Influence of Floor Space Allowance and Dietary Selenium and Zinc on Growth Performance, Clinical Pathology Measurements and Liver Enzymes, and Adrenal Weights of Weanling Pigs

E. T. Kornegay*, J. B. Meldrum†, and W. R. Chickering‡

*Department of Animal Science, College of Agriculture and Life Sciences, †Associate Dean and State University, Blacksburg 24061-0306

‡Department of Pathobiology, College of Veterinary Medicine, Virginia Polytechnic Institute and State University, Blacksburg 24061-0306

ABSTRACT: Crossbred weanling pigs (n = 96, average initial weight, 8.4 kg) were used in a 6-wk trial using a 2 x 2 x 3 factorial arrangement of treatments to determine the effects of floor space allowance (.28 and .14 m²/pig), dietary Se (40 and 200 ppb), and dietary Zn (30, 80, and 250 ppm) on growth performance, clinical pathology measurements, serum minerals, and enzymes, liver enzymes, and adrenal weights. Pigs (four/pen) were given ad libitum access to feed and water. Body weight and feed consumed were recorded weekly, and heparinized blood samples were taken for the various assays. Three pigs per pen were killed at the end of the trial for gross examination of organs and tissues and for liver enzymes assays. Pigs housed with restricted floor space ate 21% less (P < .001) and grew 18% more slowly (P < .001) than pigs housed with adequate floor space, but their gain:feed ratio was 4% higher (P < .08). Growth performance was not influenced by dietary Se and Zn treatments. There was no mortality in any of the treatments, and no visible gross abnormalities in organs and tissues at necropsy examination, except that more musculoskeletal bruising was observed for pigs housed with adequate floor space. This finding is supported by higher serum K concentration and creatine phosphokinase activity for pigs housed with adequate floor space. Corticosteroid activity and adrenal weights were similar for all treatments. Concentrations of blood Se and glutathione peroxidase were positively related to dietary Se levels, and serum Zn concentration was related to dietary Zn levels. Other effects of dietary Se and Zn on clinical pathology measurements were minimal and usually unexplained. Most two-way interactions of Se and Zn with floor space allowance were nonsignificant, which suggests that the main effects of Se, Zn, and floor space were independent. Some hematologic values, serum metabolites, serum minerals, and serum and liver enzymes were decreased or increased, which is suggestive of stress of pigs housed with restricted floor space. However, most values were unchanged, and a few changed in the direction to suggest benefits of restricting space; all values were within an expected normal range.

Key Words: Pigs, Floor Space, Stress, Selenium, Zinc


Introduction

It has been clearly established that individual pig performance, primarily growth rate and feed intake, is reduced as floor space allowance per pig is reduced (Kornegay and Notter, 1984; Moser et al., 1985; NCR-89, 1986). However, the efficiency of the facility increases as the floor space allowance per pig is decreased (Kornegay and Notter, 1984). Even though modern swine producers are very much interested in individual pig performance and efficiency, they must be concerned with the efficiency of the total facility because swine facilities are expensive to construct and operate. It is not uncommon for a swine producer to accept some reduction in the performance of individual
animals to increase facility efficiency and thus to reduce cost per unit of pork produced.

Often with little scientific evidence, many people have suggested that restricting floor space (crowding) will result in stress and adverse effects on the pig. The adverse effects mentioned include abnormal behavior as well as increased susceptibility to various diseases. It is speculated that the resultant reduction in individual pig performance causes stress, which increases variation in daily gain and makes the pig more susceptible to disease and environmental insults. Growth performance data from several weanling studies were evaluated by Kornegay et al. (1985); there was no evidence to suggest that increasing stocking density within the range of densities tested caused a greater variation in BW gains. Several researchers have also shown that supplemental antibiotics did not overcome the effects of restricted floor space on growth performance (Harper and Kornegay, 1983; Moser et al., 1985; NCR-89; 1986). High dietary Ca levels can reduce the availability of Zn. In practical swine diets, which are often formulated with high dietary Ca-P levels to maximize bone mineralization and provide “safety factors,” a deficiency of Zn thus could result if dietary Zn levels are not increased. This, coupled with the fact that many of the corn-producing areas are Se-deficient, makes it conceivable that a borderline deficiency of Zn and Se could occur. Certain food animal diseases result not from a single cause, but from a number of etiologic factors. The detrimental effects of trace mineral deficiencies might be potentiated by housing pigs with restricted floor space. The objective of this research was to characterize the influence of restricting floor space and elevating dietary Se and Zn levels on the growth performance, clinical pathology measurements, serum minerals, and enzymes, liver enzymes, and adrenal weights of weanling pigs.

Experimental Procedures

Weanling pigs (n = 96, average initial weight of 8.4 kg and age of 26 d) were used to determine the effects of floor space allowance and dietary Se and Zn levels on growth performance, clinical pathology measurements, serum minerals, and enzyme activity measured weekly and on plasma corticosteroids, liver enzymes, and adrenal weights measured at the end of the 6-wk trial. Pigs were randomly allotted from outcome groups based on weight within sex (barrows and gilts) to the 12 treatments of the 2 × 2 × 3 factorial arrangement of treatments shown in Figure 1. Littermates were balanced across treatments, and each pen of four pigs contained two barrows and two gilts. There were two replicate pens per treatment, and replicates were housed in similar nurseries.

Based on the equation developed by Kornegay and Notter (1984) to predict ADG, a floor space allowance of .28 m² per pig would produce near-maximum individual daily gain, whereas a floor space allowance of .14 m² per pig would result in approximately a 15% decrease in daily gain for the total period. The Pork Industry Handbook (Fritschen and Muehling, 1986) recommends a floor space allowance of .158 to .232 m² for pigs from 6.8 to 13.6 kg and of .278 to .372 m² for pigs from 13.6 to 27.2 kg. Thus, our floor space allowance of .28 m² per pig is well above the recommended for 6.8- to 13.6-kg pigs and is within the range recommended for 13.6- to 27.2-kg pigs. The space allowance of .14 m² per pig is well below both recommendations.

All pigs were housed in pens (.91 m × 1.22 m) with plastic-coated, welded-wire floors (10.2-cm × 50.8-cm rectangular openings) in temperature-controlled rooms. Pen width was adjusted and either a full pen (1.22 m²) or a half-pen (0.61 m²) was used to provide the desired floor space allowance (.28 and .14 m² per pig, respectively). The number of pigs was maintained constant for all pens. The feeder, located on the front of the pen, provided 45.7 cm of feeder space per full or half-pen. Pigs were allowed ad libitum access to diets during the 35-d trial. Each pen was equipped with one nipple waterer. Recommended ventilation rates (Murphy et al., 1990) and temperatures (Harp and Huhnke, 1992) were maintained.

The dietary treatments were made by adding the appropriate amount of mineral (sodium selenite for Se and zinc sulfate for Zn) to the 20% CP basal diet shown in Table 1. Two batches of each diet were made, and each batch was sampled for mineral analyses. Pigs were weighed, allotted to treatments, and put directly on test after weaning. Body weight and feed consumption were measured weekly, and heparinized blood samples were obtained from each pig by venipuncture of the anterior vena cava for the various

![Figure 1. Experimental design of treatments. Analyzed Se and Zn content was 44 and 313 ppb for 40 and 200 ppb of Se diets and 33, 107, and 268 ppm for 30, 80, and 250 ppm of Zn diets.](image-url)
Vitamin premix analyzed Se and Zn content of corn, soybean meal, and whey was 40, 29, and 23 ppb of Se; 24, 60, and 22 ppm of Zn, respectively. Analyzed antibiotic pigs in each replicate pen were randomly selected and slaughtered for gross examination of organs and tissues. The adrenal glands were removed and weighed, and a liver sample was obtained and frozen for later determination of enzymes.

Hematologic values were determined using routine counting (Coulter Model ZBI, Coulter Electronics, Hialeah, FL) and staining procedures (DiffQuick, American Scientific Instruments, McGraw Park, NJ). Serum biochemical analyses (albumin, aspartate aminotransferase, glucose, total protein, and urea N) were performed using a centrifugal analyzer (Cen-trifichem System 500, Baker Instruments, Allentown, PA). Creatine phosphokinase activity in serum was determined using a colorimetric assay kit and procedures provided by Sigma (Sigma Chemical, St. Louis, MO). Determination of serum electrolytes (Na, K, and Cl) were performed using an ion selective analyzer (Photovolt Analyzer, Potovall, New York), and Ca, Mg, and P were determined using a centrifugal analyzer (Cen-trifichem System 500). Aliquots of blood or plasma were digested with a 5:1 mixture of concentrated nitric and 70% perchloric acid, which was a modification of the wet ashing technique of Ihnat and Miller (1977). Concentrations of Zn and Cu were then determined using flame atomic absorption.

Whole-blood Se concentrations were determined using the hydride generation technique of Ihnat and Miller (1977). The activity of superoxide dismutase in whole-blood lysates was determined according to the method of McCord and Fridovich (1969).

Spectrophotometric methods were used to determine the enzymatic o-demethylation of p-nitroanisole (Kinoshita et al. 1966), hydroxylation of aniline, and quantity of cytochrome P-450 (Mazel, 1971) in liver homogenates. Total plasma corticosteroid values were determined using a competitive protein binding assay (Kattesh et al., 1980).

The data were analyzed using the GLM procedure of SAS (1988). Pen was used as the experimental unit for weekly and cumulative performance data. The model included space, Se, Zn, all two-way interactions, and the three-way interaction. For other weekly measurements, individual values were used as the experimental unit, and the model included main effects (space, Se, and Zn), all two-way interactions and the three-way interaction, pen (space × Se × Zn), and the pig (pen × space × Se × Zn), week, week × space, week × Se, and week × Zn. Pen (space × Se × Zn) was used to test main effects and associated two-way interactions and the three-way interaction. Most two-way and the three-way interactions were nonsignificant and were dropped from the model.

### Results

**Growth Performance.** Pigs housed with adequate floor space ate more during each week than those housed with restricted space (Figure 2 and Table 2; P < .001). Also, pigs with adequate space grew faster (P < .001) than those with restricted space, with the exception of wk 2, when gain was similar for both space treatments. Gain:feed ratios (G:F) generally favored (P < .08) pigs housed with restricted space but were greater during only 4 of the 6 wk, and the magnitude of change was usually much less than for ADG and ADFI. Overall, pigs housed with restricted floor space ate 21% less and grew 18% more slowly than those housed with adequate floor space. However, pigs housed with restricted space had a G:F that was 4% higher than that of pigs housed with adequate floor space. Dietary Se and Zn treatments did not affect ADG, ADFI, and G:F, except for a Se × space interaction (P < .03) for ADFI. Pigs fed the high level of Se and housed with adequate floor space consistently had greater ADFI than those fed the low level of Se (1,079 vs 1,027 g), whereas those housed with restricted floor space and fed high Se had the smaller ADFI (828 vs 843 g).

**Hematologic Values.** Main effect treatment means (across weeks) were not statistically different for any of the hematologic values (Figure 3), except the number of lymphocytes, which was lower for pigs housed with restricted floor space than for those housed with adequate space (7,430 vs 8,017, SEM = 280). However, the space × week interaction was highly significant for hematocrit, hemoglobin, and...
lymphocytes and was significant for total leukocytes. Initially and during the 1st wk, pigs housed with restricted floor space had higher hematocrit and hemoglobin than did those housed with adequate floor space. During wk 2 and 3, values were generally not different. After wk 3, the difference became progressively larger; observed hematocrit and hemoglobin values were higher for pigs housed with adequate space than for pigs housed with restricted space. At the end of the 6-wk test, values were 39.02 vs 36.54%, SEM = .35, and 12.39 vs 11.54 g/dL, SEM = .12, respectively, for hematocrit and hemoglobin. Values for all the above measurements were within a normal range (Coles, 1986).

Total leukocytes and lymphocytes were generally not influenced by floor space, until wk 3 and afterward, when numbers were higher (P < .001) for pigs housed with adequate space than for those housed with restricted space (Figure 3). At the end of the 6-wk test, values were 14,604 vs 13,108, SEM = 392 for leukocytes, and 9,249 vs 7,486, SEM = 279 for lymphocytes, respectively, for adequate and restricted housing, which are within the range for normal values (Coles, 1986).

Across treatments, hematocrit and hemoglobin values decreased by 8.6% to week 3 and then increased to levels slightly higher than the initial values at wk 5 and 6 (Figure 3). Number of leukocytes increased by 70% to peak at wk 3 and number of lymphocytes increased by 111% to peak at wk 4. Both generally reached a plateau afterward (Table 3). Band, segmented, and total neutrophils, monocytes, eosinophils, and basophils were not influenced by treatments during any week and were within a normal range (Coles, 1986). Number of band, segmented, and total neutrophils increased to wk 2 or 3 and then decreased to values similar to those obtained initially at wk 4, 5, or 6. Number of monocytes and eosinophils similarly increased to wk 2 or 3 and generally reached a plateau thereafter. The total neutrophil:lymphocyte ratio (N:L) in our study was not influenced by dietary Se and Zn treatments or floor space allowance, but it did differ (P < .001) by week. The N:L increased slightly to wk 1 and then gradually decreased over time.

**Serum Metabolites.** Serum glucose was higher (P < .04) throughout the trial for pigs housed with adequate space than for those housed with restricted space; the differences were greater during wk 4, 5, and 6 (Figure 4). However, urea N was only greater for pigs housed with adequate space than for those housed with restricted floor space during wk 5 and 6 (space × week interaction, P < .01). A space × Se interaction (P < .07) indicated no effect of floor space allowance on urea N when pigs were fed the low Se level (13.5 vs 13.6 mg/dL for adequate vs restricted), but at the high Se level, higher urea N values were observed for pigs housed with adequate floor space than for those housed with restricted floor space (14.5 vs 13.3 mg/dL, respectively).

Serum protein levels were not affected by the main effects of space or dietary Se level but seemed to be lower (P < .05) for pigs fed diets containing 80 ppm of Zn compared with those fed 30 or 250 ppm of Zn (Figure 4). After wk 2, serum protein levels were highest (Zn × week interaction, P < .09) for pigs fed the lowest dietary Zn level. A Se × week interaction (P < .02) suggested that serum protein levels were lower for the low-Se diets initially and during wk 3, 4, and 5. Higher levels were observed during wk 6, and no obvious differences were noted during wk 1 and 2.

Serum albumin levels were not influenced by the main effects of dietary Zn and space (Figure 4) but
Table 2. Weekly average daily feed intake and daily gain of weanling pigs housed with adequate (.28 m²/pig) or restricted (.14 m²/pig) floor space allowance and fed two dietary levels of Se and three dietary levels of Zn

<table>
<thead>
<tr>
<th>Treatmenta</th>
<th>Floor space, m²/pig: 28 28 28 28 28 28 28 28 28 28 28 28</th>
<th>Se level, ppb: 40 40 40 200 200 200 200 200 200 200 200 200</th>
<th>Zn level, ppm: 30 80 250 30 80 250 30 80 250 30 80 250</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avg daily feed intake, gb</td>
<td>478 389 507 551 503 486 389 357 438 349 357 341</td>
<td>423 434 592 503 600 604 511 413 543 442 462 361</td>
<td>920 872 796 928 936 851 701 738 790 717 746 754</td>
</tr>
<tr>
<td>Avg daily gain, gd</td>
<td>1,334 1,176 1,216 1,354 1,252 1,350 1,074 1,034 1,066 1,054 1,033 1,001</td>
<td>1,528 1,411 1,463 1,467 1,488 1,577 1,159 1,240 1,159 1,196 1,171 1,122</td>
<td>1,617 1,613 1,621 1,690 1,625 1,747 1,147 1,285 1,131 1,286 1,296 1,264</td>
</tr>
<tr>
<td>Overallf</td>
<td>1,067 982 1,032 1,067 1,067 1,103 830 844 855 842 845 797</td>
<td>306 273 258 342 291 305 259 215 299 228 263 259</td>
<td>264 216 239 321 235 263 297 232 272 238 266 211</td>
</tr>
</tbody>
</table>

aEach mean represents two pens of four pigs each. Average initial BW was 8.4 kg. Pooled SEM was 70.5 for weekly daily feed intake and 41.9 for weekly daily gain. The pooled SEM was 26.6 for overall daily feed intake and 16.1 for daily gain.
bWeekly effects: space (P < .001), space × Se (P < .03), week (P < .001), and space × week (P < .001).
cOverall effects: space (P < .001) and space × Se (P < .09).
dWeekly effects: space (P < .001), Se level (P < .10), week (P < .001), week × Zn (P < .10), and space × week (P < .001).
eOverall effects: space (P < .001) and Se level (P = .12).

were generally lower (P < .04) for pigs fed the low-Se diets than for those fed the high-Se diets (3.12 vs 3.21, SEM = .013 g/dL). The Zn × week interaction was significant (P < .004); however, no clear pattern was observed. For example, during wk 1 and 2, pigs fed the highest level of Zn had the highest albumin level, whereas at wk 3, 4, 5, and 6 the highest albumin level was observed for pigs fed the lowest level of Zn.

The main effects of Se, Zn, and space were not significant for serum globulin levels, but a Zn × space interaction (P < .01) revealed that pigs housed with restricted space had the highest level of serum globulin when fed 30 ppm of Zn (1.88, 1.69, and 1.68 g/dL for 30, 80, and 250 ppm Zn, respectively), whereas the highest level of serum globulin for pigs housed with adequate space was observed for pigs fed 250 ppm of Zn (1.65, 1.62, and 1.80 g/dL for 30, 80, and 250 ppm Zn, respectively). There was little difference between housing groups for pigs fed 80 ppm of Zn. A Se × week interaction (P < .06) revealed higher serum globulin levels for pigs fed the lower Se level during wk 1, 2, 3, 4, and 6 with higher levels observed initially and during wk 5 for pigs fed the higher level of Se.

Serum glucose levels declined to wk 2 and then gradually returned to initial levels (Figure 4). Serum urea N levels gradually increased to wk 2 and then remained at a plateau during the remainder of the test. Serum protein and albumin level declined (4 and 11%, respectively) to wk 2 and then gradually increased to levels above those initially obtained (20 and 33%, respectively). Serum globulin levels increased to wk 3, reached a plateau through wk 4, and declined during wk 5 and 6 to levels similar to those obtained initially.

Serum Minerals. Blood Se concentration steadily increased (P < .001) during the 6-wk study for pigs fed diets containing 200 ppb of Se but they gradually decreased to wk 4 and then slightly increased for pigs fed 40 ppb of Se (Figure 5). At the end of study, blood Se levels were more than fourfold higher for pigs fed 200 ppb of Se (35.4 vs 149.3 ppb). During the 6-wk study, blood Se levels of the pigs fed 40 ppb of Se level decreased from 65 ppb initially to a low of 19.1 ppb at wk 4 and then increased to 35.4 ppb at wk 6. Concentration of blood Se was not influenced by floor space allowance or dietary Zn level.

Serum Zn concentrations gradually decreased over time and after wk 1 were lower (P < .04) for pigs housed with restricted space than for those given adequate space. Pigs fed 250 ppm of dietary zinc had higher (P < .003) serum Zn concentrations after wk 1; concentrations were intermediate for pigs fed 80 ppm of Zn and lowest for pigs fed 30 ppm of Zn. In general, the highest level of dietary Zn maintained serum Zn concentrations during the 6-wk test.
Figure 3. Hematologic measurements of weanling pigs housed with adequate (1.28 m²/pig) or restricted (1.14 m²/pig) floor space allowance and fed two dietary levels of Se and three dietary levels of Zn.

Serum Cu concentrations were not influenced by dietary Se or Zn, except for a Se × week interaction (P < .009); higher concentrations of serum Cu were observed during wk 1 for pigs fed the low level of Se, whereas during wk 2, 3, 4, and 5, pigs fed the high level of Se had slightly higher serum Cu concentrations (Figure 5). At wk 6, however, serum Cu was again slightly higher for pigs fed the low level of Se. Serum Cu concentrations tended to be higher (P = .11) for pigs with restricted space than for those given adequate space (1.70 vs 1.81 ppm, SEM = .04). A space × week interaction (P < .05) for serum Cu concentrations supported the space effect. During all weeks, serum Cu concentrations were higher for pigs housed with restricted space. Generally, serum Cu concentrations increased over weeks.

Serum Ca was higher (P < .02) for pigs housed with adequate space than for those housed with restricted space for all weeks, except for wk 4, when there was no difference between treatments (Figure 6). Dietary Se and Zn did not affect serum Ca concentrations. Serum Ca concentrations increased after wk 2 for all treatments.

After wk 2, serum P concentrations were higher (P < .008) for pigs housed with adequate space than for those housed with restricted space (space × week interaction, P < .001). A Zn × week interaction (P < .001) indicated higher serum P concentrations at wk 2, 3, and 4 for pigs fed the lowest dietary Zn level. Over weeks and across treatments, serum P concentrations decreased to wk 2 and concentrations increased thereafter; concentrations at wk 6 were higher than initial values. Dietary Se did not affect serum P concentrations.

Serum Na and Cl concentrations were not influenced by any of the treatments (Figure 6). A space effect (P < .01) and a space × week interaction (P < .001) revealed that serum K concentration was higher during wk 1 and 2 for pigs housed with the restricted space, and they were lower during wk 3 through 6 for pigs housed with the restricted space.

Serum Mg concentrations decreased (P < .001) to wk 1 (2.6 to 2.2 mg/dL) and then remained at a plateau for the remainder of the test, with no effects of space, dietary Se, or Zn. Serum Na concentrations declined (P < .001) to wk 2, increased sharply to concentrations above initial concentrations at wk 4, and then reached a plateau for wk 5 and 6. Chloride concentrations decreased (P < .001) to wk 1, increased to wk 3, and then decreased to initial concentrations at wk 5 and 6. Serum K concentrations generally increased (P < .001) during the 6-wk test.

**Enzyme Activity.** Serum aspartate aminotransferase (AST) and superoxide dismutase were not
influenced by any of the treatments (Figure 7). Serum creatine phosphokinase (CPK) was higher \((P < .04)\) for pigs housed with adequate space during wk 3, 4, and 5; no difference was observed during the other weeks. The \(Zn \times \) week interaction \((P < .03)\) suggested higher levels of CPK at wk 3 for pigs fed 80 ppm of Zn and higher levels of CPK for pigs fed 250 ppm of Zn at wk 4 and 5.

Glutathione peroxidase (GTH) or glutathione peroxidase per gram of hemoglobin (GPH) were higher \((P < .001)\) for pigs fed 200 ppb of Se than for those fed 40 ppb of Se (Figure 7). A \(Se \times \) week interaction \((P < .001)\) for both GTH and GPH indicated no difference through wk 3, but showed that GTH and GPH values were elevated during wk 4 through 6 for pigs housed with restricted floor space.

Serum AST declined to wk 1, increased to wk 2, and then declined to wk 3 and reached a plateau at levels near those observed initially (Figure 7). Superoxide dismutase showed no consistent pattern. Serum CPK declined to wk 2, gradually increased to wk 4, and then returned to levels observed initially. The gradual decrease of GTH and GPH over weeks was caused by the reduction of GTH and GPH for pigs fed the low Se levels; pigs fed the high Se level maintained their GTH and GPH levels.

**Liver Enzymes, Corticosteroid Levels, and Adrenal Weights.** Activity of P-450 was not influenced by dietary Se and Zn levels but was lower \((P < .05)\) for pigs housed with restricted floor space than for those housed with adequate floor space (Table 4). O-demethylase and aniline hydroxylase activity were not influenced by any of the experimental treatments. Also, corticosteroid activity and adrenal weights were not influenced by any of the treatments.

Subjective Evaluation of Activity Level and Necropsy Examination. Observation of pigs in pens with adequate floor space indicated that they moved about more and fought more frequently than pigs housed in pens with restricted floor space. Pigs in pens with restricted floor space seemed to adapt and arrange themselves in the pen to achieve a great degree of comfort. This adaptation was evident from wk 3 or 4 onward, when space became more critical.

There was no mortality and no observable signs of parakeratosis indicative of a Zn deficiency in any of the treatments. Necropsy examinations of three pigs in each pen at the termination of the test revealed no visible gross abnormalities in organs or tissues, except that more bruises on skin and skeletal muscles were observed in pigs housed with adequate floor space.

**Discussion**

The predicted reduction in ADFI and ADG was observed in pigs housed with restricted floor space compared with those housed with adequate floor space, and in 4 of the 6 wk, G:F were larger for pigs housed with restricted floor space. This reduction in ADFI and ADG is in agreement with previous reports using pigs of a similar size and similar pens and floor space allowances (Kornegay and Notter, 1984; Lindemann et al., 1988; Kornegay et al., 1993). In most studies, G:F was not improved, or was slightly decreased. Lindemann et al. (1987) clearly showed that the reduction in feed intake that was observed is not due to limited feeder trough space, as had been suggested, but rather is due to unexplained factors. Varying the intake of Se and Zn did not affect ADFI, ADG, and G:F. Interactive effects of Se and Zn with space were generally not significant, with one exception: pigs housed with adequate floor space and fed 200 ppb of Se always had the largest ADFI, and pigs housed with restricted floor space and fed 40 ppb of Se always had the lowest ADFI. However, ADG and G:F were not significantly different. In agreement, other research has also shown that supplementation of a
Figure 4. Serum metabolites of weanling pigs housed with adequate (0.28 m²/pig) or restricted (0.14 m²/pig) floor space allowance and fed two dietary levels of Se and three dietary levels of Zn.

corn-soybean meal diet with Se and Zn does not consistently improve growth performance and feed efficiency (Hedges et al., 1976; Blodgett et al., 1986, 1988, 1989). Also, the lack of observable signs of parakeratosis for pigs fed a Zn-unsupplemented, corn-soybean meal diet agrees with the findings of Hedges et al. (1986). Our recent findings (Swinkels, 1992) with semipurified diets confirm earlier reports that parakeratosis cannot easily be produced when pigs are fed a corn-soybean diet (30 ppm of Zn) but requires the feeding of a dietary Zn level < 20 ppm. Numerous attempts to overcome the reduction in performance caused by restricted floor space allowance, such as feeding antibiotics (Harper and Kornegay, 1983; NCR-89 Committee, 1984; Yen and Pond, 1987) or feeding supplemental nutrients at levels higher than normally required (Mg, Krider et al., 1975; vitamin C, Yen and Pond, 1987; lysine, Kornegay et al., 1993), have failed. The most probable reason for the reduced performance is an absolute decrease in energy intake.

Hemoglobin, hematocrit, and serum glucose decreased from weaning to wk 2 or 3 for all treatments, whereas total leukocytes and lymphocytes increased. Afterward, hemoglobin, hematocrit, and serum glucose increased; this increase was greater for pigs housed with adequate floor space. The increase for total leukocytes and lymphocytes tended to reach a plateau at wk 3 or 4, but pigs housed with restricted
Figure 5. Blood and serum mineral concentrations of weanling pigs housed with adequate (.28 m²/pig) or restricted (.14 m²/pig) floor space allowance and fed two dietary levels of Se and three dietary levels of Zn.

floor space had lower values. The lower number of circulating lymphocytes might be indicative of some stress or decreased production, although corticosteroid activity and adrenal weights measured at the end of the trial were not different. Circulating lymphocytes, primarily thymus-derived cells, are notably sensitive to increases in plasma corticosteroids. Even minor stress related to increases in endogenous corticosteroids (Fauci et al., 1976; Craddock, 1978; Keller et al., 1981) will cause depletion in the numbers of circulating lymphocytes. There were no effects of floor space restriction on number of bands, segmented, and total neutrophils, monocytes, and eosinophils. All values, except those for basophils, increased to wk 2 or 3 and then either reached a plateau or returned to levels initially obtained.

The heterophil:lymphocyte ratio was suggested by Gross and Siegel (1983) to be a sensitive indicator of social stress in chicks. They suggest that a larger or widening ratio indicates that stress exists, because the count of heterophils (equivalent to neutrophils in pigs) increases and the count of lymphocytes decreases in response to the stressor. However, in our study the N:L was not increased by restricting floor space allowance or dietary Se or Zn supplementation, although the number of lymphocytes was approximately 13% lower during wk 3 through 6 for pigs with restricted space.

Yen and Pond (1987) reported in one trial an increase in the N:L at d 14 and 28 for 16 pigs housed/pen (.13 m²/pig) compared with 8 pigs housed/pen (.26 m²/pig), but differences in N:L were not observed in a second trial using the same housing treatments. Number of pigs per pen and floor space allowance were confounded in their trials. Our N:L was almost twofold higher than that reported by Yen and Pond (1987). Although our N:L generally decreased over time, which agrees with the findings of Yen and Pond (1987), the concentrations of leukocytes and lymphocytes reported by Yen and Pond (1987) were more than twofold higher than those we obtained.

Serum Zn, Ca, P, and K concentrations were generally lower after wk 1 or 2 and serum Cu concentration was higher for pigs housed with restricted floor space, which could also be indicative of subtle stress. An additional indicator of subtle stress might be the lower levels of Ca and P in pigs housed with restricted floor space. Corticosteroids cause a decrease in intestinal absorption and a decrease in renal tubular reabsorption of Ca that results in lower serum Ca concentrations (Gill, 1979). Lower serum Ca concentrations, particularly if they persisted, would stimulate the parathyroid gland to release increased amounts of parathyroid hormone, which in turn would increase urinary excretion of P, resulting in lower serum P (McGilvery, 1979). Furthermore,
Figure 6. Serum mineral concentrations of weanling pigs housed with adequate \([.28 \text{ m}^2/\text{pig})\] or restricted \([.14 \text{ m}^2/\text{pig})\] floor space allowance and fed two dietary levels of Se and three dietary levels of Zn.

The higher intestinal content of Ca, due to decreased absorption, could lead to the formation of greater quantities of poorly absorbable calcium phosphate complexes that could further decrease serum concentration of both ions (Omdahl and DeLuca, 1973). The elevation of Ca and calcium phosphate complexes could lower Zn absorption because of an antagonism between Ca and Zn (Hedges et al., 1976). Conversely, lower concentrations of serum Zn, Ca, P, and K after wk 1 or 2 for pigs with restricted floor space may have been a result of decreased mineral intake, because feed intake was reduced. Madsen et al. (1991) have reported that serum Cu concentrations were elevated as a result of nonspecific traumas, whereas Zn, Fe, and Mn concentrations were decreased. Recall, however, that more bruises were observed on skin and skeletal muscles in pigs housed with adequate floor space.

Corticosteroid activity and the weight of the adrenals determined at the end of the trial were similar, however, between pigs housed with adequate and restricted floor space, suggesting that stress, defined as elevated corticosteroid activity, was not a factor. In agreement, Yen and Pond (1987) and Kornegay et al. (1993) reported no effects of restricting floor space allowance on adrenal weight, even though growth performance was decreased. Also, Lindemann (unpublished data) and Kornegay et al. (1993) reported that corticosteroid activity taken after 4 wk on test and at the end of the test at wk 5 or
Figure 7. Serum enzyme activity of weanling pigs housed with adequate (0.28 m²/pig) or restricted (0.14 m²/pig) floor space allowance and fed two dietary levels of Se and three dietary levels of Zn.

6 was not affected by restricting floor space. However, Lindemann et al. (1987) observed higher ($P < .01$) corticosteroid activity for pigs housed 10/cage than for those housed 5/cage.

Serum K and CPK values were higher for pigs housed with adequate floor space than for pigs housed with restricted floor space, which suggests that adequately housed pigs suffered more traumatic musculoskeletal damage. Large quantities of CPK are present in skeletal muscle. Damage to muscle cell membranes allows leakage of CPK and K into the serum proportional to the degree of cellular perturbation that occurs (Duncan and Prasse, 1977). Normally, pigs fight more when floor space is restricted (Leman, 1981). However, pigs housed with restricted floor space moved about less and fought less frequently than pigs housed with adequate floor space. This adaptation was somewhat surprising but was particularly evident from wk 3 or 4 to wk 6, when floor space became more critical. Additionally, it was observed that adequately housed pigs suffered more traumatic musculoskeletal injuries (bruises, lameness) than pigs housed with restricted floor space.

Pigs housed with restricted floor space had higher GTH and GPH during the last 3 wk of the test. It is possible that this may be a physiological response to help the pig cope with increased stress, because stress is known to increase metabolism and breakdown of body tissue that would lead to the production of greater quantities of organic peroxides and free
Table 4. The effect of floor space allowance and dietary selenium and zinc on the activity of three microsomal enzymes, plasma corticosteroid concentration, and adrenal weight in weanlings pigs

<table>
<thead>
<tr>
<th>Item(^a)</th>
<th>Floor space, m(^2)/pig</th>
<th>Main treatment effects</th>
<th>Dietary Zn, ppm</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>28</td>
<td>14</td>
<td>40</td>
<td>200</td>
</tr>
<tr>
<td>Cyto P-450(^b)</td>
<td>1.35</td>
<td>1.13</td>
<td>1.19</td>
<td>1.29</td>
</tr>
<tr>
<td>e-Demethylase(^d)</td>
<td>241</td>
<td>222</td>
<td>240</td>
<td>223</td>
</tr>
<tr>
<td>Aniline hydroxylase(^e)</td>
<td>2.12</td>
<td>2.21</td>
<td>2.18</td>
<td>2.15</td>
</tr>
<tr>
<td>Corticosteroid(^f)</td>
<td>38.7</td>
<td>36.3</td>
<td>35.9</td>
<td>39.2</td>
</tr>
<tr>
<td>Adrenal wt, g</td>
<td>2.61</td>
<td>2.74</td>
<td>2.69</td>
<td>2.65</td>
</tr>
</tbody>
</table>

|                | 30              | 80                  | 230          | SEM |
| Cyto P-450\(^b\) | 1.20            | 1.21                | 1.32         | .07 |
| e-Demethylase\(^d\) | 243             | 233                 | 219          | 12  |
| Aniline hydroxylase\(^e\) | 2.25            | 2.12                | 2.12         | .07 |
| Corticosteroid\(^f\) | 39.3            | 38.8                | 34.5         | 5.3 |
| Adrenal wt, g | 2.61            | 2.63                | 2.77         | .10 |

\(^a\)Each mean for enzyme activity represents 36 pigs for floor space and Se and 24 pigs for Zn; each mean for corticosteroid value and adrenal weight represents 12 pigs for floor space and Se and 8 pigs for Zn.

\(^b\)Cytochrome P-450 activity reported as nanomoles of cytochrome P-450 per mg of microsomal protein.

\(^c\)Space effect (P < .05).

\(^d\)p-Demethylase activity reported as nanomoles of p-nitrophenol formed per 60 min per 100 mg of liver.

\(^e\)Aniline hydroxylase activity reported as micromoles of p-aminophenol formed per 30 min per g of liver.

\(^f\)Nanograms per milliliter of plasma.

radicals (Fridovich, 1978). The level of GTH would increase to combat these deleterious effects. Thus, pigs under conditions of restricted floor space might have a higher demand for Se, and if dietary supplementation is not adequate, they would deplete body stores of Se more rapidly than pigs housed with adequate floor space. However, the lack of a Se × floor space interaction does not support this hypothesis.

The level of cytochrome P-450 in the liver at the end of the test was decreased for pigs housed with restricted floor space. Decreased feed consumption (also a decreased protein consumption), lower BW, and stress, due to crowding, could contribute to diminished protein synthesis that might account for the reduced P-450 activity.

Although some hematologic values, serum metabolites, serum minerals, and serum and liver enzymes decreased or increased, which is suggestive of stress for pigs housed with restricted floor space, many values were unchanged, and some changed in a manner that suggested that restricting floor space was beneficial. Within the limits of this study, restricting floor space was not highly stressful, and it only reduced ADG by reducing ADFI.

Varying dietary Se and Zn only had a few effects on the many hematologic values, serum metabolites, serum minerals, serum and liver enzymes, and performance measurements. Furthermore, most two-way interactions of Se and Zn with floor space were nonsignificant, indicating that the main effects of Se, Zn, and floor space were independent.

As expected, concentrations of blood Se, GTH, and GPH were higher for pigs fed 200 ppb of Se than for those fed 40 ppb of Se. Also, serum Cu was generally higher, and serum protein and albumin tended to be higher for the pigs fed 200 ppb of Se. However, serum globulin levels were lower, except at wk 5, for pigs fed 200 ppb of Se. Only two Se × floor space interactions were observed. Daily feed intake was consistently higher for pigs fed 200 ppb of Se and housed with adequate floor space than for those fed 40 ppb of Se; the opposite was observed for pigs housed with restricted floor space. Serum urea N values were similar for floor space treatments when pigs were fed 40 ppb of Se, but when 200 ppb of Se was fed, higher urea N was observed for pigs housed with adequate floor space than for those housed with restricted floor space. This may reflect the increased amount of fighting and bruising that occurred, leading to increased muscle cell damage, and therefore to increased blood urea N and urinary excretion of nitrogen.

Levels of GTH and GPH decreased linearly during the 6-wk test for pigs fed 40 ppb of Se but were maintained for pigs fed 200 ppb; this supports a marginal Se deficiency for pigs fed 40 ppb of Se. A prolonged Se deficiency also leads to severe myopathies (Van Vleet et al., 1981), which can be monitored biochemically by following the increase in serum CPK. However, there were no significant main effects of Se or interactive effects of Se and floor space, which suggests that a Se deficiency, if at all present, was borderline. Also, necropsy examination at the end of the test revealed no abnormal organ or tissue conditions suggestive of a Se deficiency. The length of the test may not have been sufficient to produce clinical Se deficiency.

As expected, serum Zn levels were positively related to dietary Zn levels. Feeding 250 ppm of Zn is approximately threefold higher than the NRC requirement. There were only a few other effects of Zn observed, and they are difficult to explain (i.e., serum protein levels were lower throughout the 6-wk test for pigs fed 80 ppm of Zn and after wk 2 they were highest for pigs fed 30 ppm of Zn, with intermediate levels for pigs fed 250 ppm of Zn). The lack of an effect of varying dietary Zn levels on superoxide dismutase values suggests that the lowest level of Zn was adequate to maintain superoxide dismutase levels. Copper and Zn deficiencies are known to decrease the activity of superoxide dismutase in rats (Paynter and
Martin, 1980; Sullivan et al., 1980). Dietary Cu (22 ppm) in all diets was well above the NRC requirement.

A few treatment differences were observed for some measurements, but all measurements were generally within the range of normal values reported for pigs of similar size.

**Implications**

The major effect on weanling pigs of restricting floor space allowance was reduced growth rate resulting from decreased feed consumption. No mortality was observed and no gross abnormalities in organs and tissue were observed at necropsy. Most two-way interactions of dietary Se and Zn with floor space were nonsignificant. Of the numerous clinical pathology measurements, serum mineral concentration and enzyme activities that were characterized weekly during the 6-wk trial all were within normal ranges and only a few increased or decreased due to treatments, which is suggestive of nothing more than borderline stress at the most for pigs housed with restricted space.

**Literature Cited**


Paynter, D. I., and G. B. Martin. 1980. Investigations into combined...