	.71**	.57**	.61**	.62**	.52**	.48**	.43**	.59**	.46**	.62**	.61**	.74**	.68**	.47**	.32**	.63**	.58**	.57**	.58**
H1O				1.0	.54**	.60**	.43**	.71**	.54**	.49**	.63**	.51**	.61**	.65**	.70**	.71**	.46**	.41**	.54**	.52**	.57**	.47**
F2I					1.0	.65**	.56**	.54**	.50**	.46**	.49**	.49**	.62**	.56**	.54**	.47**	.29*	.57**	.51**	.37**	.67**	.55**
F2O						1.0	.67**	.59**	.58**	.59**	.53**	.47**	.66**	.70**	.61**	.57**	.54**	.52**	.47**	.36**	.65**	.58**
H2I							1.0	.47**	.38**	.42**	.40**	.37**	.63**	.62**	.58**	.44**	.46**	.34**	.40**	.29*	.59**	.57**
H2O								1.0	.51**	.53**	.55**	.51**	.55**	.63**	.68**	.74**	.59**	.48**	.57**	.56**	.64**	.55**
F3I									1.0	.82**	.52**	.51**	.65**	.66**	.50**	.53**	.52**	.59**	.49**	.46**	.48**	.39**
F3O										1.0	.55**	.60**	.61**	.67**	.45**	.69**	.58**	.57**	.44**	.46**	.47**	.37**
H3I											1.0	.82**	.57**	.55**	.70**	.69**	.47**	.51**	.50**	.51**	.46**	.43**
H3O												1.0	.56**	.55**	.63**	.59**	.45**	.55**	.44**	.49**	.47**	.45**
F4I													1.0	.89**	.71**	.57**	.51**	.43**	.42**	.47**	.67**	.51**
F4O														1.0	.73**	.63**	.58**	.45**	.43**	.44**	.66**	.48**
H4I															1.0	.82**	.54**	.34**	.51**	.54**	.63**	.57**
H4O																1.0	.60**	.48**	.58**	.67**	.60**	.61**
MC																	1.0	.39**	.60**	.50**	.57**	.53**
MT																		1.0	.49**	.43**	.43**	.47**
Ulna																			1.0	.65**	.62**	.61**
Tibia																				1.0	.46**	.51**
CIRCF																					1.0	.76**
CIRCH																						1.0

[a]Measurements taken at an average of 174 d on test.
[b]Values for front and hind inside and outside horn length (F1I, F1O, H1I and H1O), front and hind inside and outside toe width (F2I, F2O, H2I and H2O), front and hind inside and outside horn height (F3I, F3O, H3I and H3O), front and hind inside and outside toe length (F4I, F4O, H4I and H4O), metacarpal (MC) and metatarsal (MT) length and front and hind limb circumference (CIRCF and CIRCH).
*(P<.05).
**(P<.01).

TABLE 33. PERIOD FOUR CORRELATION COEFFICIENTS FOR FOOT AND LEG MEASUREMENTS AND SOUNDNESS SCORES OF BOARS FED TWO LEVELS OF ENERGY AND TWO LEVELS OF MINERALS AND VITAMINS[ab]

	F1I	F1O	H1I	H1O	F2I	F2O	H2I	H2O	F3I	F3O	H3I	H3O	F4I	F4O	H4I	H4O	MC	MT	Ulna	Tibia	CIRCF	CIRCH	CS
F1I	1.0	.39*	.24	.39*	.47**	.42**	.31	.38	.27	.15	.09	.15	.14	.40*	.16	.29	.51**	.30	.35*	.26	.53**	.29	-.28
F1O		1.0	.35*	.24	.13	.24	.33	.23	-.02	-.06	-.20	-.09	.23	.46**	.09	.18	.08	.25	.14	-.03	.16	.18	-.70**
H1I			1.0	.41*	.17	-.06	.50**	.18	-.001	-.02	.15	.29	-.01	.10	.45**	.27	.11	.22	.25	-.13	.29	.40*	-.39
H1O				1.0	.21	.30	.20	.42**	-.02	.05	.12	.25	-.05	.34*	.34*	.56**	.29	.50**	.27	-.06	.37*	.39*	-.38
F2I					1.0	.41*	.40*	.20	-.10	-.01	-.04	-.04	-.17	.14	.02	.07	.19	.35*	.19	.09	.59**	.35*	-.18
F2O						1.0	.28	.27	.27	.36*	.25	.18	.30	.63**	-.03	.35*	.34*	.08	.22	.28	.46**	.23	-.16
H2I							1.0	.32	.17	.17	-.22	-.07	.004	.30	.13	-.06	.19	.30	.17	.11	.35*	.55**	-.20
H2O								1.0	.27	.21	.02	.16	.19	.21	.13	.30	.31	.18	.35*	.30	.39*	.40*	-.58**
F3I									1.0	.75**	.47**	.58**	.58**	.40*	.23	.13	.54**	-.22	.34*	.45**	.37*	.15	-.10
F3O										1.0	.45**	.50**	.50**	.35*	.09	.10	.31	-.31	.25	.21	.19	.02	-.03
H3I											1.0	.77**	.47**	.14	.37*	.45**	.33*	-.36*	.33*	.37*	.29	.13	-.04
H3O												1.0	.34*	.05	.32	.53**	.55**	-.14	.62**	.51**	.45**	.16	-.05
F4I													1.0	.52**	.29	.26	.23	-.25	-.01	.20	.09	.06	-.34
F4O														1.0	.19	.42**	.31	.15	.11	.12	.27	.14	-.48*
H4I															1.0	.35*	.03	-.002	-.05	-.12	.23	.27	-.04
H4O																1.0	.30	.02	.43**	.29	.35*	.08	-.43*
MC																	1.0	.15	.56**	.55**	.53**	.33*	-.21
MT																		1.0	.05	-.18	.25	.31	-.16
Ulna																			1.0	.72**	.54**	.22	-.43*
Tibia																				1.0	.43**	.21	-.32
CIRCF																					1.0	.65**	-.28
CIRCH																						1.0	-.34
CS																							1.0

[a]Measurements taken and structural soundness scores assigned at an average of 255 d on test.
[b]Values for front and hind inside and outside horn length (F1I, F1O, H1I and H1O), front and hind inside and outside toe width (F2I, F2O, H2I and H2O), front and hind inside and outside horn height (F3I, F3O, H3I and H3O), front and hind inside and outside toe length (F4I, F4O, H4I and H4O), metacarpal (MC) and metatarsal (MT) length, front and hind limb circumference (CIRCF and CIRCH) and average committee score (CS).
*(P<.05).
**(P<.01).

TABLE 34. PERIOD FIVE CORRELATION COEFFICIENTS FOR FOOT AND LEG MEASUREMENTS OF BOARS FED TWO LEVELS OF ENERGY AND TWO LEVELS OF MINERALS AND VITAMINS[ab]

	F1I	F10	H1I	H10	F2I	F20	H2I	H20	F3I	F30	H3I	H30	F4I	F40	H4I	H40	MC	MT	Ulna	Tibia	CIRCF	CIRCH
F1I	1.0	.62*	.25	.44	.48	.26	.48	-.32	.31	.12	.17	.28	.72*	.20	.26	-.18	.75**	.13	.15	-.29	.18	-.15
F10		1.0	.71*	.70*	.58	.56	.55	.10	.06	.24	.30	.26	.36	.51	.34	.18	.65*	.43	.08	-.12	.50	-.32
H1I			1.0	.58	.30	.44	.78**	.29	-.34	-.03	.24	.06	-.04	.60*	.44	.38	.34	.38	.07	.11	.25	-.52
H10				1.0	.33	.42	.44	.39	.14	.36	.72*	.55	.44	.50	.51	.41	.29	-.07	-.27	.10	.07	-.62*
F2I					1.0	.19	.45	-.18	.01	-.24	.10	-.09	.35	.17	.50	-.12	.74**	.07	.01	.51	.36	.01
F20						1.0	.36	.13	.47	.49	.51	.58	.23	.29	.52	.54	.26	.19	-.24	-.20	.40	-.54
H2I							1.0	-.08	-.11	.37	.27	.09	.08	.53	.46	.02	.49	.20	-.19	.12	.11	-.55
H20								1.0	-.16	.05	.14	.41	-.07	.18	.16	.37	-.41	-.02	-.30	.15	-.31	-.32
F3I									1.0	.40	.35	.67*	.22	-.39	.09	-.14	.07	-.06	-.30	-.23	-.17	.06
F30										1.0	.43	.42	.32	-.05	.16	.60*	-.01	-.01	.20	-.34	.28	-.13
H3I											1.0	.71*	.20	.15	.36	.42	.22	-.56	-.36	.01	-.10	-.69*
H30												1.0	.24	-.09	.16	.18	.08	-.34	-.39	-.30	-.36	-.47
F4I													1.0	.38	.48	.24	.35	-.05	-.14	-.12	.35	-.31
F40														1.0	.42	.45	.03	.35	-.38	-.04	.57	-.69*
H4I															1.0	.63*	.17	.03	-.30	.55	.29	-.51
H40																1.0	-.21	-.02	-.12	.13	.39	-.61*
MC																	1.0	-.03	.39	-.05	.28	-.04
MT																		1.0	.16	-.16	.50	.24
Ulna																			1.0	-.16	.10	.53
Tibia																				1.0	-.09	.08
CIRCF																					1.0	-.13
CIRCH																						1.0

[a]Measurements were taken at an average of 297 d on test.
[b]Values for front and hind inside and outside horn length (F1I, F10, H1I and H10), front and hind inside and outside toe width (F2I, F20, H2I and H20), front and hind inside and outside horn height (F3I, F30, H3I and H30), front and hind inside and outside toe length (F4I, F40, H4I and H40), metacarpal (MC) and metatarsal (MT) length and front and hind limb circumference (CIRCF and CIRCH).
*(P<.05).
**(P<.01).

length. Correlation of bone lengths to one another generally yielded negative values. Front limb circumference was not significantly correlated to any of the foot measurements or bone lengths while only a few significant ($P < .01$) values were observed for hind limb circumference.

As seen in table 31, average committee scores at 87 d on test were generally negatively correlated to the foot measurements with significant values for toe width ($P < .01$), front inside toe length ($P < .01$) and front outside toe length ($P < .05$). Bone lengths were likewise negatively correlated to structural soundness score. These negative values indicate improved structural soundness with longer limb bones and larger foot measurements.

By 255 d on test all foot and leg measurements produced negative correlation coefficients for average committee score, however the number of significant values was reduced (table 33). Only front outside horn and toe length, hind outside toe width and toe length and the length of the ulna were significantly correlated with average committee score.

A high correlation was evident between the area and volume calculations (tables 35 to 39) as would be expected from the results observed for the individual measurement correlations. Only period five (297 d on test) failed to produce consistent area and volume correlations which is a

TABLE 35. PERIOD ONE CORRELATION COEFFICIENTS FOR TOE AREA, TOE VOLUME AND INCIDENCE OF FOOT LESIONS OF BOARS FED TWO LEVELS OF ENERGY AND TWO LEVELS OF MINERALS AND VITAMINS[ab]

	FARI	FARO	HARI	HARO	FVOLI	FVOLO	HVOLI	HVOLO	FPI	FPO	HPI	HPO	FHI	FHO	HHI	HHO	AFIS	AFOS	AHIS	AHOS
FARI	1.0	.73**	.65**	.45**	.94**	.73**	.72**	.54**	.17	.09	.17	-.04	.14	.28**	.09	.06	.23*	.25*	.15	.01
FARO		1.0	.72**	.63**	.76**	.95**	.77**	.72**	.15	.10	.02	-.03	.06	.24*	.09	.31**	.16	.23*	.07	.19
HARI			1.0	.52**	.67**	.72**	.92**	.58**	.28**	.13	.08	.03	.15	.25*	.09	.22*	.32**	.25*	.11	.16
HARO				1.0	.47**	.61**	.51**	.96**	.26*	.25*	-.12	-.02	.08	.16	.06	.41**	.26*	.30**	.01	.28**
FVOLI					1.0	.82**	.77**	.58**	.10	.02	.08	-.06	.10	.30**	.13	.07	.14	.20	.14	-.004
FVOLO						1.0	.80**	.72**	.06	.01	-.02	-.08	.08	.29**	.11	.29**	.10	.19	.07	.14
HVOLI							1.0	.62**	.21*	.08	.02	-.04	.13	.27*	.12	.26*	.26*	.23*	.11	.15
HVOLO								1.0	.24*	.23*	-.09	-.06	.07	.20	.10	.40**	.24*	.31**	.06	.24*
FPI									1.0	.45**	.32**	-.06	-.04	-.02	.05	.03	.80**	.34**	.21*	.01
FPO										1.0	.23*	-.05	-.05	-.01	-.01	.06	.34**	.78**	.004	.03
HPI											1.0	-.03	-.09	.07	.01	-.15	.21*	.22*	.50**	-.13
HPO												1.0	-.06	-.05	.04	.03	-.09	-.07	.04	.67**
FHI													1.0	.29**	-.09	-.06	.56**	.14	-.12	-.10
FHO														1.0	.03	.08	.15	.61**	-.01	.03
HHI															1.0	.17	-.01	.01	.81**	.09
HHO																1.0	-.01	.01	.08	.70**
AFIS																	1.0	.37**	.11	-.05
AFOS																		1.0	-.003	.05
AHIS																			1.0	.03
AHOS																				1.0

[a]Values determined and feet scored at initiation of dietary treatments.
[b]Values for front and hind inside and outside toe base area (FARI, FARO, HARI and HARO), front and hind inside and outside toe volume (FVOLI, FVOLO, HVOLI and HVOLO), front and hind inside and outside pad lesion incidence (FPI, FPO, HPI and HPO), front and hind inside and outside horn lesion incidence (FHI, FHO, HHI and HHO), front and hind inside and outside average foot lesion incidence (AFIS, AFOS, AHIS, AHOS).
*(P<.05).
**(P<.01).

TABLE 36. PERIOD TWO CORRELATION COEFFICIENTS FOR TOE AREA, TOE VOLUME AND INCIDENCE OF FOOT LESIONS OF BOARS FED TWO LEVELS OF ENERGY AND TWO LEVELS OF MINERALS AND VITAMINS[ab]

	FARI	FARO	HARI	HARO	FVOLI	FVOLO	HVOLI	HVOLO	FPI	FPO	HPI	HPO	FHI	FHO	HHI	HHO	AFIS	AFOS	AHIS	AHOS
FARI	1.0	.76**	.67**	.56**	.93**	.76**	.65**	.53**	-.09	-.13	.05	.18	-.03	.03	-.09	.14	--.08	-.09	.001	.18
FARO		1.0	.61**	.72**	.73**	.93**	.61**	.63**	-.03	-.04	.06	.22*	-.04	.12	-.05	.18	-.05	.04	.02	.25*
HARI			1.0	.55**	.63**	.61**	.87**	.54**	-.16	-.03	-.03	.01	-.12	.05	-.07	.12	-.19	.01	-.06	.04
HARO				1.0	.55**	.68**	.57**	.86**	.16	.01	-.08	.32**	-.01	.11	-.02	.29**	.09	-.08	-.08	.37**
FVOLI					1.0	.81**	.67**	.60**	-.10	-.12	.01	.19	.01	.06	-.05	.07	-.05	-.07	-.02	.15
FVOLO						1.0	.70**	.71**	-.07	-.03	.02	.21	-.03	.19	-.08	.13	-.06	.10	-.02	.24*
HVOLI							1.0	.72**	-.13	-.09	-.08	.06	-.09	.05	-.09	.06	-.15	-.04	-.11	.06
HVOLO								1.0	.10	-.04	-.12	.29**	-.01	-.05	-.03	.13	.05	-.08	-.12	.31**
FPI									1.0	.21	-.06	.26**	0	-.04	-.05	-.02	.59**	.15	-.08	.23*
FPO										1.0	-.12	.10	-.06	-.14	-.08	-.08	.08	.64**	-.15	-.001
HPI											1.0	.28*	-.04	.26*	-.06	.15	-.07	.12	.85**	.23*
HPO												1.0	-.06	.23**	-.03	.01	.11	.27*	.23*	.74**
FHI													1.0	-.10	0	.17	.81**	-.13	-.04	.08
FHO														1.0	-.04	-.03	-.10	.64**	.21	.16
HHI															1.0	-.02	-.03	-.09	.47**	-.03
HHO																1.0	.13	-.09	.12	.59*
AFIS																	1.0	-.02	-.07	.20
AFOS																		1.0	.06	.13
AHIS																			1.0	.19
AHOS																				1.0

[a]Values determined and feet scored at an average of 87 d on test.

[b]Values for front and hind inside and outside toe base area (FARI, FARO, HARI and HARO), front and hind inside and outside toe volume (FVOLI, FVOLO, HVOLI and HVOLO), front and hind inside and outside pad lesion incidence (FPI, FPO, HPI and HPO), front and hind inside and outside horn lesion incidence (FHI, FHO, HHI and HHO), front and hind inside and outside average foot lesion incidence (AFIS, AFOS AHIS and AHOS).

*(P<.05).

**(P<.01).

TABLE 37. PERIOD THREE CORRELATION COEFFICIENTS FOR TOE AREA, TOE VOLUME AND INCIDENCE OF FOOT LESIONS OF BOARS FED TWO LEVELS OF ENERGY AND TWO LEVELS OF MINERALS AND VITAMINS[ab]

	FARI	FARO	HARI	HARO	FVOLI	FVOLO	HVOLI	HVOLO	FPI	FPO	HPI	HPO	FHI	FHO	HHI	HHO	AFIS	AFOS	AHIS	AHOS
FARI	1.0	.83**	.74**	.61**	.97**	.81**	.75**	.66**	.07	-.06	.001	-.02	0	.06	-.19	.003	.07	-.04	-.09	-.02
FARO		1.0	.79**	.69**	.84**	.96**	.79**	.71**	.18	.07	-.01	.01	0	.05	-.20	.06	.18	.09	-.10	.01
HARI			1.0	.67**	.71**	.74**	.97**	.69**	.15	.05	.10	-.04	0	.03	-.20	.16	.15	.06	.004	-.04
HARO				1.0	.63**	.68**	.73**	.94**	.12	.25*	.03	.24*	0	.06	-.16	.13	.12	.26*	-.04	.24*
FVOLI					1.0	.86**	.73**	.67**	.13	.01	-.004	.07	0	.05	-.17	.03	.13	.03	-.08	.07
FVOLO						1.0	.75**	.71**	.20	.07	-.001	.05	0	.09	-.21	.02	.20	.10	-.09	.05
HVOLI							1.0	.79**	.12	.04	.10	-.02	0	-.01	-.18	.19	.12	.03	.02	-.02
HVOLO								1.0	.10	.12	.04	.17	0	.08	-.17	.14	.10	.15	-.04	.17
FPI									1.0	.40**	.32**	.33**	0	.16	-.08	.16	1.00	.44**	.27*	.33**
FPO										1.0	.16	.45**	0	-.12	.24	.06	.40**	.94**	.26*	.45**
HPI											1.0	.23	0	.11	-.12	.11	.32**	.20	.90**	.23
HPO												1.0	0	.06	.11	.26*	.33**	.46**	.27*	1.00
FHI													1.0	0	0	0	0	0	0	0
FHO														1.0	-.03	-.06	.16	.22	.09	.06
HHI															1.0	-.03	-.08	.22	.33**	.11
HHO																1.0	.16	.04	.09	.26*
AFIS																	1.0	.44**	.27*	.33**
AFOS																		1.0	.29*	.46**
AHIS																			1.0	.27*
AHOS																				1.0

[a]Values determined and feet scored at an average of 174 d on test.
[b]Values for front and hind inside and outside toe base area (FARI, FARO, HARI and HARO), front and hind inside and outside toe volume (FVOLI, FVOLO, HVOLI and HVOLO), front and hind inside and outside pad lesion incidence (FPI, FPO, HPI and HPO), front and hind inside and outside horn lesion incidence (FHI, FHO, HHI and HHO), front and hind inside and outside average foot lesion incidence (AFIS, AFOS, AHIS and AHOS).
*(P<.05).
**(P<.01).

TABLE 38. PERIOD FOUR CORRELATION COEFFICIENTS FOR TOE AREA, TOE VOLUME AND INCIDENCE OF FOOT LESIONS OF BOARS FED TWO LEVELS OF ENERGY AND TWO LEVELS OF MINERALS AND VITAMINS[ab]

	FARI	FARO	HARI	HARO	FVOLI	FVOLO	HVOLI	HVOLO	FPI	FPO	HPI	HPO	FHI	FHO	HHI	HHO	AFIS	AFOS	AHIS	AHOS
FARI	1.0	.58**	.31	.35*	.93**	.62**	.46**	.36*	.01	.06	.12	-.10	0	.35*	0	-.21	.01	.26	.12	-.17
FARO		1.0	.25	.42**	.59**	.94**	.32	.36**	-.02	-.10	.28	.29	0	.49**	0	-.28	-.02	.25	.28	.14
HARI			1.0	.25	.32	.24	.87**	.21	-.15	-.22	.26	-.15	0	.06	0	-.19	-.15	-.17	.26	-.24
HARO				1.0	.35*	.39*	.38*	.92**	-.09	-.05	.13	.35	0	.11	0	.05	-.09	-.05	.13	.35*
FVOLI					1.0	.70**	.51**	.43**	-.09	.01	.01	-.07	0	.36*	0	-.21	-.09	.24	.01	-.15
FVOLO						1.0	.38*	.39*	.06	-.13	.16	.25	0	.55**	0	-.26	.06	.24	.16	.11
HVOLI							1.0	.48**	-.09	-.15	.19	-.06	0	.15	0	-.27	-.09	-.08	.19	-.16
HVOLO								1.0	-.14	-.04	.03	.35*	0	.10	0	-.05	-.14	-.03	.03	.30
FPI									1.0	-.05	0	-.08	0	0	0	-.06	1.00	-.05	0	-.12
FPO										1.0	.13	-.15	0	.05	0	-.04	-.05	.85**	.13	-.11
HPI											1.0	.06	0	-.04	0	-.06	0	.10	1.00	.02
HPO												1.0	0	-.05	0	-.09	-.08	-.10	.06	.84**
FHI													1.0	0	0	0	0	0	0	0
FHO														1.0	0	.21	0	.47**	-.04	.12
HHI															1.0	0	0	0	0	0
HHO																1.0	-.06	-.08	-.06	.39*
AFIS																	1.0	.05	0	-.12
AFOS																		1.0	.10	-.07
AHIS																			1.0	.02
AHOS																				1.0

[a]Values determined and feed scored at an average of 255 d on test.
[b]Values for front and hind inside and outside toe base area (FARI, FARO, HARI and HARO), front and hind inside and outside toe volume (FVOLI, FVOLO, HVOLI and HVOLO), front and hind inside and outside pad lesion incidence (FPI, FPO, HPI and HPO), front and hind inside and outside horn lesion incidence (FHI, FHO, HHI and HHO), front and hind inside and outside average foot lesion incidence (AFIS, AFOS, AHIS and AHOS).
*(P .05).
**(P .01).

TABLE 39. PERIOD FIVE CORRELATION COEFFICIENTS FOR TOE AREA, TOE VOLUME AND INCIDENCE OF FOOT LESIONS OF BOARS FED TWO LEVELS OF ENERGY AND TWO LEVELS OF MINERALS AND VITAMINS[ab]

	FARI	FARO	HARI	HARO	FVOLI	FVOLO	HVOLI	HVOLO	FPI	FPO	HPI	HPO	FHI	FHO	HHI	HHO	AFIS	AFOS	AHIS	AHOS
FARI	1.0	.38	.57	-.04	.91**	.35	.52	.01	0	-.14	.11	-.17	0	.20	0	0	0	-.01	.11	-.17
FARO		1.0	.66*	.52	.38	.95**	.68*	.57	0	.06	-.29	.36	0	-.09	0	0	0	-.001	-.29	.36
HARI			1.0	.27	.49	.53	.95**	.30	0	.11	.13	.18	0	-.01	0	0	0	.09	.13	.18
HARO				1.0	-.10	.58	.33	.95**	0	.19	.25	.26	0	-.12	0	0	0	.10	.25	.26
FVOLI					1.0	.39	.50	.04	0	-.18	.04	-.35	0	.32	0	0	0	.02	.04	-.35
FVOLO						1.0	.59	.63*	0	-.10	-.31	.26	0	.06	0	0	0	-.05	-.31	.26
HVOLI							1.0	.42	0	.12	.06	.14	0	.19	0	0	0	.20	.06	.14
HVOLO								1.0	0	.16	.23	.15	0	.02	0	0	0	.14	.23	.15
FPI									1.0	0	0	0	0	0	0	0	0	0	0	0
FPO										1.0	0	.52	0	0	0	0	0	.84**	0	.52
HPI											1.0	0	0	0	0	0	0	0	1.0	0
HPO												1.0	0	0	0	0	0	.44	0	1.0
FHI													1.0	0	0	0	0	0	0	0
FHO														1.0	0	0	0	.54	0	0
HHI															1.0	0	0	0	0	0
HHO																1.0	0	0	0	0
AFIS																	1.0	0	0	0
AFOS																		1.0	0	.44
AHIS																			1.0	0
AHOS																				1.0

[a]Values determined and feet scored at an average of 297 d on test.

[b]Values for front and hind inside and outside toe base area (FARI, FARO, HARI and HARO), front and hind inside and outside toe volume (FVOLI, FVOLO, HVOLI and HVOLO), front and hind inside and outside pad lesion incidence (FPI, FPO, HPI and HPO), front and hind inside and outside horn lesion incidence (FHI, FHO, HHI and HHO), front and hind inside and outside average foot lesion incidence (AFIS, AFOS, AHIS and AHOS).

*(P<.05).

**(P<.01).

reflection of a similar lack of correlation among foot measurements at that time.

Significant ($P < .05$ to $.01$) positive correlations were apparent between incidence of front outside horn lesions and area or volume of the front toes at period one (0 d on test) (table 35). A similar effect was seen for hind outside horn lesion incidence and hind toe area and volume. Hind toe area and volume also displayed consistent positive correlations to incidence of front inside pad lesions. The incidence of lesions on front inside and front outside pads ($P < .05$) and front inside and front outside horns ($P < .05$) were also significantly correlated. Correlations between average foot scores and toe areas or volumes reflected the values obtained for individual pad or horn lesion incidence.

Fewer significant correlations between incidence of pad or horn lesions and volume or area of toes was observed during period two (87 d on test) than were seen in period one (table 36). Although not significant, inside pad and horn incidence and front outside pad incidence became negatively correlated with toe area and volume. Hind outside pad lesion incidence was positively correlated to front ($P < .05$) and hind ($P < .01$) outside toe area and to hind outside toe volume ($P < .01$), while hind horn lesion incidence was positively correlated to hind outside toe area

(P < .01).

During the final three periods low lesion incidence and reduced animal numbers made calculation of correlation coefficients impossible in several cases. Few significant correlations between lesion incidence and toe area or volume were evident during these periods. During period three (174 d on test; table 37) hind inside horn lesion incidence exhibited consistent trends towards negative correlation to toe area and volume. Also during this period, pad scores were generally positively correlated to each other (P < .01). By period four (255 d on test; table 38) front outside horn lesion incidence was positively correlated to front inside toe area and volume (P < .05) and to front outside toe area and volume (P < .01). The lack of significant correlations in periods four and five (tables 38 and 39) indicate that as boars mature the area or volume of the toe has little effect on the incidence of foot lesions. Penny et al. (1963) reported that larger outside toes may result in a greater risk of injury to those toes. Likewise, Newton et al. (1978) observed that lesions of the sole of the foot were most prevalent in pigs with longer and wider toes. The present study found only minimal evidence to support such a hypothesis and suggests little consistent correlation between toe area or volume and the incidence of lesion. Additionally, the present study indicates very little consistant relationship among the incidence of lesions at the various locations of the front or hind feet.

<u>Bone correlations</u>.

Correlations between bone dimensional, mechanical and chemical characteristics are presented in tables 40 to 43.

Bone weight and bone length were highly positively correlated to the external shaft diameters and less highly correlated, although still generally significant ($P < .05$ to $.01$), to bone wall thicknesses. Bone dimensions were positively correlated to each other with the exception of the third metatarsal abaxial dorsopalmar thickness which displayed little correlation to the other measurements of that bone. Metacarpal and metatarsal dimensional characteristics (weight, length, shaft diameters and wall thicknesses) exhibited strong positive correlation to bone breaking strength, stiffness and flexural modulus and consistent negative correlation to Young's modulus of elasticity (YME). The present findings are in agreement with those of Arthur et al. (1982b) who reported that bone (metacarpal and metatarsal) weight was negatively correlated to YME (-.33). Arthur et al. (1982b) further reported a positive relationship between bone breaking strength, stiffness, and flexural modulus. Likewise, Kornegay et al.

TABLE 40. CORRELATION COEFFICIENTS FOR THIRD METACARPAL BONE CHARACTERISTICS OF BOARS FED TWO LEVELS OF ENERGY AND TWO LEVELS OF MINERALS AND VITAMINS[a]

	BWGT	BLGTH	PDIM	AXDIM	ABDIM	PTH	AXTH	ABTH	BRST	YME	STIFF	FM	EE	ASH	Ca	P	Mg	Cu	Zn	Fe	Mn
BWGT	1.0	.97**	.89**	.96**	.91**	.60**	.31*	.53**	.83**	-.58**	.69**	.69**	-.39**	.47**	.38**	.02	-.56**	-.34**	-.20	-.36**	-.06
BLGTH		1.0	.84**	.92**	.89**	.53**	.31*	.46**	.76**	-.55**	.64**	.64**	-.35**	.48**	.39**	.02	-.58**	-.41**	-.19	-.38**	-.09
PDIM			1.0	.88**	.84**	.42**	.25	.42**	.66**	-.59**	.61**	.61**	-.24	.40**	.39**	.05	-.49**	-.29*	-.25*	-.27*	-.01
AXDIM				1.0	.92**	.55**	.28*	.49**	.81**	-.60**	.69**	.69**	-.33**	.49**	.41**	.08	-.60**	-.31**	.14	-.29*	-.06
ABDIM					1.0	.53**	.28*	.42**	.71**	-.61**	.59**	.59**	-.22	.51**	.39**	.10	-.59**	-.24	-.16	-.21	.04
PTH						1.0	.42**	.59**	.63**	-.30*	.51**	.51**	-.44**	.27*	.20	-.09	-.32*	-.24	-.19	-.18	-.03
AXTH							1.0	.39**	.34**	-.21	.28*	.28*	-.16	.25*	.11	.05	-.15	.01	-.23	.05	.20
ABTH								1.0	.58**	-.30*	.46**	.46**	-.45**	.30*	.15	.02	-.32*	-.14	-.18	-.17	-.01
BRST									1.0	-.18	.88**	.88**	-.59**	.31*	.33**	.03	-.43**	-.32*	-.32*	-.34**	-.11
YME										1.0	.10	.10	-.06	-.37**	-.25*	.03	.39**	.12	-.08	.09	-.15
STIFF											1.0	.99**	-.51**	.27*	.25*	.12	-.37**	-.30*	-.32*	-.24	-.14
FM												1.0	-.51**	.27*	.25*	.12	-.37**	-.30*	-.32*	-.24	-.14
EE													1.0	-.25*	.05	.10	.18	.32*	.25	.22	-.14
ASH														1.0	-.02	-.13	-.41**	-.22	.04	.10	.12
Ca															1.0	.26*	-.50**	-.08	-.11	-.27*	.33**
P																1.0	-.27*	.30*	.15	.17	-.06
Mg																	1.0	.26*	-.05	.13	.12
Cu																		1.0	.23	.41**	-.07
Zn																			1.0	.33**	.32*
Fe																				1.0	.25
Mn																					1.0

[a]Values for bone weight (BWGT), bone length (BLGTH), palmar dimension (PDIM), axial dorsopalmar dimension (AXDIM), abaxial dorsopalmar dimension (ABDIM), palmar thickness (PTH), axial dorsopalmar thickness (AXTH), abaxial dorsopalmar thickness (ABTH), breaking strength (BRST), Young's modulus of elasticity (YME), stiffness (STIFF), flexural modulus (FM), ether extract (EE), ash, calcium (Ca), phosphorus (P), magnesium (Mg), copper (Cu), zinc (Zn), iron (Fe) and manganese (Mn).

*(P<.05).

**(P<.01).

TABLE 41. CORRELATION COEFFICIENTS FOR FOURTH METACARPAL BONE CHARACTERISTICS OF BOARS FED TWO LEVELS OF ENERGY AND TWO LEVELS OF MINERALS AND VITAMINS[a]

	BWGT	BLGTH	PDIM	AXDIM	ABDIM	PTH	AXTH	ABTH	BRST	YME	STIFF	FM	EE	ASH	Ca	P	Mg	Cu	Zn	Fe	Mn
BWGT	1.0	.96**	.90**	.97**	.94**	.49**	.33*	.52**	.85**	-.62**	.88**	.88**	-.28*	.30*	.26*	.05	-.58**	-.16	-.44**	-.23	-.46
BLGTH		1.0	.86**	.90**	.86**	.46**	.28*	.47**	.74**	-.61**	.80**	.80**	-.18	.38**	.18	.01	-.61	-.20	-.38**	-.17	-.42**
PDIM			1.0	.88**	.90**	.35**	.36**	.53**	.71**	-.67**	.79**	.79**	-.15	.20	.27*	.16	-.61**	-.10	-.42**	-.19	-.42**
AXDIM				1.0	.96**	.52**	.34**	.48**	.83**	-.67**	.86**	.86**	-.27*	.25	.31*	.09	-.61**	-.13	-.41**	-.14	-.43**
ABDIM					1.0	.57**	.37**	.51**	.79**	-.72**	.80**	.80**	-.23	.24	.29*	.06	-.64**	-.10	-.43**	-.16	-.42**
PTH						1.0	.43**	.31**	.49**	-.52**	.34**	.34**	-.34**	.13	.07	-.02	-.28*	.04	-.32*	.03	-.08
AXTH							1.0	.35**	.34*	-.34**	.34**	.34**	-.26*	.14	.24	-.11	-.13	-.03	-.42**	-.11	.11
ABTH								1.0	.56**	-.41**	.49**	.49**	-.51**	.25	-.03	.11	-.40**	-.07	-.40**	-.22	-.22
BRST									1.0	-.33*	.91**	.91**	-.51**	.33*	.25	.03	-.43**	-.10	-.53**	-.30*	-.43
YME										1.0	-.26*	-.26*	.14	-.10	-.06	-.07	.47**	.17	.22	-.06	.10
STIFF											1.0	.99**	-.30*	.31*	.33*	.08	-.52**	-.08	-.45**	-.23	-.47**
FM												1.0	-.30*	.31*	.33*	.08	-.52**	-.08	-.45**	-.23	-.47**
EE													1.0	-.21	.01	-.07	-.01	.12	.33*	.28*	.10
ASH														1.0	-.14	-.22	-.21	-.15	-.08	-.06	.14
Ca															1.0	.36**	-.27*	.07	-.20	-.30*	-.18
P																1.0	-.24	.21	-.17	.05	-.03
Mg																	1.0	.16	.04	-.03	.24
Cu																		1.0	-.12	.06	.17
Zn																			1.0	.32*	.09
Fe																				1.0	.30*
Mn																					1.0

[a]Values for bone weight (BWGT), bone length (BLGTH), palmar dimension (PDIM), axial dorsopalmar dimension (AXDIM), abaxial dorsopalmar dimension (ABDIM), palmar thickness (PTH), axial dorsopalmar thickness (AXTH), abaxial dorsopalmar thickness (ABTH), breaking strength (BRST), Young's modulus of elasticity (YME), stiffness (STIFF), flexural modulus (FM), ether extract (EE), ash, calcium (Ca), phosphorus (P), magnesium (Mg), copper (Ca), zinc (Zn), iron (Fe) and manganese (Mn).

*(P<.05).

**(P<.01).

TABLE 42. CORRELATION COEFFICIENTS FOR THIRD METATARSAL BONE CHARACTERISTICS OF BOARS FED TWO LEVELS OF ENERGY AND TWO LEVELS OF MINERALS AND VITAMINS[a]

	BWGT	BLGTH	PDIM	AXDIM	ABDIM	PTH	AXTH	ABTH	BRST	YME	STIFF	FM	EE	ASH	Ca	P	Mg	Cu	Zn	Fe	Mn
BWGT	1.0	.96**	.76**	.97**	.94**	.42**	.45**	.24	.76**	-.47**	.73**	.54**	-.04	.40**	.04	.15	-.58**	-.25	-.39**	-.40**	-.39**
BLGTH		1.0	.71**	.90**	.89**	.48**	.42**	.26*	.69**	-.46**	.65**	.48**	-.06	.39**	.02	.14	-.59**	-.20	-.37**	-.32*	-.29**
PDIM			1.0	.75**	.77**	.30*	.46**	.14	.59**	-.57**	.48**	.39**	.07	.30*	.14	.20	-.42**	-.23	-.45**	-.44**	-.43**
AXDIM				1.0	.97**	.40**	.47**	.18	.74**	-.53**	.71**	.55**	.04	.36**	.05	.17	-.59**	-.23	-.38**	-.41**	-.41**
ABDIM					1.0	.44**	.47**	.18	.69**	-.61**	.65**	.52**	.13	.30*	.05	.23	-.60**	-.15	-.37**	-.33*	-.37**
PTH						1.0	.40**	.31*	.39**	-.32*	.36**	.32*	-.01	.18	.01	.19	-.40**	-.12	-.40**	-.15	-.21
AXTH							1.0	.22	.49**	-.36**	.40**	.35**	-.11	.40**	.04	-.06	-.27*	.03	-.51**	-.19	-.10
ABTH								1.0	.21	-.22	.21	.10	-.14	.23	.01	-.04	-.16	-.07	-.04	-.08	.12
BRST									1.0	-.17	.89**	.81**	-.32*	.41**	.06	-.01	-.37**	-.25	-.43**	-.49**	-.46**
YME										1.0	.06	-.18	-.39**	-.17	-.05	-.30*	.44**	-.06	.30*	.07	.13
STIFF											1.0	.82**	-.26*	.28*	.04	.02	-.36**	-.33*	-.28*	-.46**	-.40**
FM												1.0	-.06	.19	.04	.06	-.38**	-.26*	-.24	-.37*	-.37**
EE													1.0	-.45**	.25	.28*	-.18	.21	.14	.20	.09
ASH														1.0	-.27*	-.32*	-.06	-.19	-.23	-.13	-.02
Ca															1.0	.52**	-.39**	-.18	-.15	-.09	-.11
P																1.0	-.48**	.12	-.12	.02	-.10
Mg																	1.0	.12	.19	.08	.16
Cu																		1.0	.06	.41**	.36**
Zn																			1.0	.43**	.46**
Fe																				1.0	.70**
Mn																					1.0

[a]Values for bone weight (BWGT), bone length (BLGTH), palmar dimension (PDIM), axial dorsopalmar dimension (AXDIM), abaxial dorsopalmar dimension (ABDIM), palmar thickness (PTH), axial dorsopalmar thickness (AXTH), abaxial dorsopalmar thickness (ABTH), breaking strength (BRST), Young's modulus of elasticity (YME), stiffness (STIFF), flexural modulus (FM), ether extract (EE), ash, calcium (Ca), phosphorus (P), magnesium (Mg), copper (Cu), zinc (Zn), iron (Fe) and manganese (Mn).
*(P<.05).
**(P<.01).

TABLE 43. CORRELATION COEFFICIENTS FOR FOURTH METATARSAL BONE CHARACTERISTICS OF BOARS FED TWO LEVELS OF ENERGY AND TWO LEVELS OF MINERALS AND VITAMINS[a]

	BWGT	BLGTH	PDIM	AXDIM	ABDIM	PTH	AXTH	ABTH	BRST	YME	STIFF	FM	EE	ASH	Ca	P	Mg	Cu	Zn	Fe	Mn
BWGT	1.0	.97**	.92**	.97**	.95**	.64**	.72**	.33*	.79**	-.49**	.68**	.75**	-.28*	.32*	.47**	.25	-.65**	.14	-.13	-.35**	-.19
BLGTH		1.0	.87**	.92**	.90**	.70**	.69**	.37**	.75**	-.48**	.67**	.71**	-.26	.32*	.43**	.20	-.60**	.13	-.16	-.39**	-.22
PDIM			1.0	.89**	.94**	.60**	.64**	.28*	.63**	-.60**	.61**	.64**	-.07	.19	.43**	.23	-.57**	.21	-.14	-.27*	-.17
AXDIM				1.0	.96**	.61**	.71**	.28*	.77**	-.50**	.71**	.78**	-.28*	.34**	.45**	.27*	-.69**	.16	-.06	-.24	-.13
ABDIM					1.0	.63**	.68**	.30*	.72**	-.53**	.70**	.73**	-.22	.31*	.42**	.26*	-.67**	.19	-.10	-.23	-.16
PTH						1.0	.53**	.38**	.50**	-.33*	.66**	.50**	-.18	.17	.30*	-.09	-.38**	-.02	-.18	-.28*	-.14
AXTH							1.0	.47**	.73**	-.28*	.58**	.66**	-.44**	.34**	.39**	.30*	-.47**	.19	-.33*	-.13	-.09
ABTH								1.0	.39**	-.16	.31*	.34**	-.30*	.35**	.17	.10	-.24	.03	-.11	-.06	.07
BRST									1.0	-.06	.64**	.90**	-.50**	.32*	.52**	.34**	-.66**	.03	-.15	-.32*	-.19
YME										1.0	-.11	.08	-.14	-.14	-.21	-.08	.28*	-.22	.04	-.06	-.12
STIFF											1.0	.72**	-.31*	.22	.36**	.15	-.53**	.13	-.13	-.26*	-.19
FM												1.0	-.43**	.24	.38**	.27*	.56**	.01	-.09	-.34**	-.25
EE													1.0	-.31*	.01	-.19	.32*	-.05	.28*	.12	.29*
ASH														1.0	.11	.03	-.33*	-.01	-.03	-.15	.18
Ca															1.0	.36*	-.55**	.13	.11	-.04	.24
P																1.0	-.48**	.24	.03	.17	.20
Mg																	1.0	-.17	-.10	-.11	-.17
Cu																		1.0	.11	.35**	.08
Zn																			1.0	.29*	.36**
Fe																				1.0	.61**
Mn																					1.0

[a]Values for bone weight (BWGT), bone length (BLGTH), palmar dimension (PDIM), axial dorsopalmar dimension (AXDIM), abaxial dorsopalmar dimension (ABDIM), palmar thickness (PTH), axial dorsopalmar thickness (AXTH), abaxial dorsopalmar thickness (ABTH), breaking strength (BRST), Young's modulus of elasticity (YME), stiffness (STIFF), flexural modulus (FM), ether extract (EE), ash, calcium (Ca), phosphorus (P), magnesium (Mg), copper (Cu), zinc (Zn), iron (Fe) and manganese (Mn).
*(P<.05).
**(P<.01).

(1981b) reported a positive correlation (.34) between metacarpal weight and breaking strength, while Schroeder et al. (1974) observed similar results for the femur. Bone weight, length, shaft diameters and wall thicknesses were consistently negatively correlated to the bone ether extract content with the exception of the third metatarsal for which little relationship was evident. Positive correlations were observed between bone weight and size and bone ash with this being most prominent for the third metacarpal and least evident for the fourth metacarpal. The correlation between bone dimensional characteristics and the mineral content of bone ash varied for each mineral. The Ca content of bone ash was generally positively correlated to bone dimensions with the exception of very low coefficients for the third metatarsal. Little relationship was evident between bone dimensions and the P content of bone ash, while a strong negative correlation was noted between bone dimensions and ash Mg content. Metacarpal and metatarsal weight, length, shaft diameters and wall thickness measurements were generally negatively correlated to the trace mineral (Cu, Zn, Fe and Mn) content of bone ash, however, the magnitude and significance level of the correlation coefficients varied.

The third and fourth metacarpals exhibited negative correlations ($P < .01$) between bone ether extract content and bone breaking strength, stiffness and flexural modulus. Little relationship was evident between ether extract and YME. In contrast, the third and fourth metatarsal ether extract was negatively correlated to YME. Although the magnitude varied among bones, a negative correlation was seen between bone ash and YME, while all other breaking characteristics were positively correlated to bone ash. Likewise, Arthur et al. (1982b) reported a positive correlation (.25) between metacarpal and metatarsal ash content and their respective breaking strengths. In contrast, Schroeder et al. (1974) and Kornegay et al. (1981b) reported little correlation between metacarpal ash content and breaking strength indicating that bone ash is not a reliable indicator of bone strength.

With the exception of the third metatarsal the relationship between the mechanical bone properties and the Ca content of bone ash closely parallels the relationship between bone mechanical properties and bone ash. This result was to be expected due to the high content of Ca in the bone ash. Bone ash P content had very little correlation to any of the strength characteristics. Relatively consistent negative correlations were evident between bone breaking strength, stiffness and flexural modulus values and the content of Mg, Cu, Zn, Fe and Mn in bone ash.

A strong positive correlation exists between bone breaking strength and bone stiffness and flexural modulus. Therefore as bone strength is increased the capability of the bone to resist bending is also increased. This may be a disadvantage under practical situations where some degree of bone flexibility is needed to cope with shock loading situations.

Chapter VI

CONCLUSIONS

The results of this study support the current NRC mineral and vitamin recommendations for growing boars as adequate for maximal foot and leg development as elevated levels (150% NRC) had little effect. Additionally, restricting growth rate was generally ineffective in producing boars with substantially larger feet and legs as maturity was approached although trends in this direction were apparent with correction for body weight differences. Limit-fed boars were, however, judged to be more structurally sound in appearance. This may be a result of a more mature skeletal system in limit-fed boars at a given weight due to a slower growth rate than that of ad libitum-fed boars. Dietary treatment had no consistent affect on incidence or severity of foot lesions. Furthermore, little relationship was apparent between toe base area or volume and the incidence or severity of foot lesions.

Limit-fed boars tended to have larger metacarpals and metatarsals as compared with ad libitum-fed boars at an equal weight. The 150% mineral-vitamin level resulted in increased bone wall thickness, Ca content of the bone ash and bone breaking strength. Strong positive correlations between bone breaking strength and stiffness and flexural modulus, however, indicate a reduced ability of the bone to bend as breaking strength is increased which may not be desirable under practical farm conditions.

The present study provides little support for feeding mineral and vitamin levels in excess of the current NRC recommendations or for restricting growth rate as methods of producing boars better capable to withstand the rigors of modern confinement operations. This does not rule out nutritional intervention as a potential approach to the unsoundness problem but will hopefully stimulate further research into the elucidation of the role of nutrition in structural unsoundness.

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Chapter VII

APPENDIX

Table 1

A pig inverter was designed and constructed for use during foot and leg measurement and characterization. The inverter was cylindrically-shaped with a removable plywood floor. The boar was driven into the inverter and its feet securely tied to a crossbar on the inverter. The inverter was then rotated 180 degrees to render the boar supine and the floor removed to allow access to all four feet.

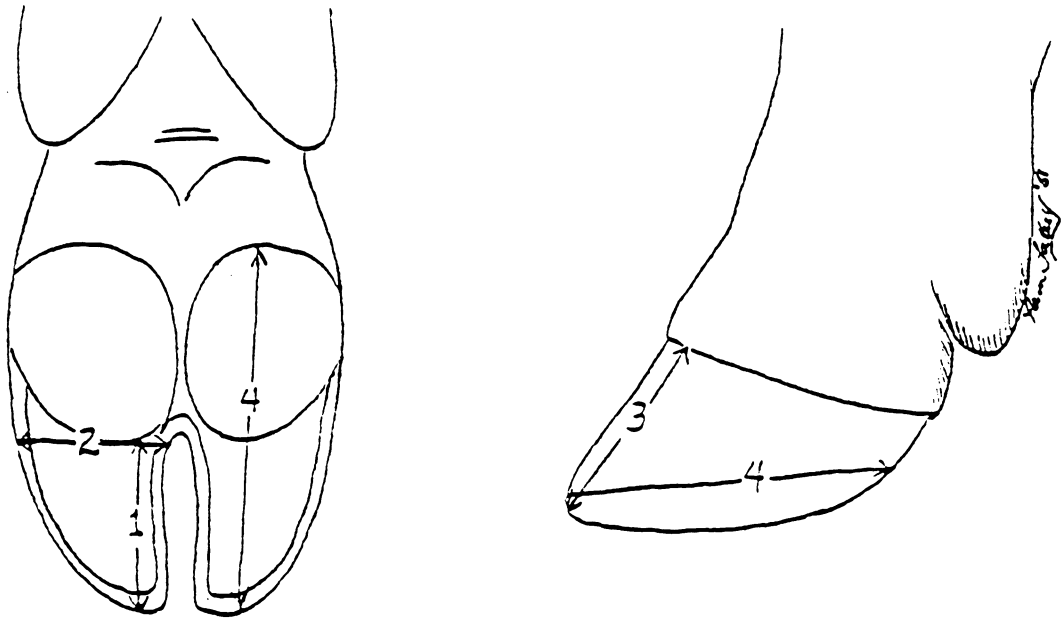

Figure 1. Toe Measurements: Measurement 1 - Horn Length - the distance from the distal periphery of the pad to the tip of the toe; Measurement 2 - Toe Width - taken along the distal periphery of the pad; Measurement 3 - Horn Height - distance from the coronary band to the tip of the toe; Measurement 4 - Toe Length - distance from the proximal periphery of the pad to the tip of the toe.

Table 2

The following variables were calculated from the toe measurements:

(1) Percent horn = (measurement 1 ÷ measurement 4) x 100

(2) toe base area = measurement 2 x measurement 4

(3) toe volume = measurement 2 x measurement 4 x measurement 3. The following assumptions were necessary to develop the calculated variables:

(1) The shape of the base of the toe is rectangular.

(2) The base of the toe and the horn which encompasses the entire toe produce a three-dimensional rectangle.

(3) Deviations from these shapes were consistent among boars. These calculations do not provide exact values but can be used as comparative estimations.

Bones of the legs were palpated for proximal and distal joints. Length of the third metacarpal and metatarsal, ulna and tibia were measured using a table calibrated in centimeters. The circumference of the forelimb was taken proximal to the accessory carpal and immediately distal to the distal end of the ulna around the styloid process. Circumference of the hindlimb was taken distally to the hock joint.

Pads and horns were subjectively scored for the presence or absence of lesions using a scale of 0 to 3. A score of 0 is indicative of no lesions, 1 indicative of superfluous lesions, 2 indicative of moderate lesions and 3 indicative of severe lesions hindering normal locomotion.

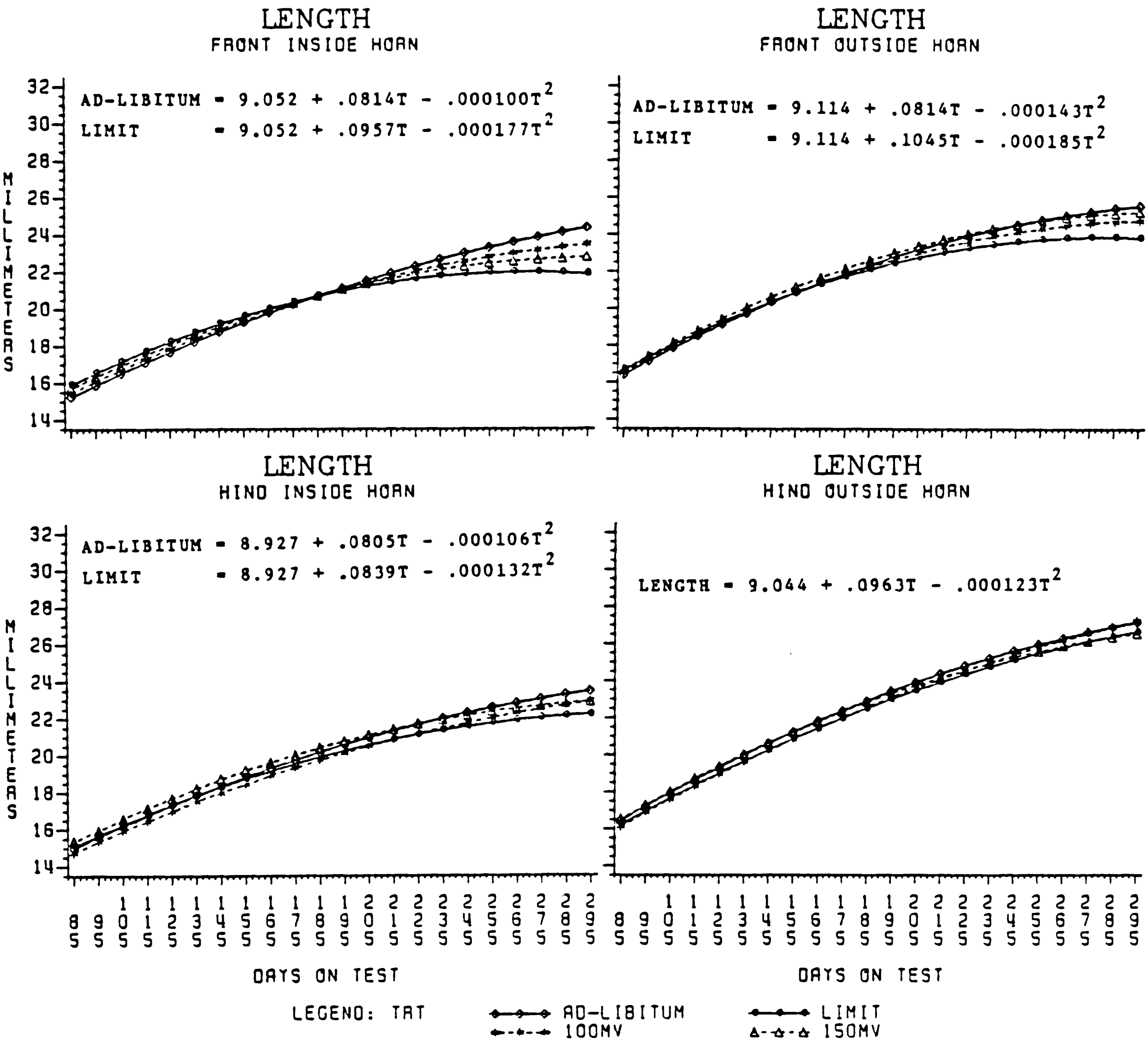

Figure 2. Horn length of inside and outside toes of boars fed two energy levels (ad libitum vs limit) and two mineral and vitamin levels (100 vs 150% NRC). Main effect means are shown and prediction equations are presented if main effects are significant (P<.10).

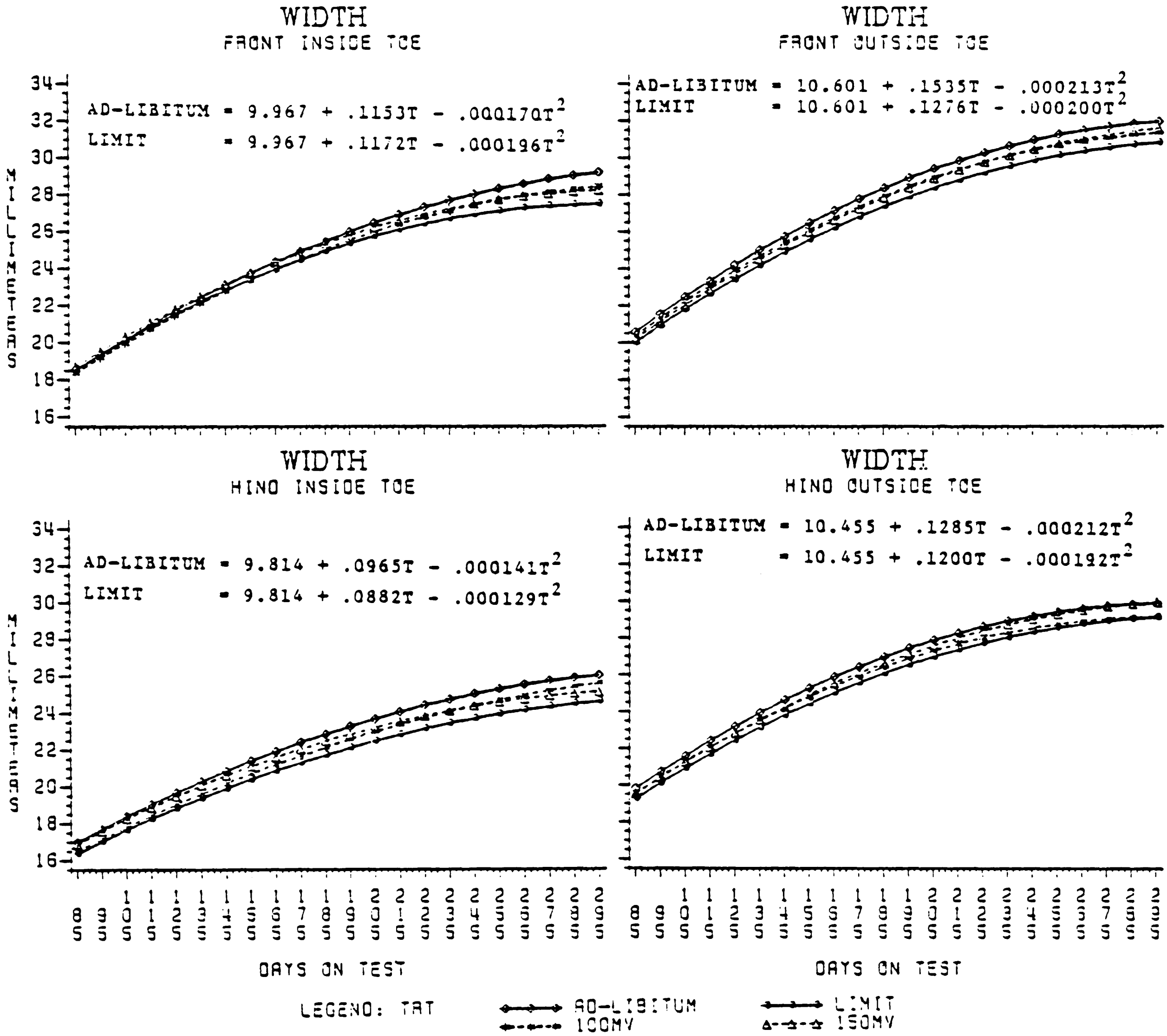

Figure 3. Toe width of inside and outside toes of boars fed two energy levels (ad libitum vs limit) and two mineral and vitamin levels (100 vs 150% NRC). Main effect means are shown and prediction equations are presented if main effects are significant (P<.10).

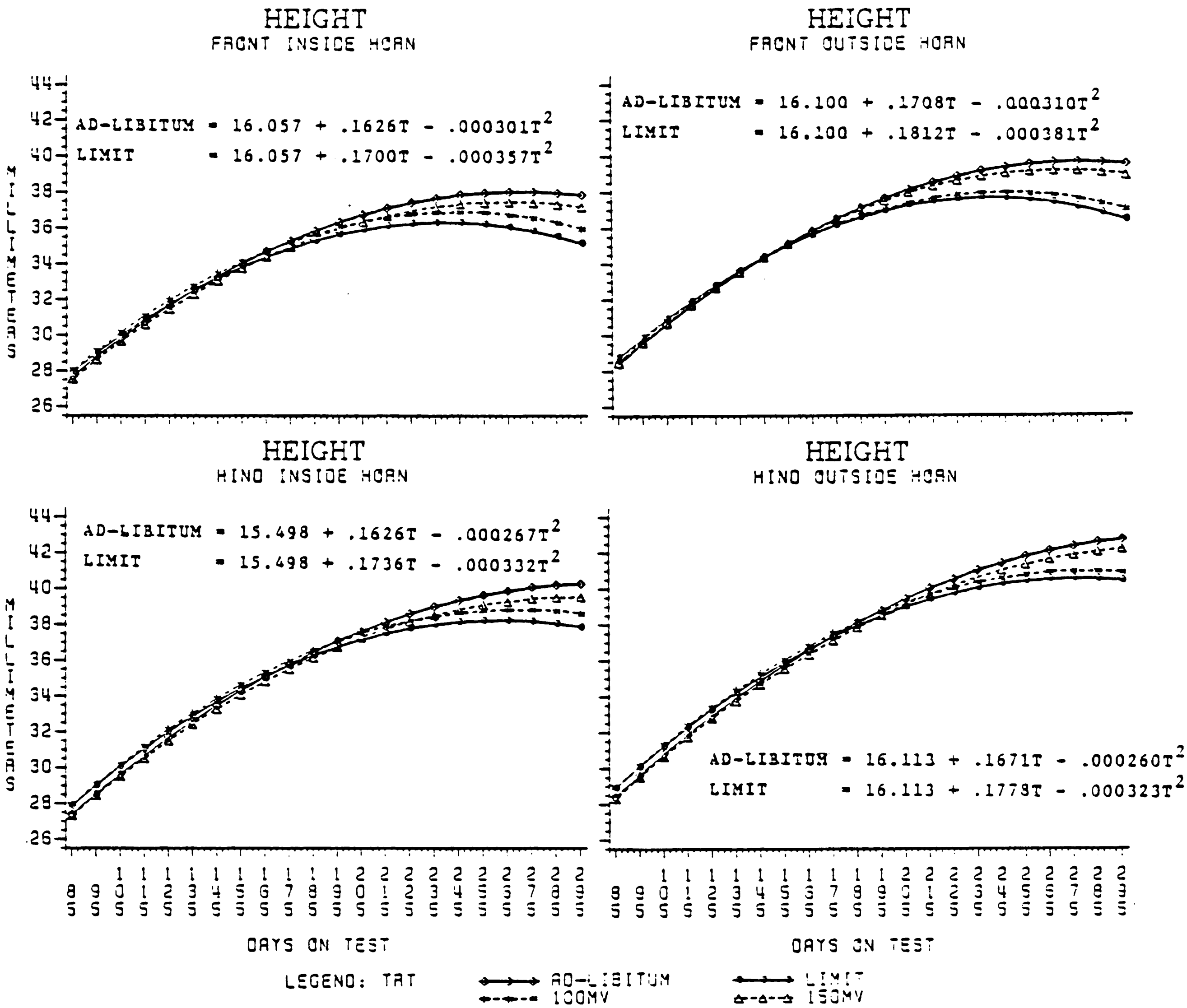

Figure 4. Horn height of inside and outside toes of boars fed two energy levels (ad libitum vs limit) and two mineral and vitamin levels (100 vs 150% NRC). Main effect means are shown and prediction equations are presented if main effects are significant (P<.10).

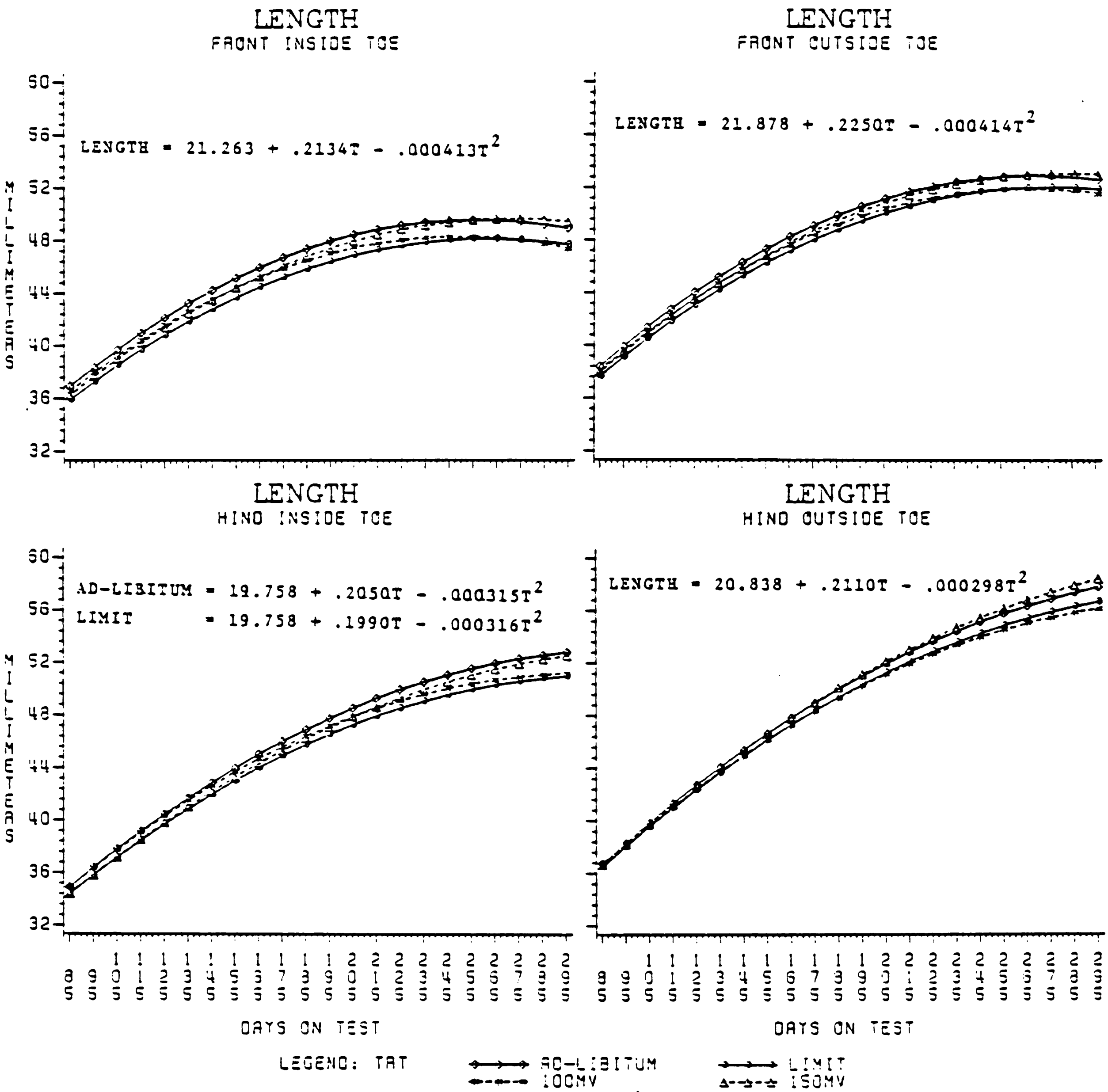

Figure 5. Toe length of inside and outside toes of boars fed two energy levels (ad libitum vs limit) and two mineral and vitamin levels (100 vs 150% NRC). Main effect means are shown and prediction equations are presented if main effects are significant (P<.10).

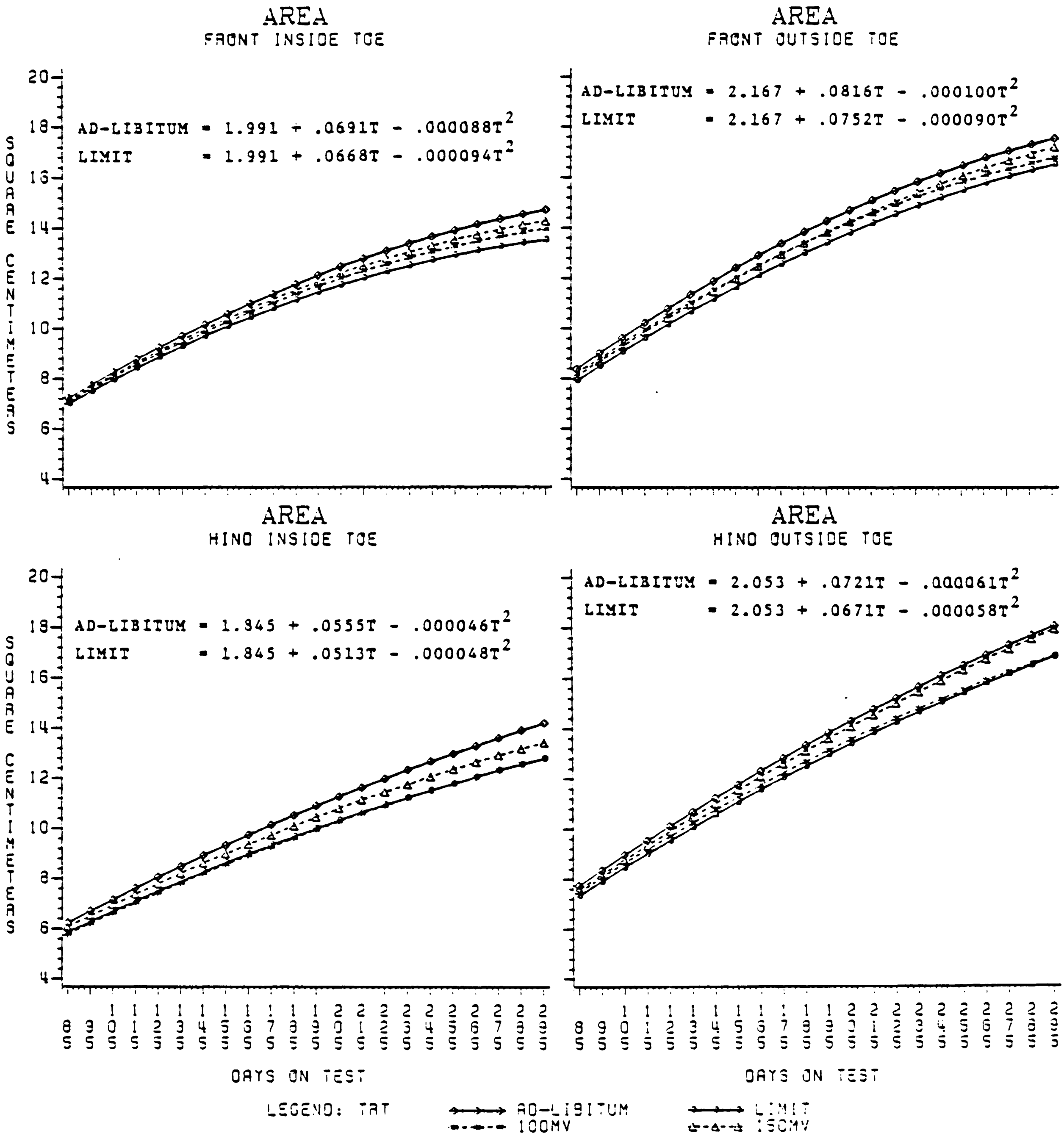

Figure 6. Toe base area of inside and outside toes of boars fed two energy levels (ad libitum vs limit) and two mineral and vitamin levels (100 vs 150% NRC). Main effect means are shown and prediction equations are presented if main effects are significant (P<.10).

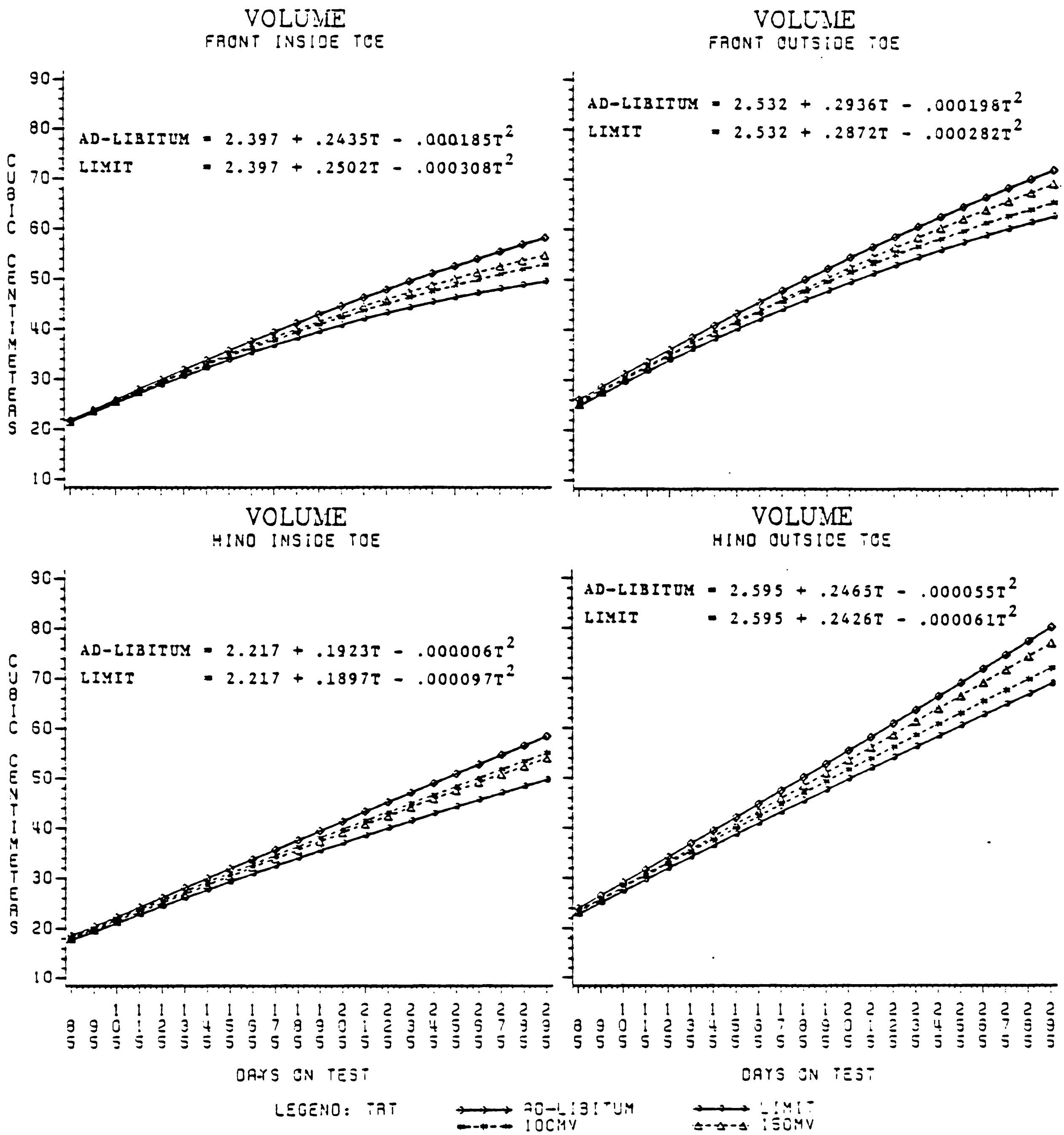

Figure 7. Toe volume of inside and outside toes of boars fed two energy levels (ad libitum vs limit) and two mineral and vitamin levels (100vs 150% NRC). Main effect means are shown and prediction equations are presented if main effects are significant (P<.10).

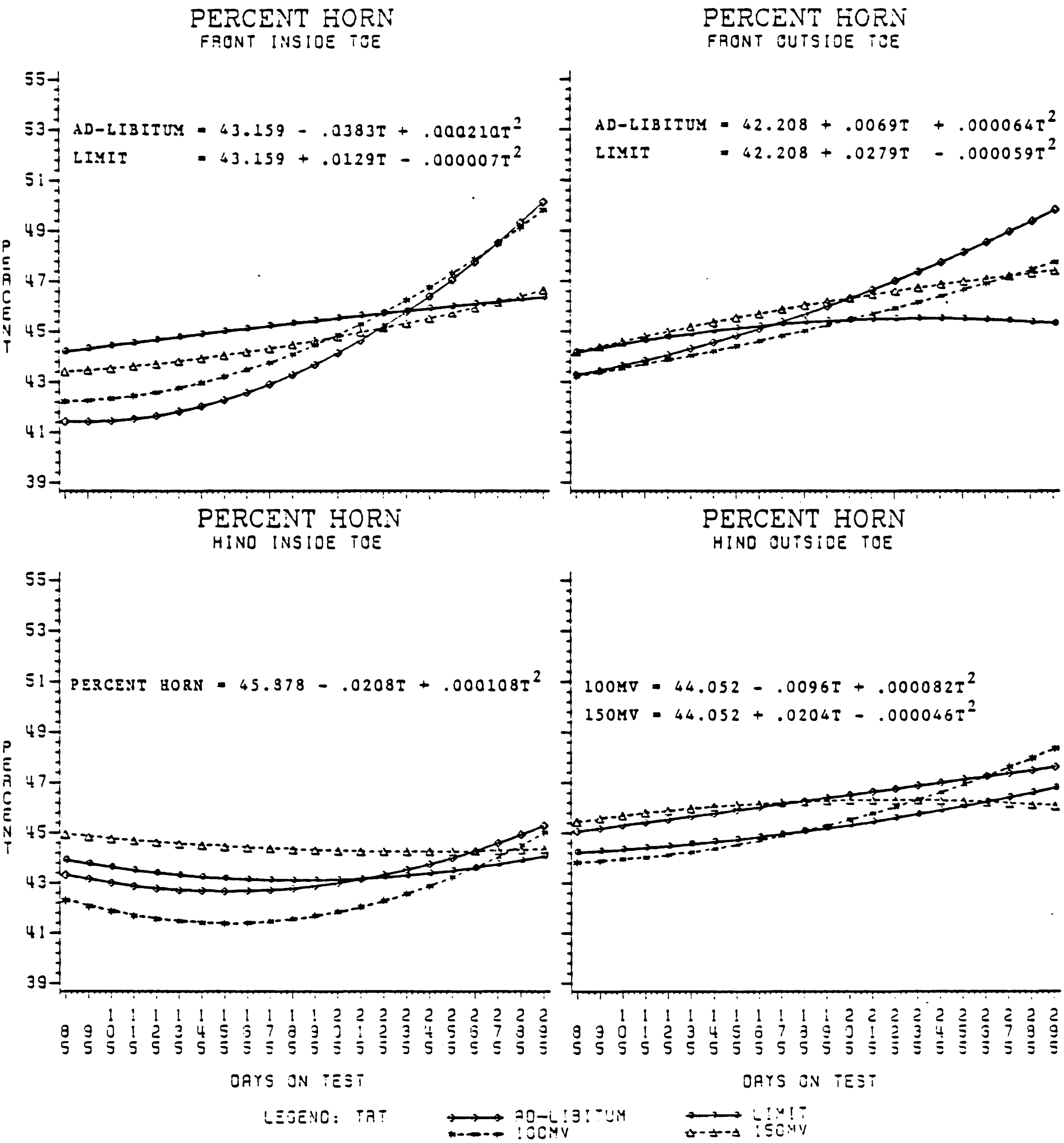

Figure 8. Percentage horn of inside and outside toes of boars fed two energy levels (ad libitum vs limit) and two mineral and vitamin levels (100 vs 150% NRC). Main effect means are shown and prediction equations are presented if main effects are significant (P<.10).

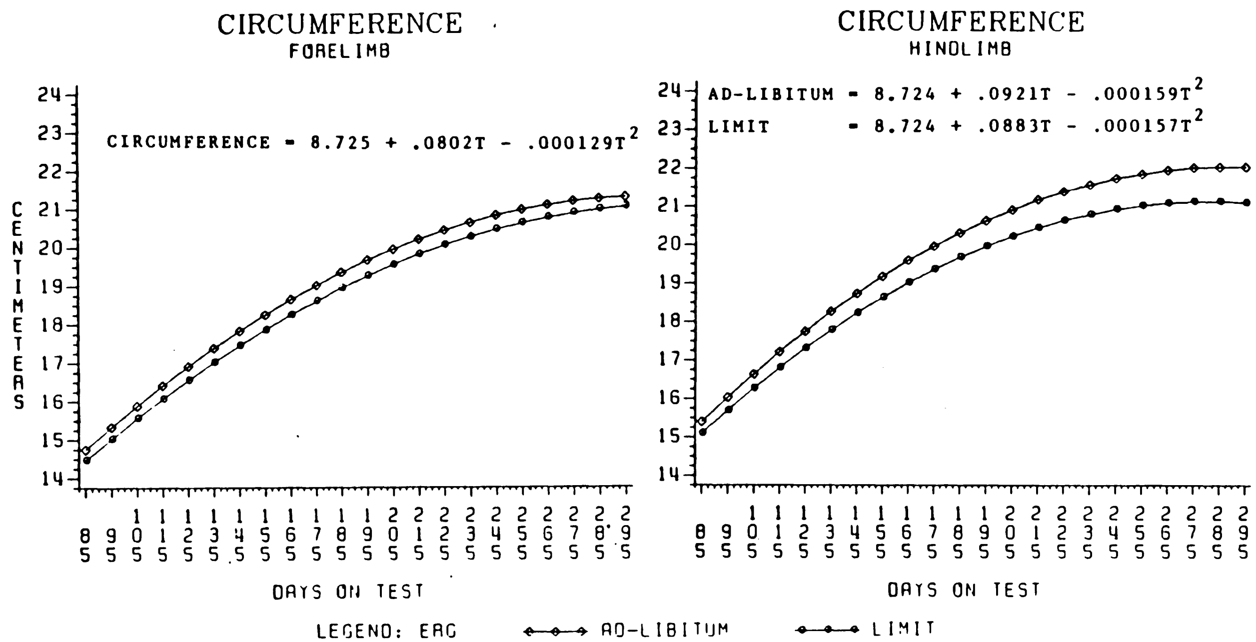

Figure 9. Circumference of the forelimb and hindlimb of boars fed two energy levels (ad libitum vs limit) and two mineral and vitamin levels (100 vs 150% NRC). Main effect means for energy level are shown and prediction equations are presented if main effects are significant (P<.10).

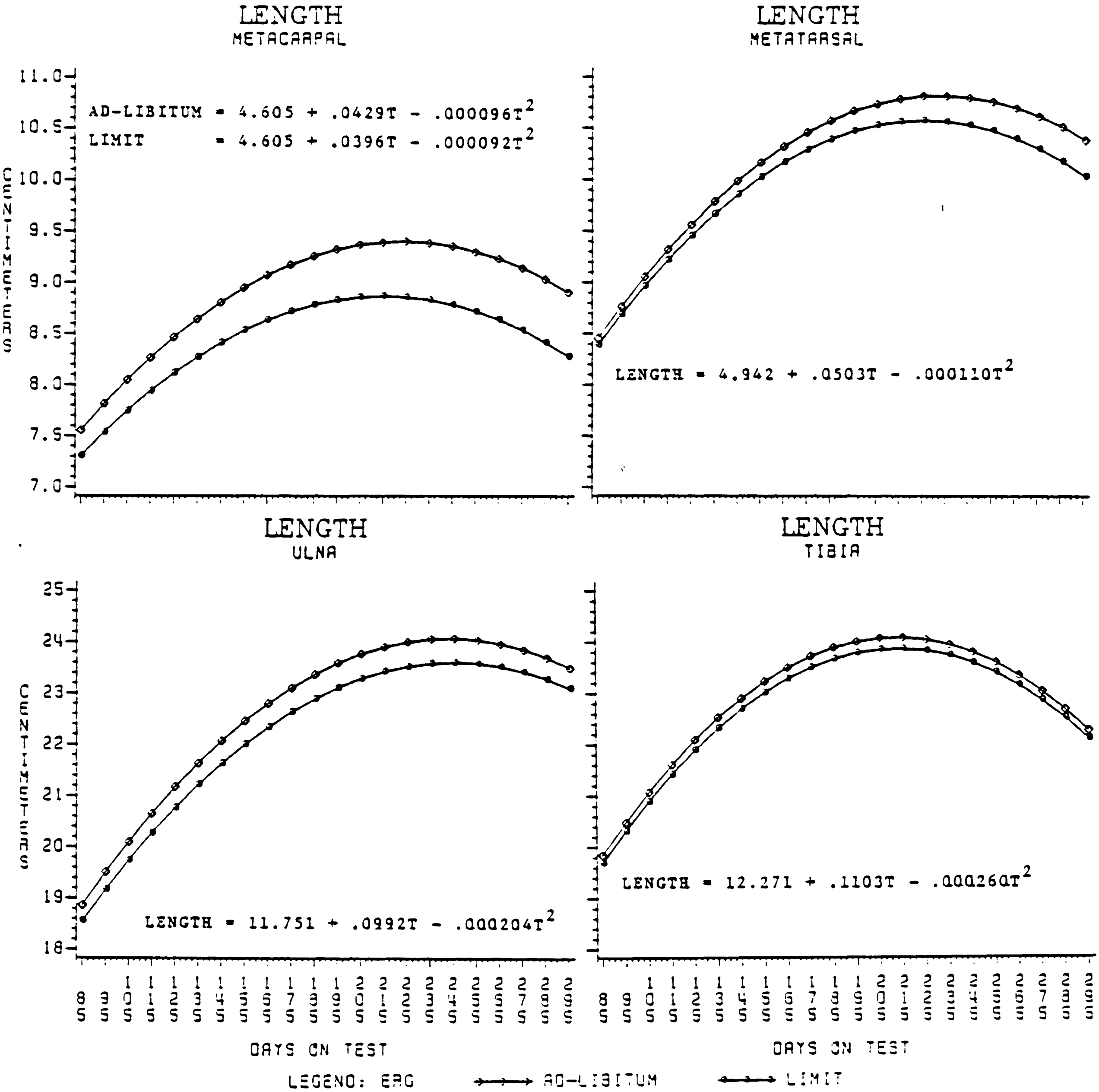

Figure 10. Metacarpal, metatarsal, ulna and tibia lengths of boars fed two energy levels (ad libitum vs limit) and two mineral and vitamin levels (100 vs 150% NRC). Main effect means for energy level are shown and prediction equations are presented if main effects are significant (P<.10).

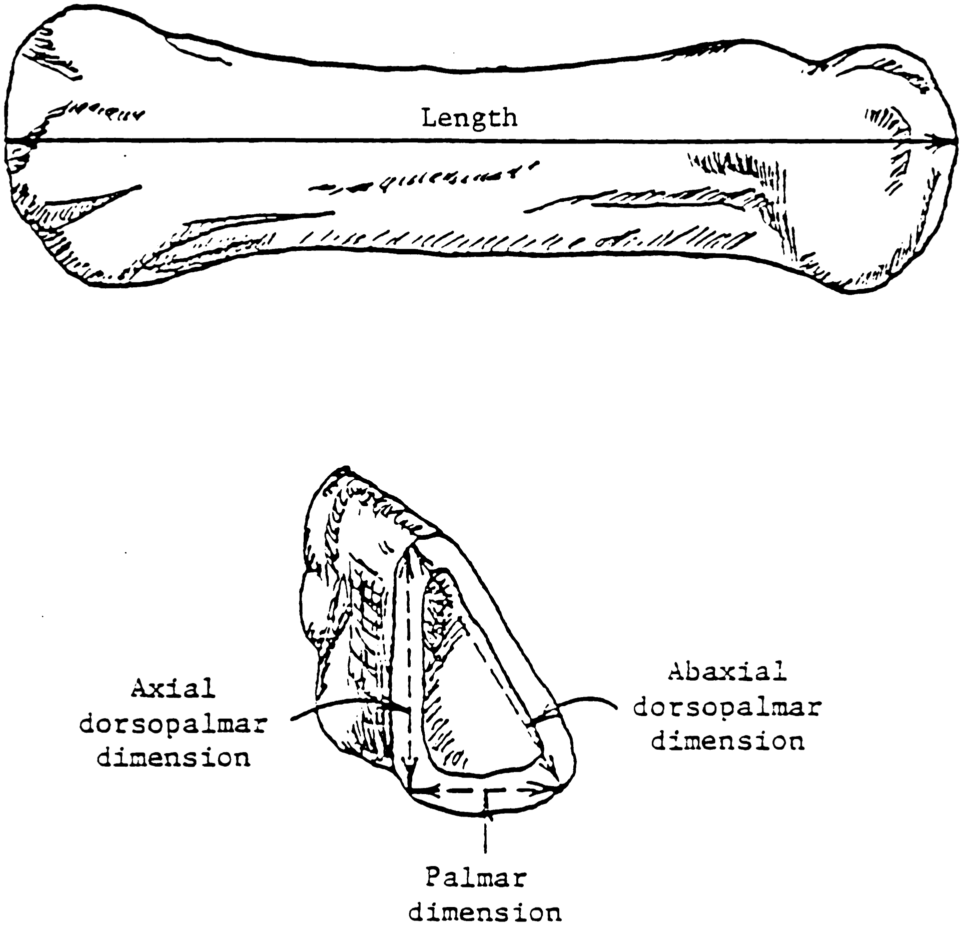

Figure 11. Top - Total bone length; Bottom - Palmar, axial dorsopalmar and abaxial dorsopalmar shaft diameters. Palmar, axial dorsopalmar and abaxial dorsopalmar thicknesses were taken midpoint on each respective side.

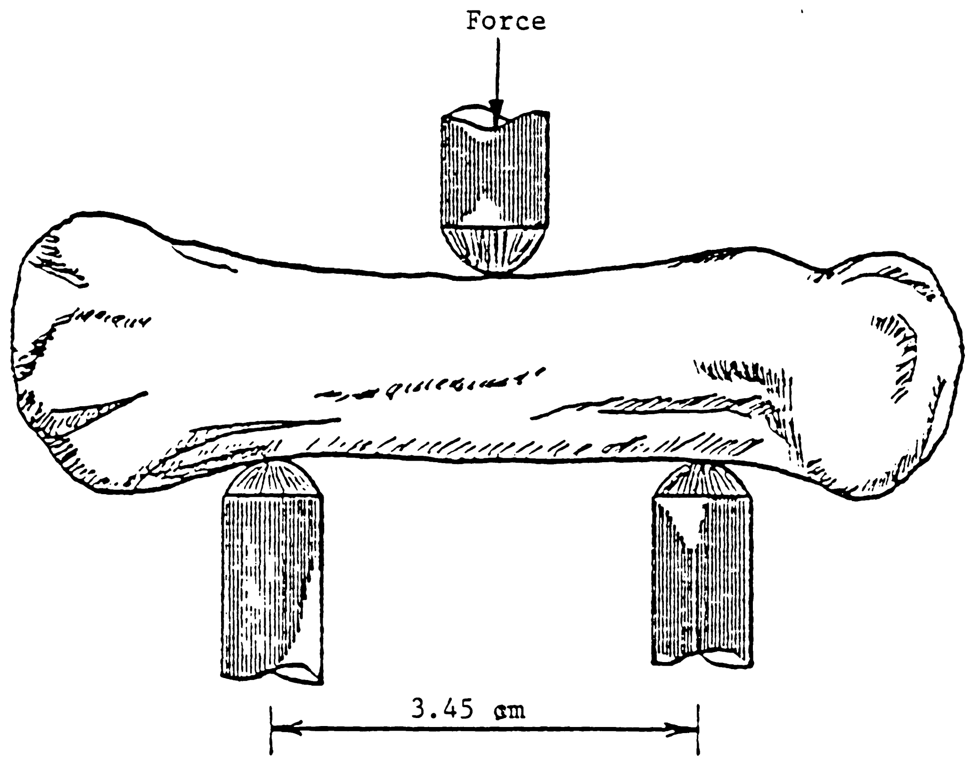

Figure 12. Example of a three-point loading test. The sample rests on two supports with the force applied from above midpoint between the supports.

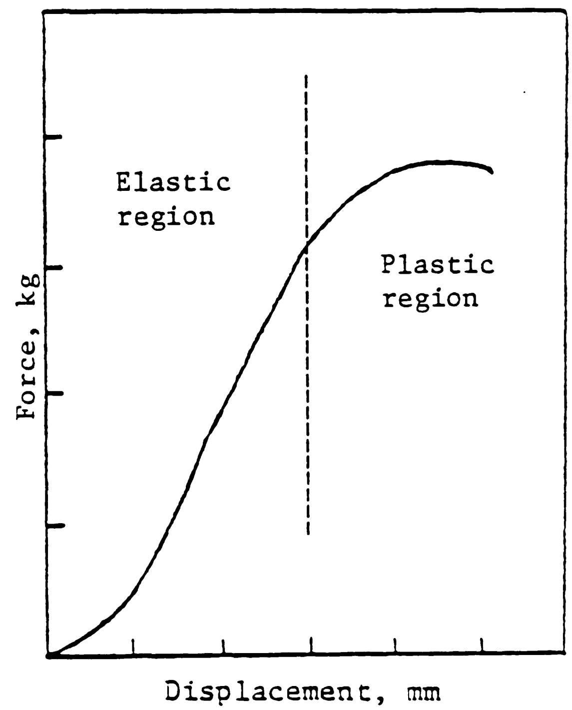

Figure 13. Example of a force deformation curve recorded during a flexure test.

Table 3

Breaking strength was determined as the maximum point on the force deformation curve. At this point failure of the bones resulted. Stiffness is the capability of the bone to resist bending and is estimated by the force per unit of deflection in the sample. This value was determined as the slope of the straight-line portion within the elastic region of the force deformation curve. The elasticity, or the capability of the bone to return to its original shape after being deformed by a force, was indicated by Young's modulus of elasticity (YME). The modulus of elasticity measures the force per unit area required to produce a given deformation per unit bone length and was calculated as:

$$YME = \frac{\text{Stiffness} \times (\text{test length})^3}{48 \times XMI}$$

where Test Length = 3.45 cm. The second moment of inertia (XMI) was calculated as:

$$XMI = 1/36\ (b_o h_o^3 - b_i h_i^3)$$

where the major and minor dimensions of the outer triangle are the base b_o, and height, h_o, and the major and minor dimensions of the inner triangle are base, b_i, and height, h_i. Flexural modulus (FM) was calculated as:

$$FME = YME \times XMI$$

Flexural modulus is therefore a measure similar to stiffness, however, taking into account the test length of the bone.

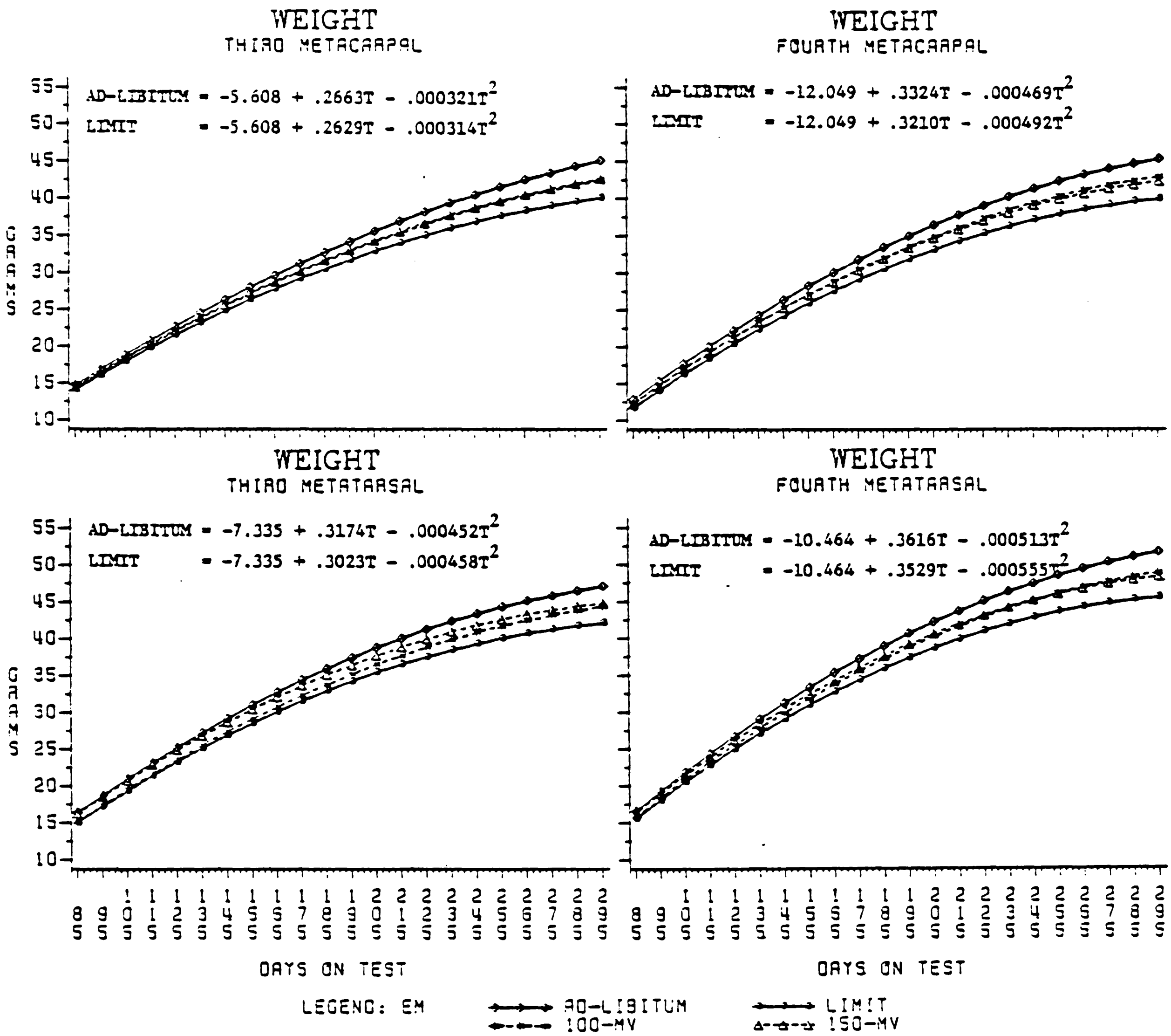

Figure 14. Metacarpal and metatarsal weight for boars fed two energy levels (ad libitum vs limit) and two mineral and vitamin levels (100 vs 150% NRC). Main effect means are shown and prediction equations are presented if main effects are significant (P<.10).

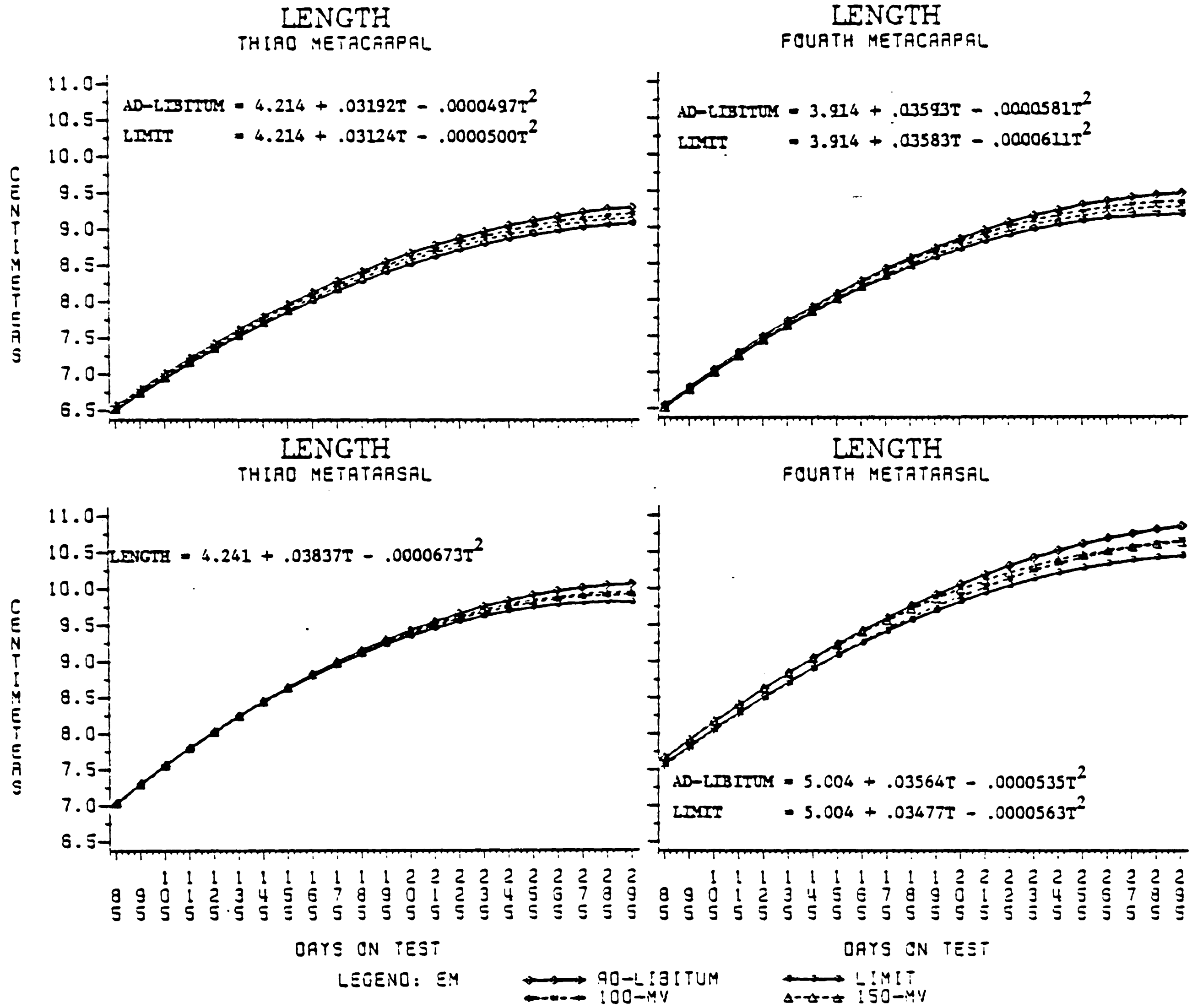

Figure 15. Metacarpal and metatarsal length for boars fed two energy levels (ad libitum vs limit) and two mineral and vitamin levels (100 vs 150% NRC). Main effect means are shown and prediction equations are presented if main effects are significant (P<.10).

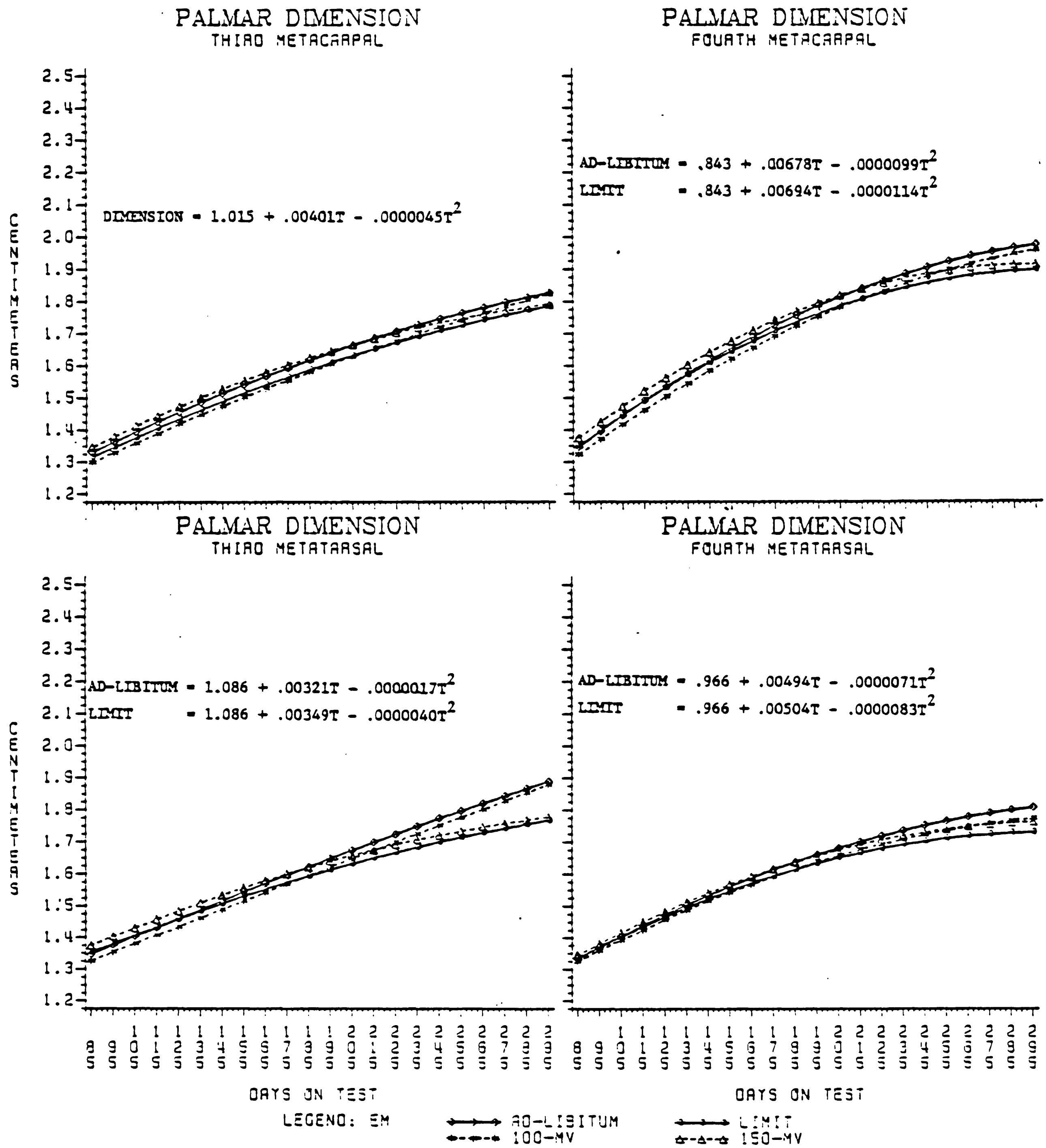

Figure 16. Metacarpal and metatarsal palmar dimension for boars fed two energy levels (ad libitum vs limit) and two mineral and vitamin levels (100 vs 150% NRC). Main effect means are shown and prediction equations are presented if main effects are significant (P<.10).

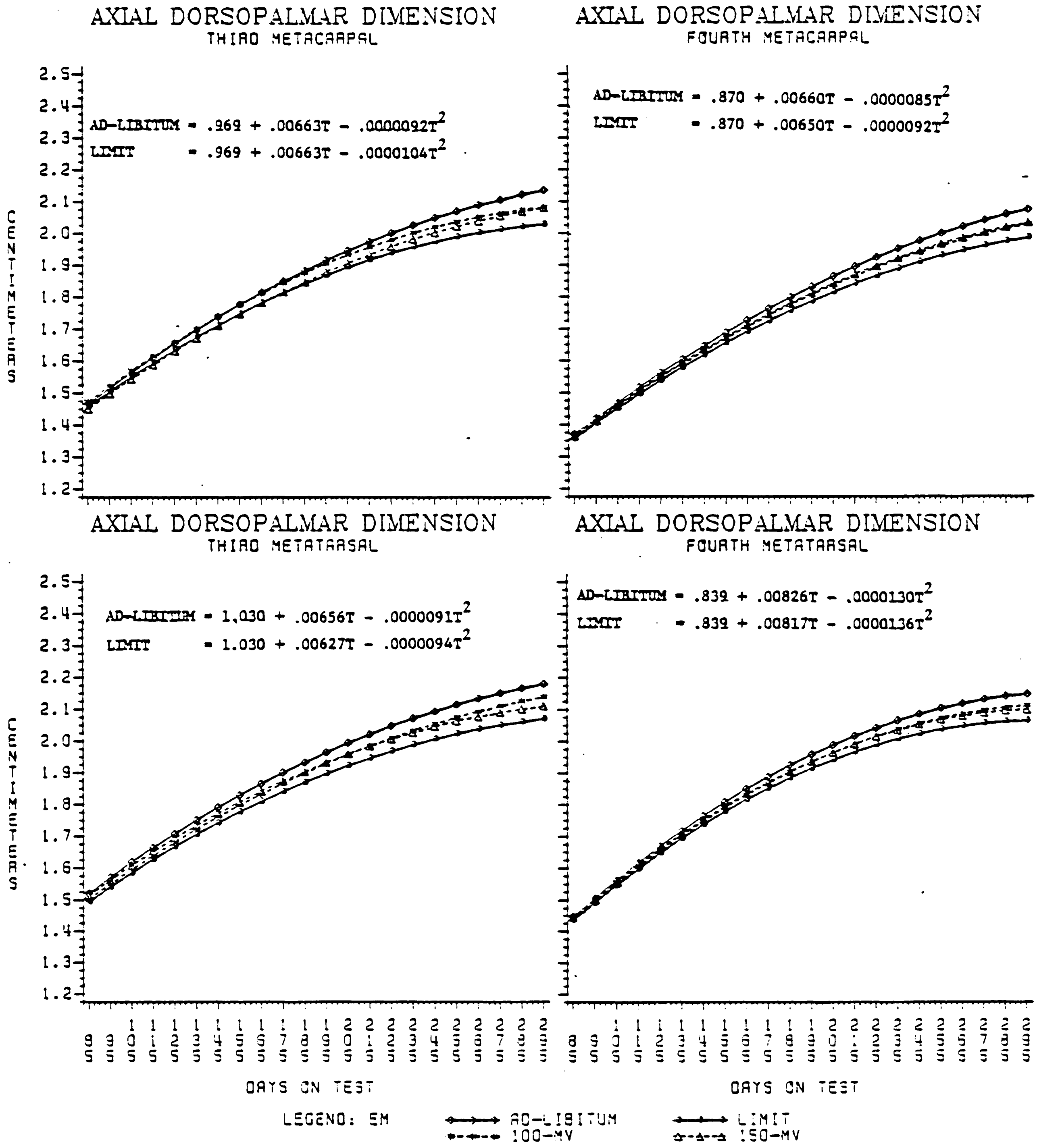

Figure 17. Metacarpal and metatarsal axial dorsopalmar dimension for boars fed two energy levels (ad libitum vs limit) and two mineral and vitamin levels (100 vs 150% NRC). Main effect means are shown and prediction equations are presented if main effects are significant (P<.10).

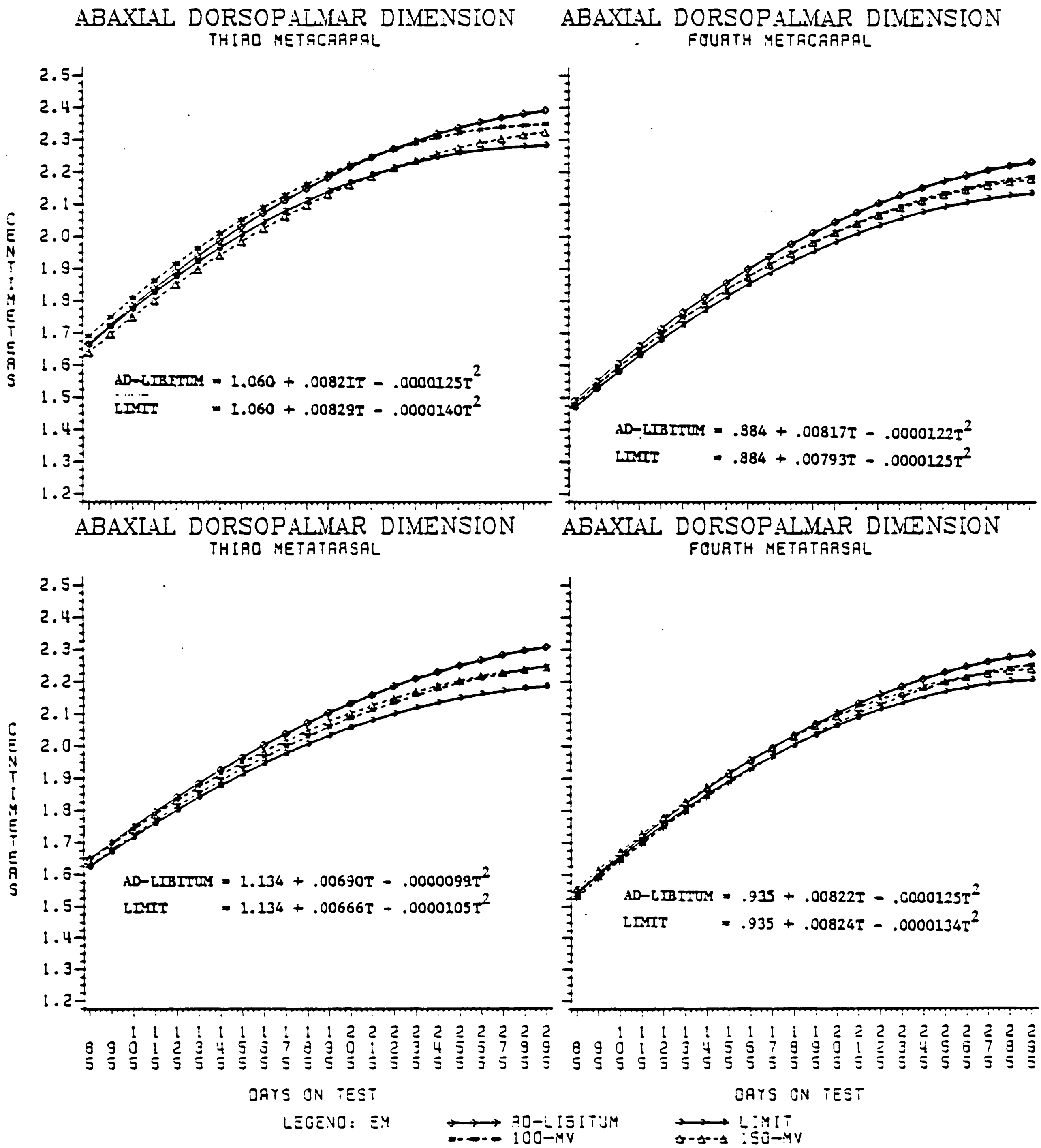

Figure 18. Metacarpal and metatarsal abaxial dorsopalmar dimension for boars fed two energy levels (ad libitum vs limit) and two mineral and vitamin levels (100 vs 150% NRC). Main effect means are shown and prediction equations are presented if main effects are significant (P<.10).

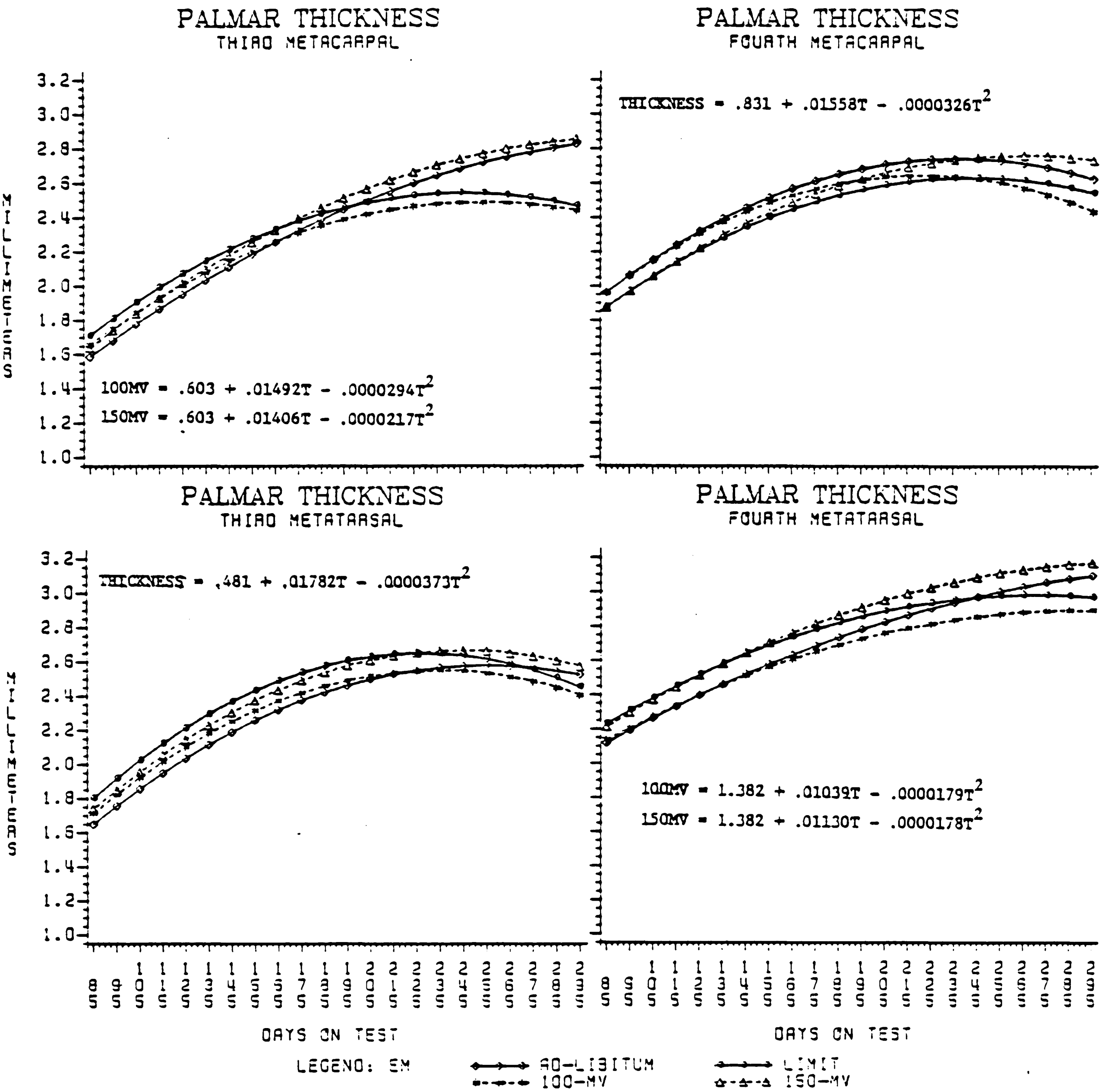

Figure 19. Metacarpal and metatarsal palmar thickness for boars fed two energy levels (ad libitum vs limit) and two mineral and vitamin levels (100 vs 150% NRC). Main effect means are shown and prediction equations are presented if main effects are significant (P<.10).

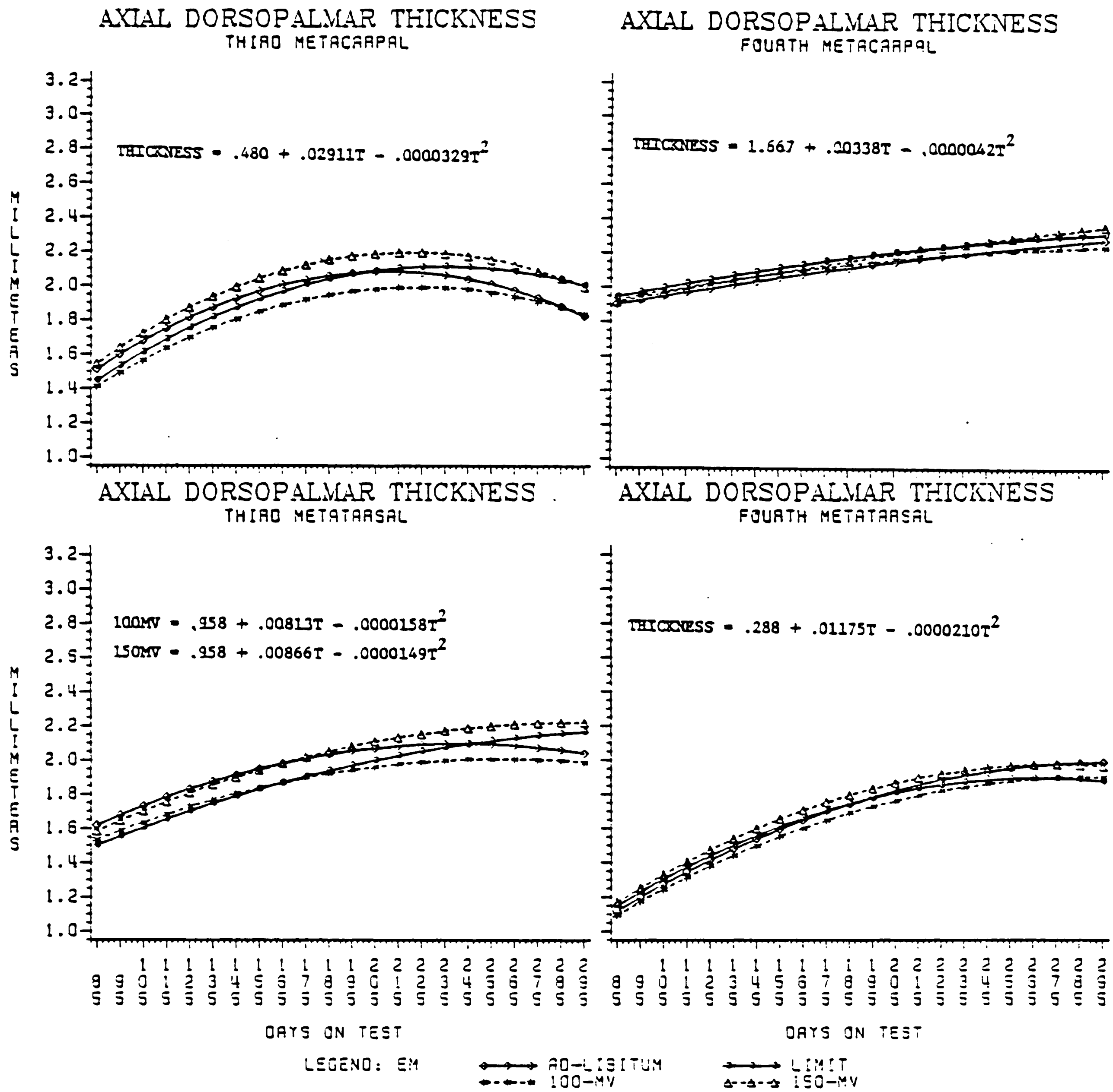

Figure 20. Metacarpal and metatarsal axial dorsopalmar thickness for boars fed two energy levels (ad libitum vs limit) and two mineral and vitamin levels (100 vs 150% NRC). Main effect means are shown and prediction equations are presented if main effects are significant (P<.10).

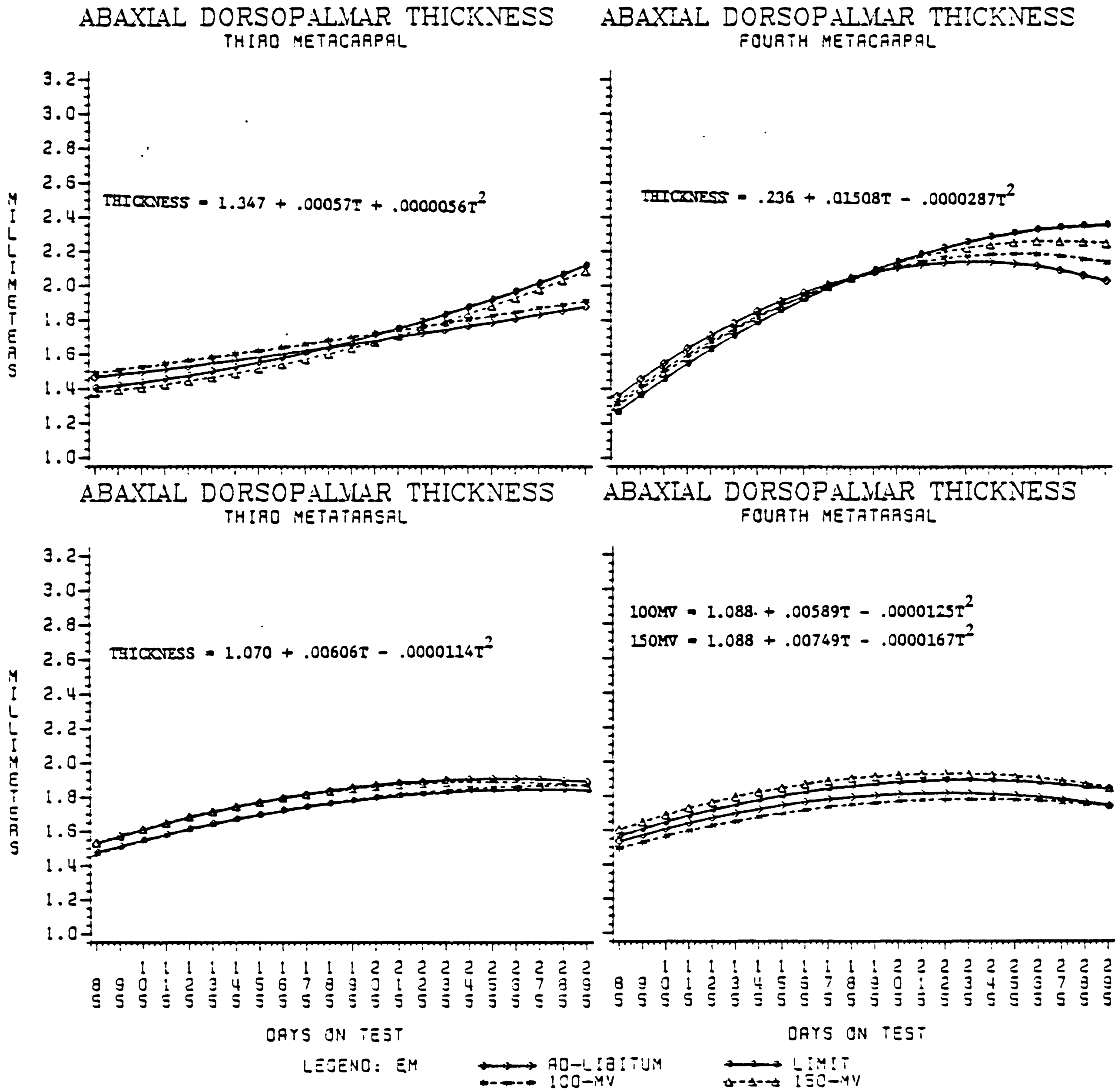

Figure 21. Metacarpal and metatarsal abaxial dorsopalmar thickness for boars fed two energy levels (ad libitum vs limit) and two mineral and vitamin levels (100 vs 150% NRC). Main effect means are shown and prediction equations are presented if main effects are significant ($P<.10$).

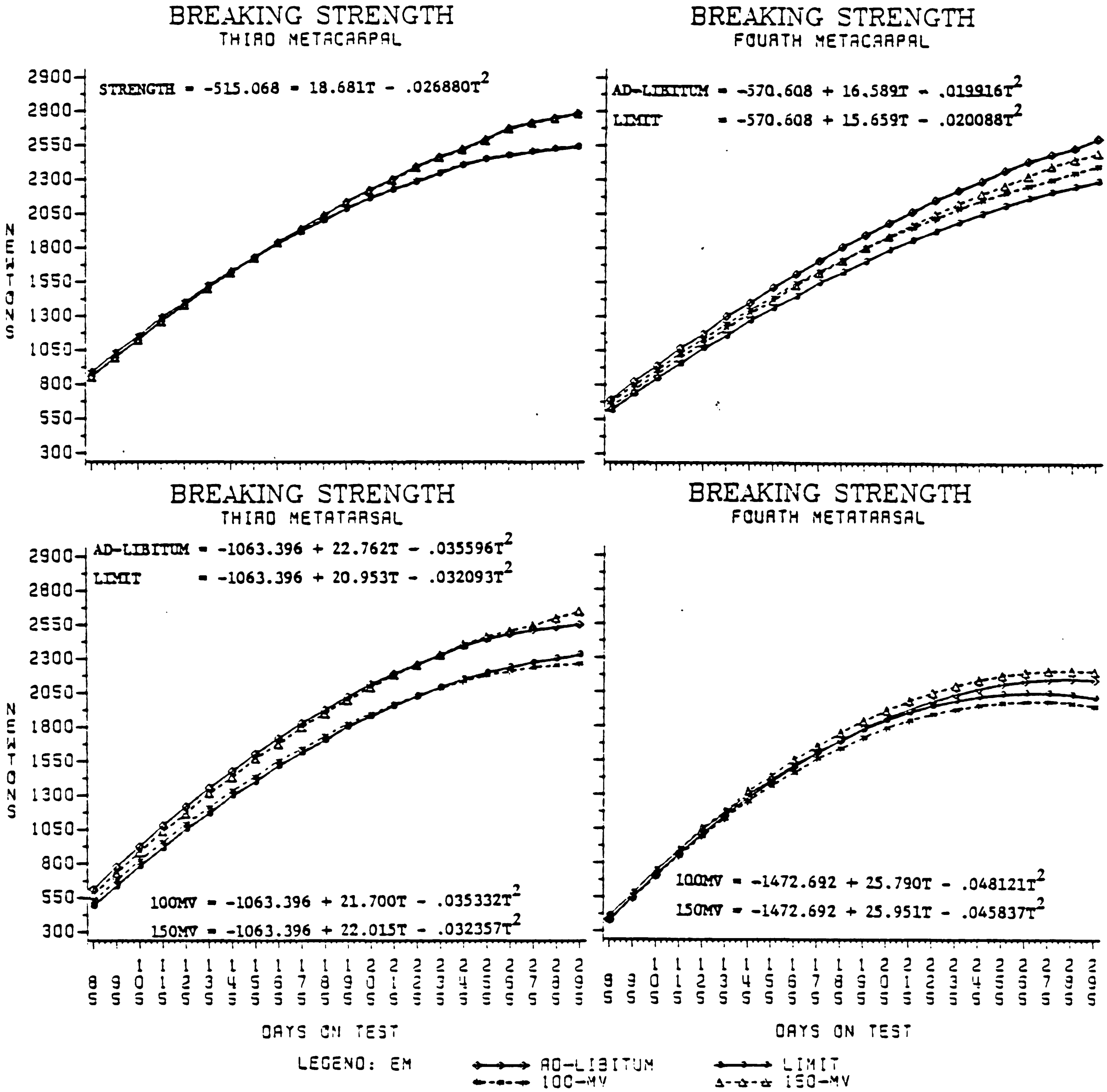

Figure 22. Metacarpal and metatarsal breaking strength for boars fed two energy levels (ad libitum vs limit) and two mineral and vitamin levels (100vs 150% NRC). Main effect means are shown and prediction equations are presented if main effects are significant (P<.10).

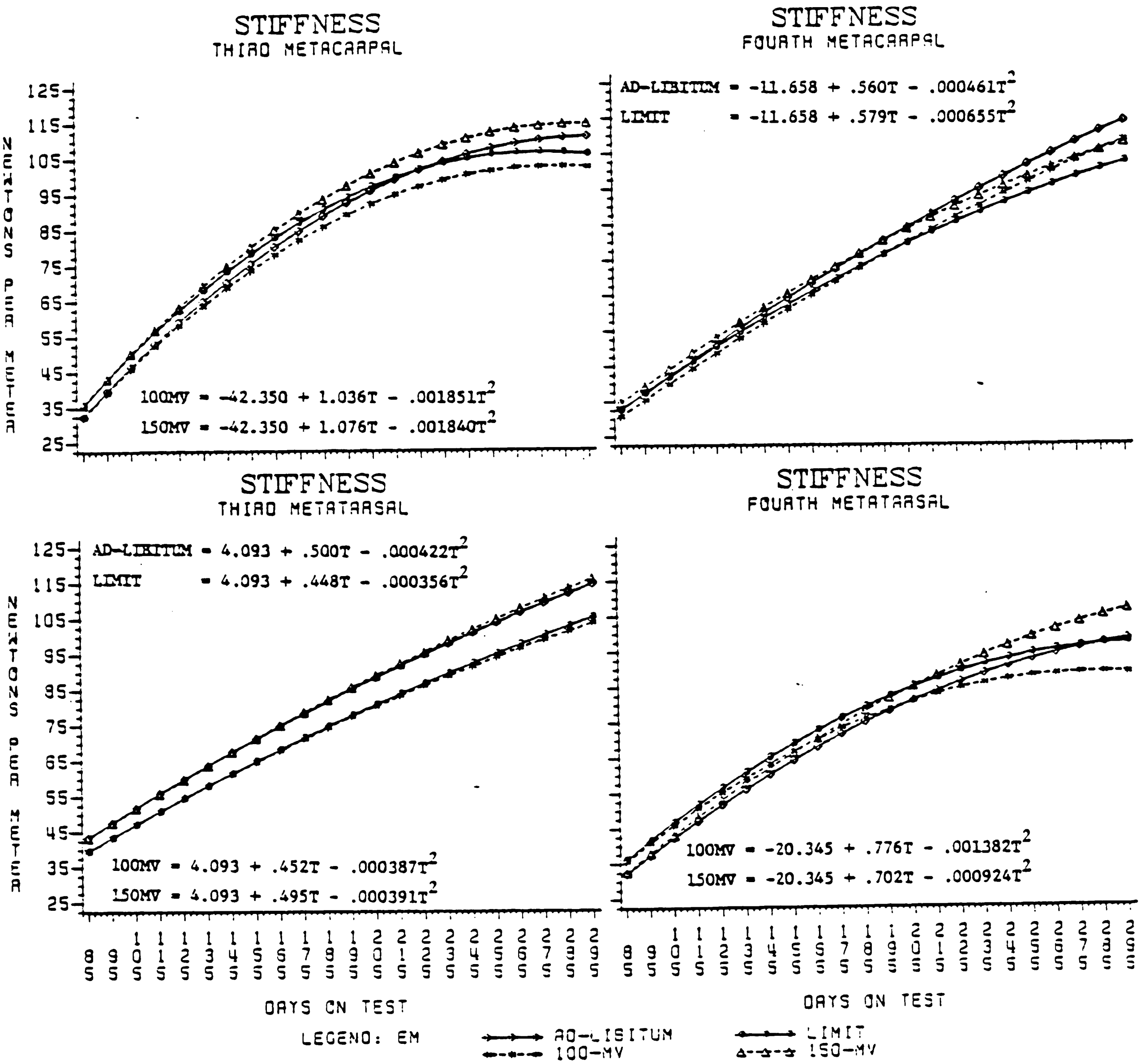

Figure 23. Metacarpal and metatarsal stiffness (x 10^4) for boars fed two energy levels (ad libitum vs limit) and two mineral and vitamin levels (100 vs 150% NRC). Main effect means are shown and prediction equations are presented if main effects are significant (P<.10).

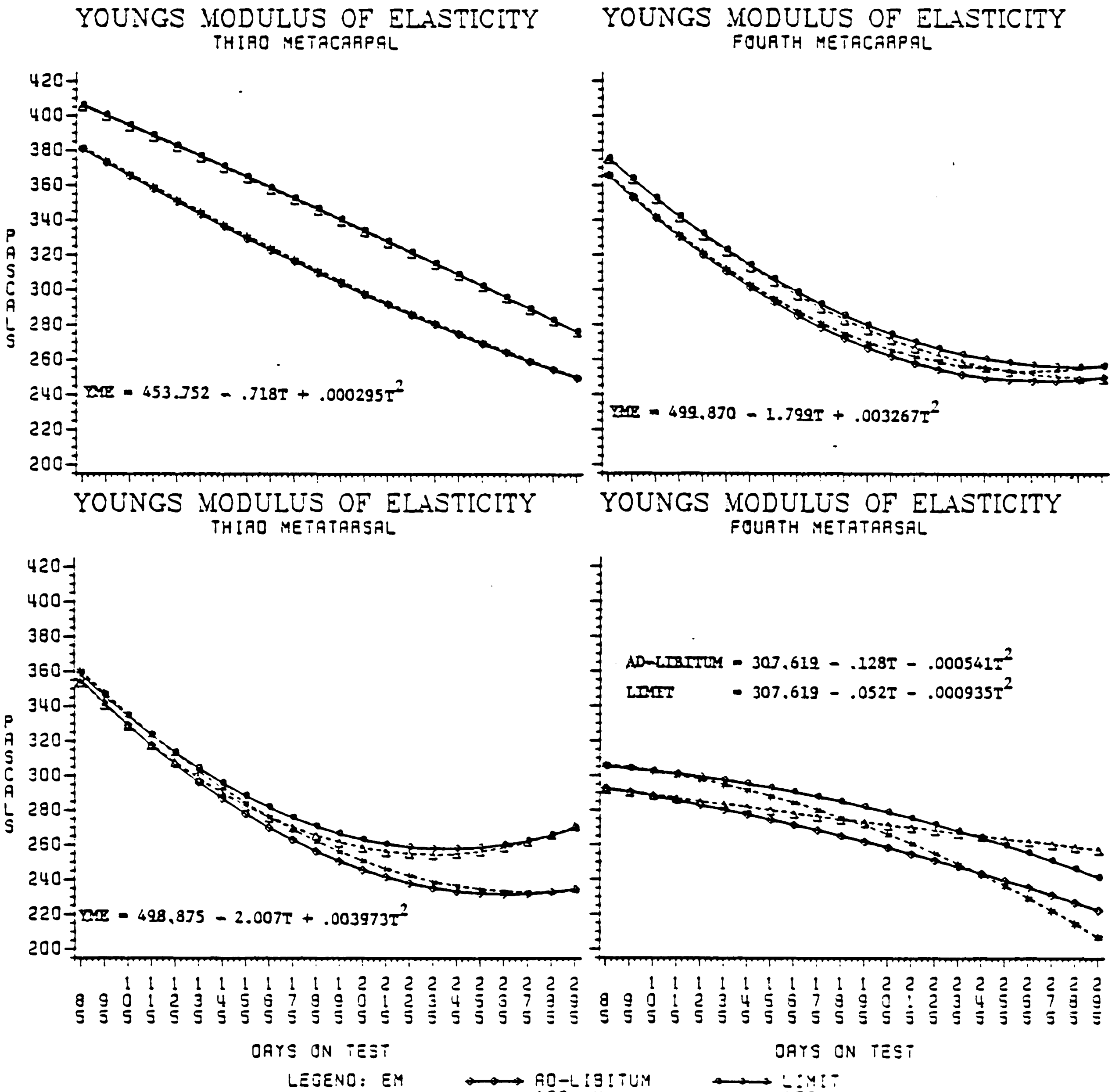

Figure 24. Metacarpal and metatarsal Young's modulus of elasticity ($x\ 10^6$) for boars fed two energy levels (ad libitum vs limit) and two mineral and vitamin levels (100 vs 150% NRC). Main effect means are shown and prediction equations are presented if main effects are significant ($P<.10$).

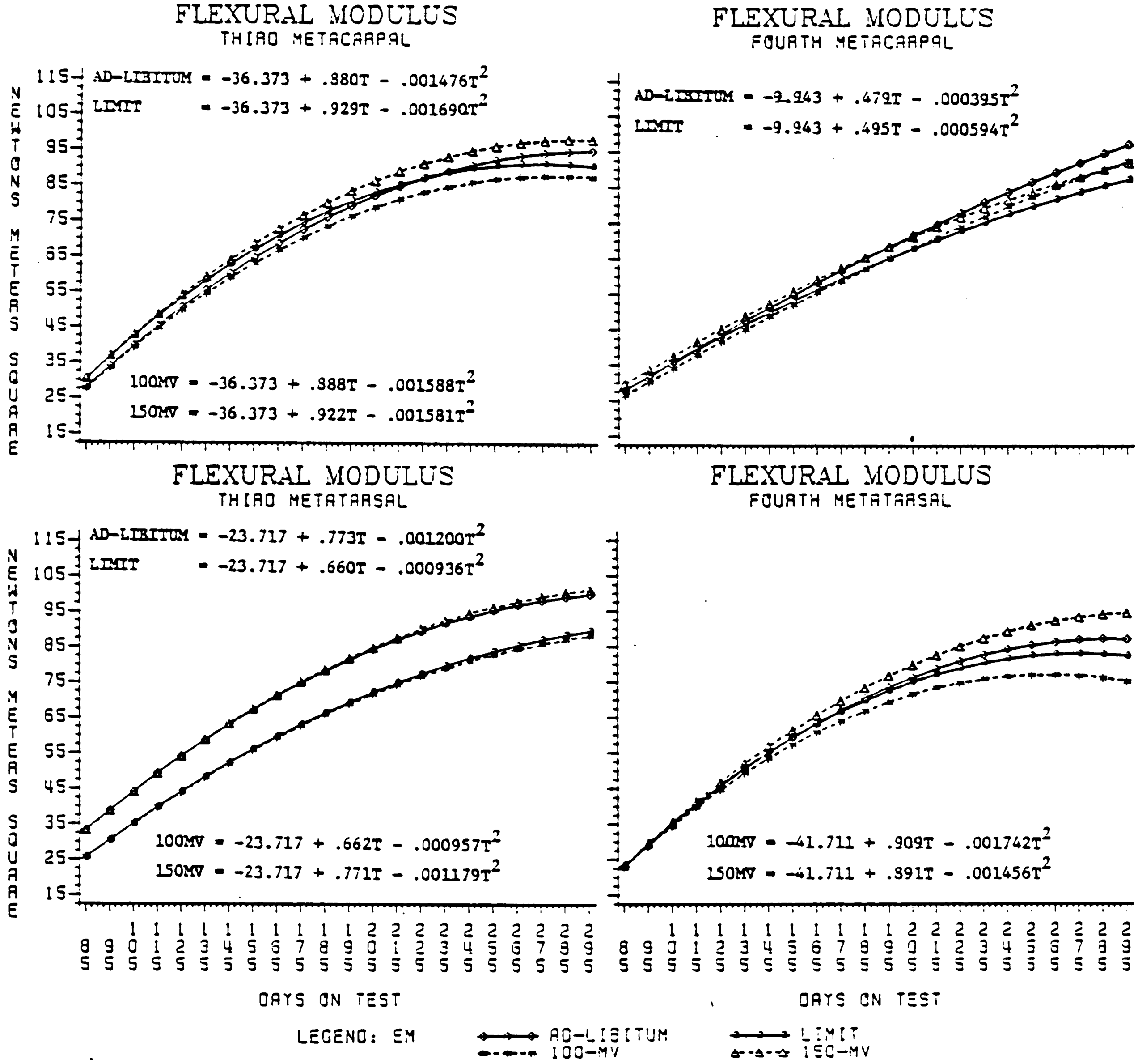

Figure 25. Metacarpal and metatarsal flexural modulus (x 10^{-2}) for boars fed two energy levels (ad libitum vs limit) and two mineral and vitamin levels (100 vs 150% NRC). Main effect means are shown and prediction equations are presented if main effects are significant (P<.10).

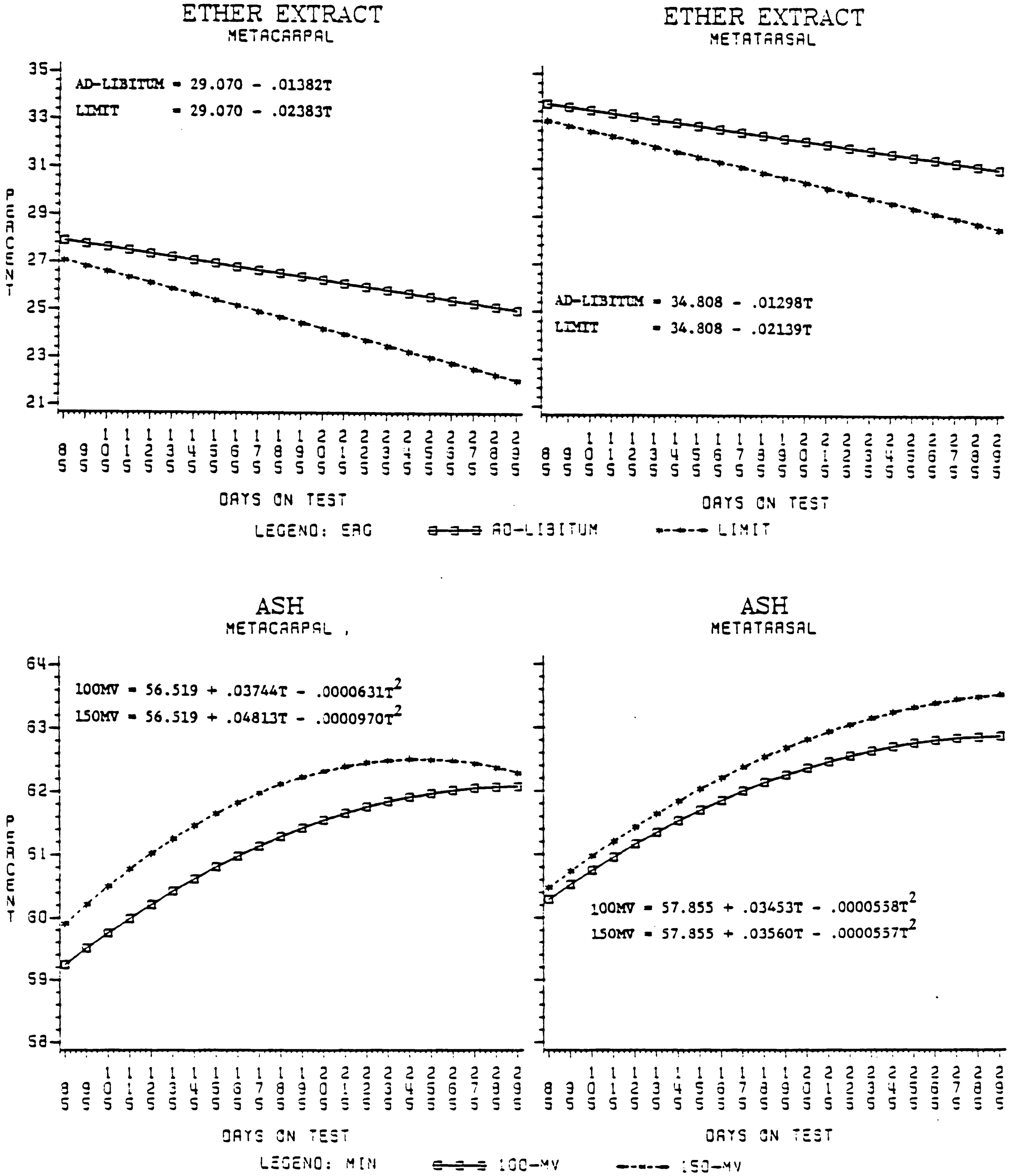

Figure 26. Metacarpal and metatarsal ether extract and ash content for boars fed two energy levels (ad libitum vs limit) and two mineral and vitamin levels (100 vs. 150% NRC). Main effect means are shown and prediction equations are presented if main effects are significant (P<.10).

TABLE 4. PREDICTED MEANS AND ACTUAL AND WEIGHT-CORRECTED MEAN DIFFERENCE AT 85, 190 AND 295 DAYS ON TEST FOR THIRD METACARPAL MINERAL COMPOSITION OF BOARS AD LIBITUM- OR LIMIT-FED

Item	Days on test[a]		
	85	190	295
Calcium, %[bc]	26.30 ± 1.78	30.50 ± 1.00	30.16 ± 1.02
Actual difference[d]	-1.20 ± 1.14	-1.52 ± 1.24	-.56 ± 1.44
Weight-corrected difference[e]	-1.63 ± 1.13	-1.78 ± 1.23	.14 ± 1.43
Phosphorus, %[b]	14.97 ± .25	15.24 ± .14	15.06 ± .14
Actual difference	.18 ± .16	.12 ± .18	-.27 ± .20
Weight-corrected difference	.09 ± .16	.14 ± .17	.13 ± .20
Calcium: Phosphorus ratio[e]	1.84 ± .04	1.92 ± .02	1.99 ± .02
Actual difference	-.03 ± .03	-.02 ± .03	.03 ± .03
Weight-corrected difference	.03 ± .03	.03 ± .03	-.02 ± .03
Magnesium, %[befgh]	.81 ± .02	.66 ± .01	.65 ± .01
Actual difference	-.04 ± .02*	-.04 ± .02*	.01 ± .02
Weight-corrected difference	-.02 ± .02	-.02 ± .02	.01 ± .02
Copper, ppm[bhi]	12.28 ± .80	10.01 ± .44	9.66 ± .45
Actual difference	.07 ± .51	-.01 ± .55	-.27 ± .64
Weight-corrected difference	.18 ± .52	.26 ± .56	.18 ± .65
Zinc, ppm[bjk]	260.91 ± 10.41	247.56 ± 6.07	240.79 ± 6.06
Actual difference	2.79 ± 6.86	5.71 ± 7.52	8.05 ± 8.54
Weight-corrected difference	4.01 ± 6.90	7.38 ± 7.57	8.99 ± 8.59
Iron, ppm[bce]	52.54 ± 4.87	53.39 ± 2.69	42.64 ± 2.83
Actual difference	2.69 ± 3.11	2.38 ± 3.38	-1.96 ± 3.98
Weight-corrected difference	2.38 ± 3.11	4.08 ± 3.38	4.41 ± 3.98
Manganese, ppm[b]	6.83 ± .85	6.78 ± .49	6.09 ± .49
Actual difference	.64 ± .56	.53 ± .61	-.57 ± .70
Weight-corrected difference	.44 ± .55	.62 ± .60	.39 ± .69

*Energy effect (P<.05).

[a]Mean body weight (kg): 43.4 and 41.7 at 85 d; 122.1 and 104.5 at (P<.01) 190 d; 180.2 and 131.7 at (P<.001) 295 d, respectively for ad libitum- and limit-fed boars (linear age effect, P<.001; quadratic age effect, P<.05; energy x linear age effect, P<.001; energy x quadratic age effect, P<.05).

[b]Percent or ppm of ash.

[c]Quadratic age effect (P<.10).

[d]Differences are expressed as ad libitum-fed minus limit-fed. Actual differences are unadjusted for body weight differences; whereas, the weight-corrected differences measure the deviation of the actual treatment difference from that which would have been expected from treatment differences in body weight.

[e]Linear age effect (P<.001).

[f]Quadratic age effect (P<.001).

[g]Energy x quadratic age effect (P<.10).

[h]Energy x mineral-vitamin x quadratic age effect (P<.05).

[i]Linear age effect (P<.01).

[j]Linear age effect (P<.05).

[k]Energy x mineral-vitamin x linear age effect (P<.05).

TABLE 5. ACTUAL AND WEIGHT-CORRECTED MEAN DIFFERENCES AT 85, 190 AND 295 DAYS ON TEST FOR THIRD METACARPAL MINERAL COMPOSITION OF BOARS FED 100 OR 150% NRC MINERAL AND VITAMIN LEVELS

Item	Days on test[a]		
	85	190	295
Calcium, %[b]			
Actual difference[c]	-1.33 ± 1.14	-1.67 ± 1.24	-.59 ± 1.44
Weight-corrected difference[c]	-1.44 ± 1.13	-1.80 ± 1.24	-.60 ± 1.43
Phosphorus, %[b]			
Actual difference	-.03 ± .16	.03 ± .18	.20 ± .20
Weight-corrected difference	-.05 ± .16	.02 ± .17	.22 ± .20
Calcium : Phosphorus ratio			
Actual difference	-.01 ± .03	.02 ± .03	.01 ± .03
Weight-corrected difference	-.02 ± .03	-.03 ± .03	-.02 ± .03
Magnesium, %[de]			
Actual difference	.02 ± .02	.03 ± .02	.04 ± .02
Weight-corrected difference	.02 ± .02	.04 ± .02	.05 ± .02
Copper, ppm[e]			
Actual difference	-.24 ± .51	-.20 ± .55	.20 ± .64
Weight-corrected difference	-.19 ± .52	-.13 ± .56	-.24 ± .65
Zinc, ppm[f]			
Actual difference	-1.62 ± 6.86	-4.97 ± 7.52	-9.81 ± 8.54
Weight-corrected difference	-1.21 ± 6.90	-4.44 ± 6.90	-9.59 ± 7.57
Iron, ppm			
Actual difference	-.25 ± 3.11	-.19 ± 3.38	.29 ± 3.98
Weight-corrected difference	-.06 ± 3.11	.09 ± 3.39	.49 ± 3.98
Manganese, ppm			
Actual difference	.17 ± .56	.39 ± .61	.60 ± .70
Weight-corrected difference	.17 ± .55	.39 ± .60	.64 ± .69

[a]Mean body weight (kg): 43.8 and 41.3 at 85 d; 115.2 and 111.3 at 190 d; 157.7 and 154.2 at 295 d, respectively for boars fed 100 vs 150% mineral and vitamin levels.
[b]Percent or ppm of ash.
[c]Differences are expressed as 100% minus 150% mineral and vitamin level. Actual differences are unadjusted for body weight; whereas, the weight-corrected differences measure the deviation of the actual treatment differences from that which would have been expected from treatment differences in body weight.
[d]Mineral-vitamin x linear age effect (P<.01).
[e]Energy x mineral-vitamin x quadratic age effect (P<.05).
[f]Energy x mineral-vitamin x linear age effect (P<.05).

TABLE 6. PREDICTED MEANS AND ACTUAL AND WEIGHT-CORRECTED MEAN DIFFERENCES AT 85, 190 AND 295 DAYS ON TEST FOR FOURTH METACARPAL MINERAL COMPOSITION OF BOARS AD LIBITUM- OR LIMIT-FED

Item	Days on test[a]		
	85	190	295
Calcium, %[bc]	28.28 ± .59	29.24 ± .33	29.67 ± .33
Actual difference[d]	-.21 ± .38	-.24 ± .41	.02 ± .47
Weight-corrected difference[d]	-.36 ± .37	-.39 ± .41	.05 ± .46
Phosphorus, %[be]	15.10 ± .23	15.13 ± .13	15.14 ± .13
Actual difference	-.10 ± .15	-.03 ± .16	.24 ± .18
Weight-corrected difference	-.11 ± .15	-.05 ± .16	.22 ± .18
Calcium : Phosphorus ratio[c]	1.88 ± .04	1.93 ± .02	1.96 ± .02
Actual difference	0 ± .03	-.01 ± .03	-.03 ± .03
Weight-corrected difference	-.01 ± .03	-.02 ± .03	-.03 ± .03
Magnesium, %[bfgh]	.79 ± .02	.69 ± .01	.66 ± .01
Actual difference	0 ± .01	-.01 ± .02	-.03 ± .02
Weight-corrected difference	.01 ± .01	0 ± .02	-.01 ± .02
Copper, ppm[b]	10.50 ± .89	10.17 ± .49	9.84 ± .50
Actual difference	.57 ± .57	.45 ± .62	-.58 ± .71
Weight-corrected difference	.45 ± .56	.56 ± .61	.17 ± .70
Zinc, ppm[bef]	270.35 ± 9.24	251.99 ± 5.35	238.31 ± 5.78
Actual difference	7.22 ± 6.07	6.96 ± 6.59	-3.44 ± 8.11
Weight-corrected difference	8.27 ± 6.12	10.64 ± 6.64	4.36 ± 8.18
Iron, ppm[bc]	49.39 ± 4.59	50.55 ± 2.67	43.07 ± 2.74
Actual difference	-3.42 ± 3.01	-4.37 ± 3.29	-1.71 ± 3.85
Weight-corrected difference	-3.56 ± 3.06	-3.15 ± 3.34	2.58 ± 3.90
Manganese, ppm[bf]	7.68 ± .75	6.93 ± .43	5.68 ± .43
Actual difference	-.42 ± .49	-.52 ± .53	-.18 ± .61
Weight-corrected difference	-.42 ± .49	-.23 ± .54	.73 ± .62

[a]Mean body weight (kg): 43.4 and 41.7 at 85 d; 122.1 and 104.5 at (P<.01) 190 d; 180.2 and 131.7 at (P<.001) d, respectively for ad libitum- and limit-fed boars (linear age effect, P<.001; quadratic age effect, P<.05; energy x linear age effect, P<.001; energy x quadratic age effect, P<.05).

[b]Percent or ppm of ash.

[c]Linear age effect (P<.05).

[d]Differences are expressed as ad libitum-fed minus limit-fed. Actual differences are unadjusted for body weight differences; whereas, the weight-corrected differences measure the deviation of the acutal treatment difference from that which would have been expected from treatment differences in body weight.

[e]Energy x mineral-vitamin x quadratic age effect (P<.05).

[f]Linear age effect (P<.001).

[g]Quadratic age effect (P<.05).

[h]Energy x linear age effect (P<.10).

TABLE 7. ACTUAL AND WEIGHT-CORRECTED MEAN DIFFERENCE AT 85, 190 AND 295 DAYS ON TEST FOR FOURTH METACARPAL MINERAL COMPOSITION OF BOARS FED 100 OR 150% NRC MINERAL AND VITAMIN LEVELS

Item	Days on test[a]		
	85	190	295
Calcium, %[b]			
Actual difference[c]	.13 ± .38	.23 ± .41	.24 ± .47
Weight-corrected difference[c]	.10 ± .37	.18 ± .41	.23 ± .46
Phosphorus, %[bde]			
Actual difference	-.11 ± .15	.01 ± .16	.42 ± .18
Weight-corrected difference	-.11 ± .15	.01 ± .16	.42 ± .18
Calcium : Phosphorus ratio			
Actual difference	.02 ± .03	.01 ± .03	-.04 ± .03
Weight-corrected difference	.02 ± .03	.01 ± .03	-.04 ± .03
Magnesium, %[b]			
Actual difference	-.01 ± .01	-.01 ± .02	.01 ± .02
Weight-corrected difference	-.01 ± .01	-.01 ± .02	.01 ± .02
Copper, ppm[b]			
Actual difference	.10 ± .57	.39 ± .62	.88 ± .71
Weight-corrected difference	.09 ± .56	.40 ± .61	.91 ± .70
Zinc, ppm[be]			
Actual difference	-6.10 ± 6.07	-9.97 ± 6.58	-9.98 ± 8.14
Weight-corrected difference	-5.61 ± 6.12	-9.18 ± 6.64	-9.05 ± 8.21
Iron, ppm[b]			
Actual difference	.15 ± 3.01	.78 ± 3.29	1.93 ± 3.85
Weight-corrected difference	.17 ± 3.05	.86 ± 3.34	2.09 ± 3.91
Manganese, ppm[b]			
Actual difference	-.54 ± .49	-.27 ± -.53	1.03 ± .61
Weight-corrected difference	-.52 ± .49	-.25 ± -.54	1.03 ± .62

[a]Mean body weight (kg): 43.8 and 41.3 at 85 d; 115.2 and 111.3 at 190 d; 157.7 and 154.2 at 295 d, respectively for boars fed 100 vs 150% mineral and vitamin levels.
[b]Percent or ppm of ash.
[c]Differences are expressed as 100% minus 150% mineral and vitamin level. Actual differences are unadjusted for body weight; whereas, the weight-corrected differences measure the deviation of the actual treatment differences from that which would have been expected from treatment differences in body weight.
[d]Mineral-vitamin x linear age effect (P<.10).
[e]Energy x mineral-vitamin x quadratic age effect (P<.05).

TABLE 8. PREDICTED MEANS AND ACTUAL AND WEIGHT-CORRECTED MEAN DIFFERENCES AT 85, 190 AND 295 DAYS ON TEST FOR THIRD METATARSAL MINERAL COMPOSITION OF BOARS AD LIBITUM- OR LIMIT-FED

Item	Days on test[a]		
	85	190	295
Calcium, %[b]	29.42 ± .56	29.24 ± .32	29.55 ± .32
Actual difference[c]	.32 ± .36	.39 ± .40	.09 ± .45
Weight-corrected difference[c]	.32 ± .36	.35 ± .40	-.02 ± .45
Phosphorus, %[bd]	15.21 ± .23	15.23 ± .13	15.27 ± .14
Actual difference	.07 ± .15	.17 ± .17	.30 ± .19
Weight-corrected difference	.06 ± .15	.15 ± .17	.25 ± .19
Calcium : Phosphorus ratio	1.93 ± .04	1.92 ± .02	1.94 ± .02
Actual difference	.01 ± .02	.01 ± .03	-.03 ± .03
Weight-corrected difference	.01 ± .02	.01 ± .03	-.03 ± .03
Magnesium, %[bdef]	.79 ± .03	.66 ± .01	.65 ± .02
Actual difference	-.02 ± .02	-.03 ± .02	-.03 ± .02
Weight-corrected difference	0 ± .02	-.01 ± .02	-.02 ± .02
Copper, ppm[bg]	11.94 ± .83	10.27 ± .47	9.61 ± .48
Actual difference	-.65 ± .54	-.93 ± .59	-.64 ± .67
Weight-corrected difference	-.66 ± .54	-.66 ± .59	.22 ± .68
Zinc, ppm[bg]	272.06 ± 9.65	246.97 ± 5.65	241.48 ± 5.78
Actual difference	2.81 ± 6.34	5.47 ± 6.94	7.24 ± 8.12
Weight-corrected difference	5.42 ± 6.35	7.87 ± 6.94	5.62 ± 8.13
Iron, ppm[be]	56.07 ± 4.80	50.90 ± 2.71	39.55 ± 2.70
Actual difference	-.04 ± 3.12	.16 ± 3.41	.64 ± 3.80
Weight-corrected difference	.33 ± 3.20	2.51 ± 3.50	6.64 ± 3.89+
Manganese, ppm[be]	8.45 ± .79	6.73 ± .45	5.62 ± .46
Actual difference	-.36 ± .51	.34 ± .56	.17 ± .65
Weight-corrected difference	-.30 ± .53	-.05 ± .58	.86 ± .67

+Energy effect (P<.10).
[a]Mean body weight (kg): 43.4 and 41.7 at 85 d; 122.1 and 104.5 at (P<.01) 190 d; and 131.7 at (P<.001) d, respectively for ad libitum- and limit-fed boars (linear effect, P<.001; quadratic age effect, P<.05; energy x linear age effect, P<.001; energy x quadratic age effect, P<.05).
[b]Percent or ppm of ash.
[c]Differences are expressed as ad libitum-fed minus limit-fed. Actual differences are unadjusted for body weight differences; whereas, the weight-corrected differences measure the deviation of the actual treatment difference from that which would have been expected from treatment differences in body weight.
[d]Energy x linear age effect (P<.10).
[e]Linear age effect (P<.001).
[f]Quadratic age effect (P<.01).
[g]Linear age effect (P<.01).

TABLE 9. ACTUAL AND WEIGHT-CORRECTED MEAN DIFFERENCE AT 85, 190 AND 295 DAYS ON TEST FOR THIRD METATARSAL MINERAL COMPOSITION OF BOARS FED 100 OR 150% NRC MINERAL AND VITAMIN LEVELS

	Days on test[a]		
Item	85	190	295
Calcium, %[bc]			
Actual difference[d]	-1.08 ± .36**	-1.13 ± .40**	.24 ± .45
Weight-corrected difference[d]	-1.09 ± .36**	-1.14 ± .40**	.23 ± .45
Phosphorus, %[b]			
Actual difference	-.16 ± .15	-.12 ± .17	.17 ± .19
Weight-corrected difference	-.16 ± .15	-.13 ± .17	.17 ± .19
Calcium : Phosphorus ratio[e]			
Actual difference	-.05 ± .02*	-.06 ± .03*	-.01 ± .03
Weight-corrected difference	-.05 ± .02*	-.06 ± .03*	-.01 ± .03
Magnesium, %[b]			
Actual difference	.02 ± .02	.02 ± .02	0 ± .02
Weight-corrected difference	.02 ± .02	.03 ± .02	0 ± .02
Copper, ppm[b]			
Actual difference	.18 ± .54	.01 ± .59	-.57 ± .67
Weight-corrected difference	.23 ± .54	.09 ± .59	-.53 ± .68
Zinc, ppm[b]			
Actual difference	-1.23 ± 6.35	-1.14 ± 6.94	.74 ± 8.12
Weight-corrected difference	-.23 ± 6.36	.14 ± 6.95	1.23 ± 8.13
Iron, ppm[b]			
Actual difference	.08 ± 3.11	-.50 ± 3.40	-1.81 ± 3.80
Weight-corrected difference	.35 ± 3.19	-.07 ± 3.49	-1.41 ± 3.89
Manganese, ppm[b]			
Actual difference	-.27 ± .51	-.12 ± .56	.57 ± .65
Weight-corrected difference	-.22 ± .53	-.05 ± .58	.61 ± .67

*,** Mineral-vitamin effect ($P<.05$ and .01, respectively).
[a] Mean body weight (kg): 43.8 and 41.3 at 85 d; 115.2 and 111.3 at 190 d; 157.7 and 154.2 at 295 d, respectively for boars fed 100 vs 150% mineral and vitamin levels.
[b] Percent or ppm of ash.
[c] Mineral-vitamin x quadratic age effect ($P<.01$).
[d] Differences are expressed as 100% minus 150% mineral and vitamin level. Actual differences are unadjusted for body weight; whereas, the weight-corrected differences measure the deviation of the actual treatment differences from that which would have been expected from treatment differences in body weight.
[e] Mineral-vitamin x quadratic age effect ($P<.10$).

TABLE 10. PREDICTED MEANS AND ACTUAL AND WEIGHT-CORRECTED MEAN DIFFERENCES AT 85, 190 AND 295 DAYS ON TEST FOR FOURTH METATARSAL MINERAL COMPOSITION OF BOARS AD LIBITUM- OR LIMIT-FED

	Days on test[a]		
Item	85	190	295
Calcium, %[bcd]	28.17 ± .53	29.21 ± .30	29.66 ± .31
Actual difference[e]	.43 ± .34	.27 ± .37	-.68 ± .43
Weight-corrected difference[e]	.20 ± .33	.12 ± .36	-.34 ± .42
Phosphorus, %[b]	15.01 ± .26	15.08 ± .15	15.29 ± .15
Actual difference	-.04 ± .17	-.08 ± .19	-.10 ± .22
Weight-corrected difference	-.09 ± .17	-.11 ± .18	-.01 ± .21
Calcium : Phosphorus ratio	1.88 ± .04	1.94 ± .02	1.94 ± .02
Actual difference	.04 ± .03	.03 ± .03	-.03 ± .03
Weight-corrected difference	.03 ± .03	.02 ± .03	-.02 ± .03
Magnesium, %[bdfg]	.79 ± .02	.67 ± .01	.64 ± .01
Actual difference	-.01 ± .02	-.01 ± .02	0 ± .02
Weight-corrected difference	.01 ± .02	.01 ± .02	.01 ± .02
Copper, ppm[bh]	9.10 ± .65	10.00 ± .73	9.90 ± .36
Actual difference	-.09 ± .42	-.08 ± .45	.06 ± .50
Weight-corrected difference	-.18 ± .41	-.18 ± .45	.06 ± .50
Zinc, ppm[bd]	258.59 ± 11.35	254.20 ± 6.44	248.25 ± 6.66
Actual difference	7.80 ± 7.35	6.19 ± 8.04	-7.86 ± 9.37
Weight-corrected difference	6.96 ± 7.37	7.59 ± 8.05	-.58 ± 9.39
Iron, ppm[bc]	53.01 ± 5.48	48.81 ± 3.12	40.46 ± 3.19
Actual difference	.11 ± 3.58	-.99 ± 3.91	-3.47 ± 4.49
Weight-corrected difference	-.47 ± 3.58	.70 ± 3.91	3.83 ± 4.48
Manganese, ppm[b]	7.36 ± .79	6.38 ± .45	6.16 ± .47
Actual difference	.12 ± .51	.19 ± .56	.16 ± .66
Weight-corrected difference	.14 ± .51	.31 ± .56	.49 ± .65

[a] Mean body weight (kg): 43.4 and 41.7 at 85 d; 122.1 and 104.5 at (P<.01) 190 d; 180.2 and 131.7 at (P<.001) 295 d, respectively for ad libitum- and limit-fed boars (linear age effect, P<.001; quadratic age effect, P<.05; energy x linear age effect, P<.001; energy x quadratic age effect, P<.05).

[b] Percent or ppm of ash.

[c] Linear age effect (P<.01).

[d] Energy x mineral-vitamin x quadratic age effect (P<.10).

[e] Differences are expressed as ad libitum-fed minus limit-fed. Actual differences are unadjusted for body weight differences; whereas, the weight-corrected differences measure the deviation of the actual treatment difference from that which would have been expected from treatment differences in body weight.

[f] Linear age effect (P<.001).

[g] Quadratic age effect (P<.05).

[h] Energy x mineral-vitamin x linear age effect (P<.05).

TABLE 11. ACTUAL AND WEIGHT-CORRECTED MEAN DIFFERENCE AT 85, 190 AND 295 DAYS ON TEST FOR FOURTH METATARSAL MINERAL COMPOSITION OF BOARS FED 100 OR 150% NRC MINERAL AND VITAMIN LEVELS

Item	Days on test[a] 85	190	295
Calcium, %[bc]			
Actual difference[d]	.01 ± .34	-.13 ± .37	-.43 ± .43
Weight-corrected difference[d]	-.05 ± .33	-.20 ± .36	-.44 ± .42
Phosphorus, %[b]			
Actual difference	-.04 ± .17	-.05 ± .19	0 ± .22
Weight-corrected difference	-.05 ± .17	-.06 ± .19	0 ± .21
Calcium : Phosphorus ratio			
Actual difference	.01 ± .03	0 ± .03	.03 ± .03
Weight-corrected difference	0 ± .03	0 ± .03	-.03 ± .03
Magnesium, %[bc]			
Actual difference	-.01 ± .02	-.01 ± .02	.02 ± .02
Weight-corrected difference	-.01 ± .02	0 ± .02	.02 ± .02
Copper, ppm[bef]			
Actual difference	.38 ± .42	.61 ± .45	.58 ± .50
Weight-corrected difference	.35 ± .41	.57 ± .45	.57 ± .50
Zinc, ppm[bc]			
Actual difference	2.43 ± 7.35	.96 ± 8.04	-5.43 ± 9.37
Weight-corrected difference	2.47 ± 7.37	1.09 ± 8.06	-5.19 ± 9.39
Iron, ppm[b]			
Actual difference	2.71 ± 3.58	2.38 ± 3.91	-2.03 ± 4.49
Weight-corrected difference	2.75 ± 3.58	2.56 ± 3.91	-1.59 ± 4.49
Manganese, ppm[b]			
Actual difference	.02 ± .51	.19 ± .56	.54 ± .66
Weight-corrected difference	.03 ± .51	.22 ± .57	.56 ± .66

[a]Mean body weight (kg): 43.8 and 41.3 at 85 d; 115.2 and 111.3 at 190 d; 157.7 and 154.2 at 295 d, respectively for boars fed 100 vs 150% mineral and vitamin levels.
[b]Percent or ppm of ash.
[c]Energy x mineral-vitamin x quadratic age effect (P<.10).
[d]Differences are expressed as 100% minus 150% mineral and vitamin level. Actual differences are unadjusted for body weight; whereas, the weight-corrected differences measure the deviation of the actual treatment differences from that which would have been expected from treatment differences in body weight.
[e]Mineral-vitamin x linear age effect (P<.10).
[f]Energy x mineral-vitamin x linear age effect (P<.05).

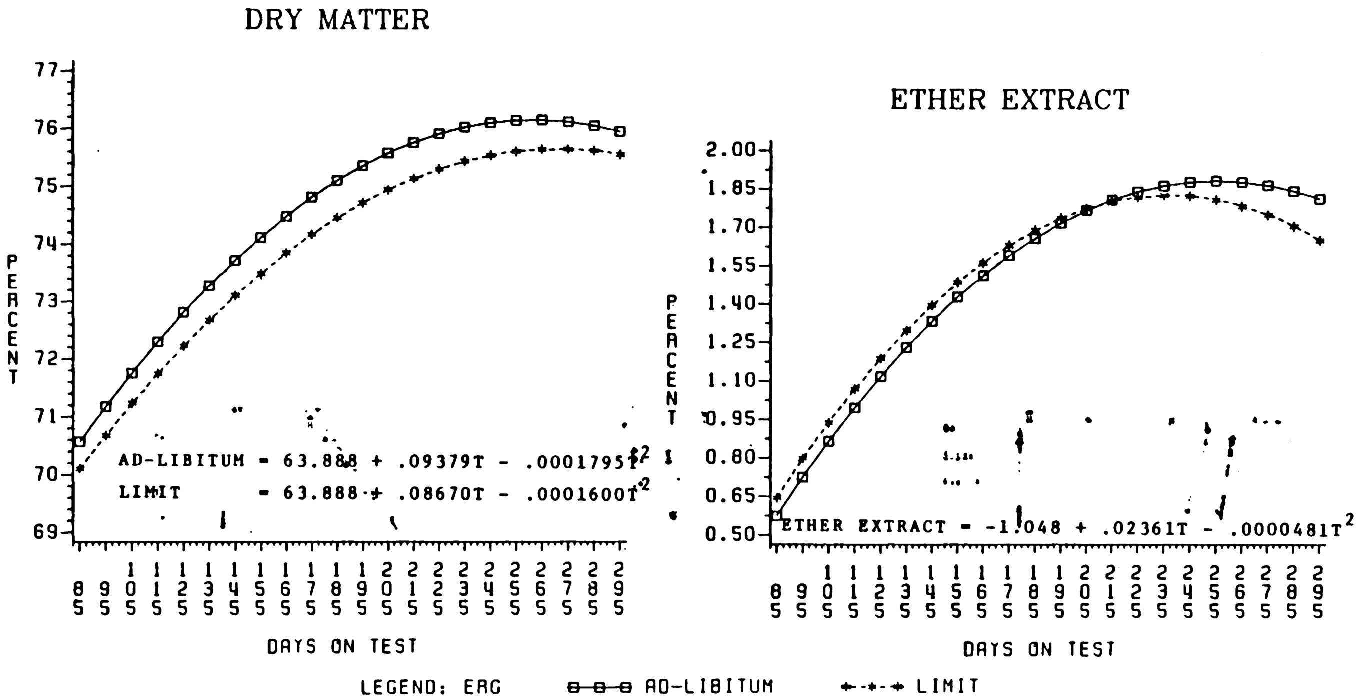

Figure 27. Horn dry matter and ether extract content for boars fed two energy levels (ad libitum vs limit) and two mineral and vitamin levels (100 vs 150% NRC). Main effect means for energy level are shown and prediction equations are presented if main effects are significant (P<.10).

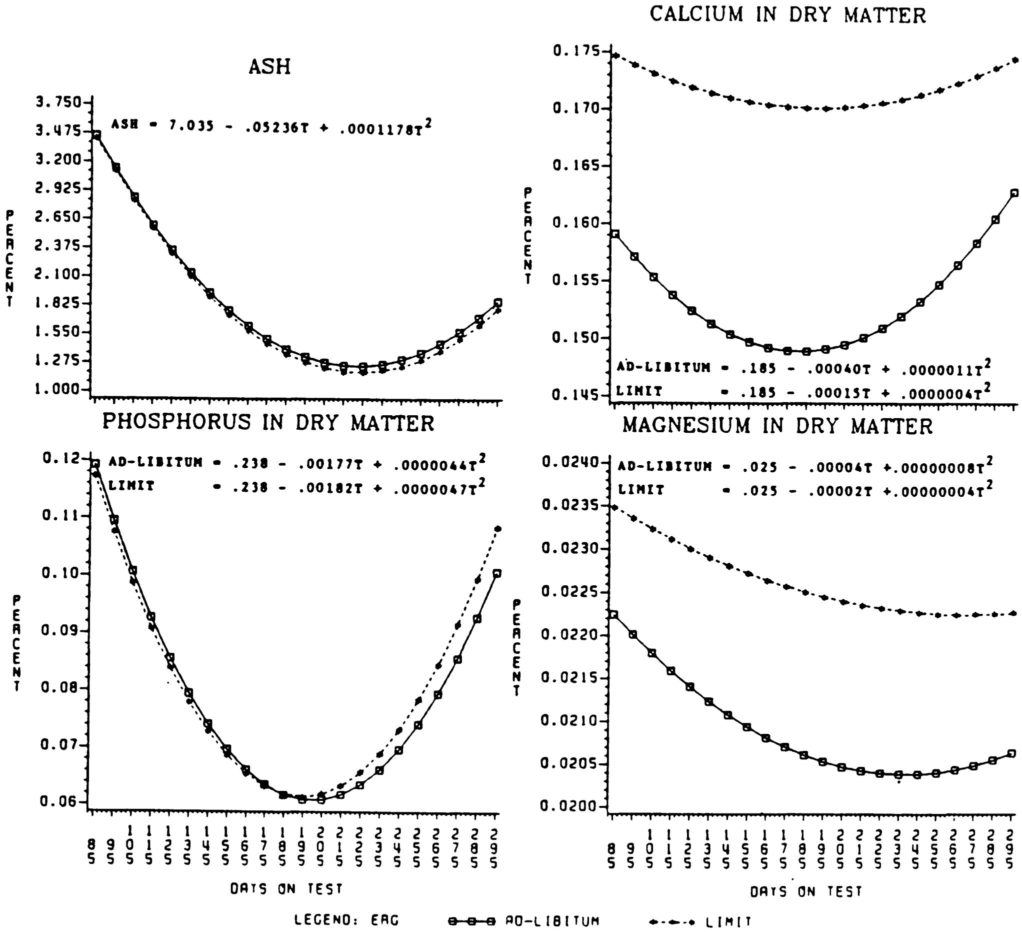

Figure 28. Horn ash, calcium, phosphorus and magnesium for boars fed two energy levels (ad libitum vs limit) and two mineral and vitamin levels (100 vs 150% NRC). Main effect means for energy level are shown and prediction equations are presented if main effects are significant (P<.10).

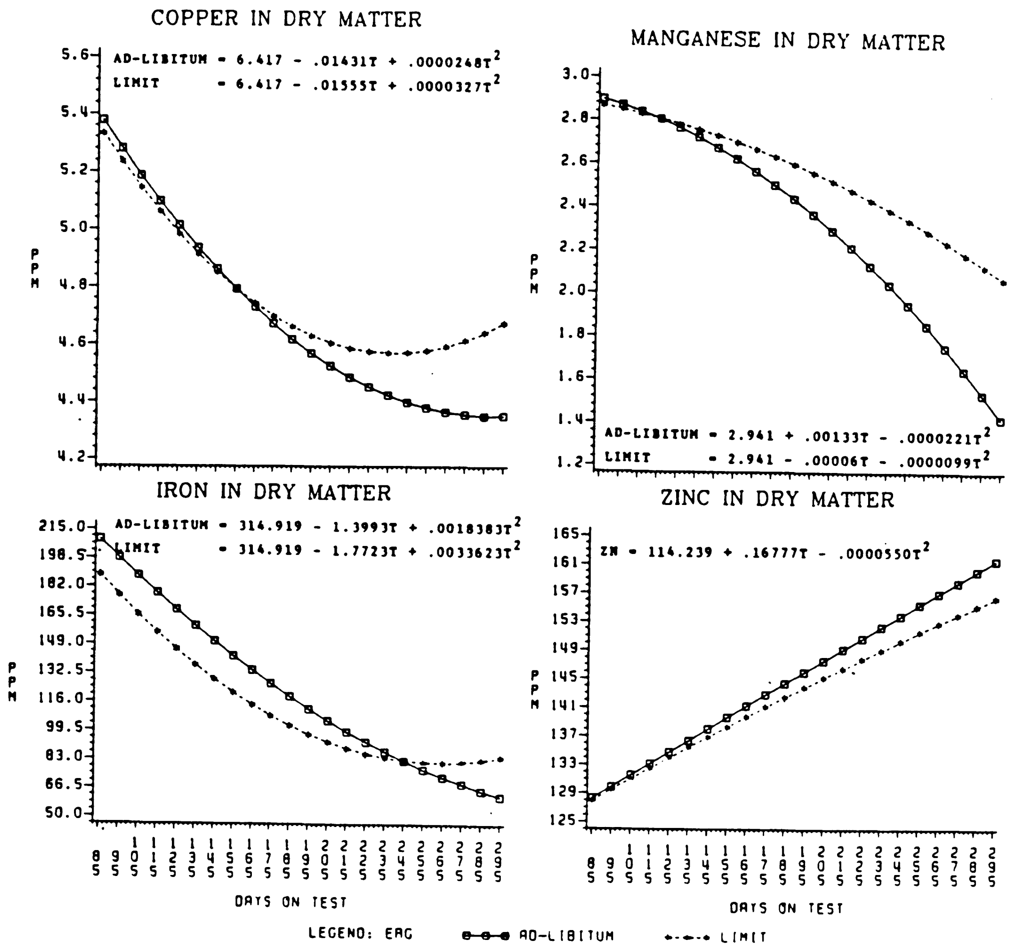

Figure 29. Horn copper, zinc, iron and manganese for boars fed two energy levels (ad libitum vs limit) and two mineral and vitamin levels (100 vs 150% NRC). Main effect means for energy level are shown and prediction equations are presented if main effects are significant (P<.10).

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EFFECT OF RESTRICTED GROWTH RATE AND ELEVATED LEVELS OF MINERALS AND VITAMINS ON FEET AND LEG CHARACTERISTICS, SOUNDNESS SCORES AND METACARPAL AND METATARSAL CHARACTERISTICS OF GROWING BOARS

by

Allan J. Lepine

(ABSTRACT)

The effects of dietary energy level (ad libitum vs 75% of ad libitum) and mineral-vitamin intake (100 vs 150% NRC recommendations) on foot and leg development, incidence and severity of foot lesions, soundness scores and metacarpal and metatarsal characteristics of growing boars was studied. Boars assigned to the dietary treatments at 5 wk of age were serially necropsied beginning at 120 d of age. Foot and leg characterization was carried out at four periods (35, 122, 209 and 290 d of age) and at necropsy. Bone samples were obtained at necropsy.

Toe measurements increased over time with outside toes larger than inside toes. The hind outside toe was consistantly larger than the other toes. Mineral-vitamin level had little effect on toe measurements, while ad libitum feeding produced larger feet and legs as compared with limit-fed boars at an equal age. Correction for body weight differences removed the energy level differences and often produced trends favoring

the limit-fed boars. Dietary treatment had little effect on the incidence and severity of pad or horn lesions, however, restricting feed intake produced boars more structurally sound in appearance.

Bone size increased with age, while bone ether extract decreased and bone ash content increased. As age increased, Ca content of bone ash increased, P level remained unchanged and Mg, Cu, Zn, Fe and Mn levels decreased. Metatarsals were longer and heavier than metacarpals. Percentage of bone ether extract increased with ad libitum feeding while the 150% mineral-vitamin level resulted in increased percentage bone ash. At an equal age, bone size and mechanical characteristics were greater for ad libitum-fed boars, however, weight-correction produced trends favoring limit-fed boars. Greater bone wall thickness and mechanical characteristics resulted from elevated dietary mineral and vitamin levels.

Little consistent correlation was apparent between toe area or volume and the incidence of foot lesions or among the incidence of lesions at the various locations on the front or hind feet.