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Effects of Potassium Supplementation at Two Levels of Lysine in Weanling Pig Diets

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EFFECTS OF POTASSIUM SUPPLEMENTATION AT TWO LEVELS OF LYSINE IN WEANLING PIG DIETS

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This thesis is approved as a creditable and independent investigation by a candidate for the degree, Master of Science, and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

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INTRODUCTION

It has long been established that lysine is the first limiting amino acid in cereal based diets for growing pigs. Some studies have shown that corn is first limiting in tryptophan for growing pigs while other studies indicate that lysine and tryptophan are equally limiting. Soybean meal is usually added to corn diets to supply the lysine required but in some countries where soybean meal is not easily available, fish and meat meals are the common protein supplements. In the developing countries, soybean meal, fish meal and meat meal are not only in short supply but also very expensive. Lysine is thus a major problem as the first limiting amino acid. Other sources of supplemental lysine such as synthetic lysine and ways of improving lysine utilization in the growing pig would therefore be desirable.

There are many factors affecting the utilization of lysine and other amino acids in pigs. Some of these factors are heat during feed processing, method of processing, the crude protein level in the diet, the caloric density (energy level) of the diet, the balance of essential amino acids, the source and biological availability of the amino acids, physiological stage of the animal, frequency of feeding and the electrolyte balance in the diet. Cations such as sodium and potassium have been shown to affect lysine and protein metabolism in non-ruminants.

The effects of potassium varies in different species. In the chicken, potassium supplementation to an imbalanced diet, improves

performance by alleviating lysine-arginine antagonisms. In rats, potassium deficiency has been found to raise the concentrations of lysine, arginine and histidine in the kidneys and muscles. Potassium supplementation to rat diets lowers the amino acid concentration of the tissues. It has therefore been proposed that in cases of potassium deficiency, the basic amino acids enter the cells by diffusion, due to electrostatic force, in order to maintain the cation-anion balance. In cases of kwashiorkor, a tropical malnutritional condition in children, protein deficiency has been associated with low plasma potassium concentrations. Potassium supplementation to the diets of kwashiorkor children has alleviated and cured the disease.

In pigs, potassium supplementation to low lysine or low protein diets has been found to improve growth performance. Except for the ameliorating effects of potassium, there is no need for potassium supplementation in swine diets since most feedstuffs contain amounts of potassium that exceed the requirements for all classes of pigs. The thesis reported herein is that potassium supplementation in weanling pig diets improves performance through the efficient utilization of lysine. The experiments were conducted to determine the response of weanling pigs to potassium supplementation at two levels of dietary lysine. The effects of potassium on plasma lysine and potassium was also determined.

LITERATURE REVIEW

Lysine Requirements for Young Pigs

The National Research Council (N.R.C., 1979) lists lysine requirements of 0.95%, 0.79% and 0.70% for pigs weighing 5-10 kg, 10-20 kg and 20-35 kg respectively. Lysine requirements have, however, been found to vary and are affected by a number of factors.

The lysine requirement for 16-33 kg pigs was found to be 0.6% when a 10.6% protein diet was fed and 1.2% when a 22.0% diet was used (Brinegar et al. 1950). Young pigs on 14% protein diets supplemented with lysine were found to perform as well as those on unsupplemented basal starter diets containing 16% protein (Magruder et al. 1961). Jurgens et al. (1967) found that adding 0.1% lysine to the diet did not significantly affect performance of pigs fed 16% protein diets. Those on 14% protein diets had improved performance with lysine supplementation.

The lysine requirement for weanling and growing pigs was found to be higher than that recommended by the National Research Council by Fetuga et al. (1975). They fed 8.0 kg pigs diets containing 16%, 18%, 20% and 22% protein supplemented with either 0.0%, 0.05%, 0.1% or 0.15% synthetic L-lysine. Growth rate and feed efficiency improved as protein levels were increased from 16.0% to 20.0%. Carcass leanness increased and fatness decreased as protein and lysine levels were increased. The data showed optimal performance at 20% protein with a calculated lysine level of 1.17%.

Results from Jurgens et al. (1967) indicate that the lysine level fed to pigs for optimum daily gains may be different from that required for optimum lean carcass quality. Although dietary protein levels did not produce significant differences in carcass quality, pigs fed diets that were supplemented with lysine had a significantly higher percent ham and loin than those fed unsupplemented diets. Supplementing lysine in 16.0% protein diets did not improve performance but pigs fed 12.0% protein diets that were supplemented with lysine had better gains and feed efficiency than pigs fed 12.0% protein basal diets.

In experiments by Taylor et al. (1979), lysine level was maintained constant at 0.95% of the diet. Over a 25-55 kg live weight range studied, performance was unaffected by reducing the crude protein level from 17.6 to 14.5 percent. Below 14.5% crude protein, daily gain and feed efficiency deteriorated linearly.

The lysine requirement of young pigs is dependent on the protein level of the diet (Brinegar et al. 1950, McWard et al. 1959, Baker et al. 1975, Easter et al. 1980). The lysine requirement for growing pigs when expressed as a percent of the diet has been found to change by 0.02% with each 1.0% change in dietary protein level.

McWard et al. (1959) fed 13.6 kg weanling pigs semi-purified diets containing either 12.8% or 21.7% protein to determine the response to varied levels of lysine. The rates of gain at the two levels of protein were found to be the same but the lysine requirement varied with the level of protein. At 12.8% protein, the pigs required 0.71% lysine in their diets or 5.55% of the dietary protein. At 21.7% protein

the lysine need was 0.95% of the diet or 4.38% of the protein. These values may be contrasted with those of Brinegar et al. (1950), who found that the lysine requirement for 16-33 kg pigs was 0.6% and 1.2% for 10.6% and 22.0% protein diets respectively. The lysine requirements of 0.6% and 1.2% of the ration correspond to 5.7% and 5.5% of the protein in the 10.6% and 22.0% protein diets respectively. Thus the lysine requirement, when expressed as a percent of the protein decreased as the level of the protein increased. McWard et al. (1958), expressed the lysine requirement (within the protein range studied) by the following equation: $Y = 7.23 - 0.131 X$, where Y = the lysine need and X is the percent protein in the diet. The amino acid requirement has also been found to be a constant percentage of the available energy. It is thus possible to calculate the lysine requirement at various protein and caloric densities.

The theory that the lysine requirement expressed as a percentage of the diet decreases by 0.02% with each 1.0% reduction in dietary protein, was proposed by Easter and Baker (1980). They used 0.77, 0.56 and 0.49% lysine in the diet to meet the requirements for growing, early finishing and late finishing pigs, respectively. Addition of synthetic lysine to the negative control diet to provide the same lysine concentration as that in the positive control diet resulted in gain equivalent to that obtained with the positive control diet. Between the negative and positive control diets, adding lysine at a concentration dictated by the 0.02 percentage unit reduction for each 1.0% difference in protein level, resulted in gains that were not different ($P > 0.05$) from

those of the positive control. The data suggest that 14.0, 11.5 and 11.0% protein diets can be used successfully for growing (24 kg), early finishing (47 kg) and late finishing (75 kg) pigs respectively, provided supplemental lysine is included. Thus the dietary lysine requirements for optimum performance may be less than that recommended by the N.R.C. (1979) when part of the soybean meal in a corn-soybean meal diet is replaced by crystalline lysine.

Baker et al. (1975) estimated the lysine requirement for maximum gains for growing pigs to be 0.77 and 0.69% at 16.0 and 12.0% protein respectively. The 0.02% decrease in dietary lysine for each 1.0% decrease in the dietary protein level was also found to be true for this experiment. The lower lysine requirement at 12.0% protein than at 16.0% protein can be attributed to the fact that the crystalline lysine supplemented in the 12.0% protein diet is 100% digestible and therefore more available. Furthermore, feed intake in pigs fed lower protein diets was relatively high so that although the lysine content was low, the total lysine intake was equivalent to that of pigs fed the higher lysine diets.

Energy level (caloric density) of the diet also affects lysine requirements of growing pigs. Nutrient needs are usually expressed per unit of diet fed on the assumption that a given animal fed ad libitum will consume similar amounts of any given diet per unit of time. Such an assumption is not valid since it has been shown that caloric density of the diet influences feed intake. It has been observed that addition of fat to a diet, which increases the caloric density, will decrease

the rate of feed intake. Mitchell et al. (1965b) found the lysine requirement of baby pigs to be 1.2-1.34% when fed a 22% protein diet containing 3344 kcal metabolizable energy (ME). For the 50 kg finishing pig, the lysine requirement was in the range of 0.36-0.41% when a diet containing 12% protein and 3219 kcal of ME per kg was fed. They did not find an interaction between lysine and energy on rate of gain. However there was a significant lysine-energy level interaction for feed per unit of gain.

Abernathy et al. (1958) investigated the interrelationship of protein, lysine and energy in diets for growing pigs. Faster gains were obtained with pigs fed diets containing 18% protein than with those fed 14% protein diets. However, they found a highly significant depression of rate of gain when 0.1% L-lysine was supplemented to a low energy diet. The inhibitory effect of lysine was reduced as the caloric density of the diet increased. Increasing the caloric density of the diet resulted in a highly significant linear increase in gains with a corresponding decrease in the quantity of feed required to produce a unit of gain. As the caloric density decreased, the diet was consumed in increasing amounts. Therefore, the amino acids required in the diet decreased.

The inhibitory effect of lysine is hard to explain because growth depression normally occurs when an amino acid is not supplied in sufficient quantity. It is postulated that tissue protein synthesis consequently slows down with a resultant accumulation of other free amino acids in the circulation. This accumulation results in depressed appetite which serves to curtail further protein ingestion.

The actual absorption rates of protein bound amino acids have been shown to vary owing to many factors. Batterham (1974) showed that frequency of feeding affects the utilization of free lysine by growing pigs. Pigs weighing 20-47 kg were given a wheat-safflower diet supplemented with either 0.0, 2.0 or 4.0 grams of L-lysine per kilogram. The diets were fed either once daily or in six equal portions at intervals of 3 hours. Frequency of feeding had no effect on the response of pigs given the control diet. However, a significant interaction between frequency of feeding and lysine supplementation occurred for growth rate. Growth responses to the supplementation of 2.0 and 4.0 grams L-lysine per kg diet with once daily feeding were only 43 and 69% respectively of those achieved under the frequent feeding regimen.

Seerley et al. (1973) found that pigs fed lysine in feed or water had similar rates of gain, feed per gain ratio and carcass measurements. Lysine supplementation was most beneficial in the diet when the pigs were smaller by supporting faster gains with less feed per unit of gain. It was also found that after five days in solution, 95% of the original concentration of lysine was still present in the water. Lysine in solution for 30 days was found to stimulate growth as well as freshly mixed solution of lysine. These experiments indicate that lysine can be provided in solution to animals with good results.

Lysine in Vegetable Protein

The quality of a protein or mixture of proteins is determined not only by its absolute content of essential and non-essential amino acids but also by the relative proportions (balance) of the essential amino

acids. Various sources of protein have been investigated to find their value as sources of lysine and other amino acids. The role of protein concentrates is to counteract amino acid deficiencies (usually lysine) in the cereal component of the diet. Lysine is the first limiting amino acid in cereal based diets and its availability is high. Total lysine values are therefore the most convenient way of assessing the nutritive value of vegetable proteins and formulating swine diets.

Tarverner and Rayner (1975), investigated the nutritive value of vegetable protein for growing pigs using the Silcock available lysine values. An equal amount of protein from rapeseed meal and soybean meal, either expeller or solvent extracted, was included in wheat based diets. The diets were then fed in restricted amounts to pigs weighing 20-45 kilograms. Total and available lysine content of the diets decreased in the following order: solvent extracted soybean meal, expeller extracted soybean meal, expeller extracted rapeseed meal, solvent extracted rapeseed meal. Growth rates and feed conversion ratios varied in the same order and were significantly correlated to total and available lysine.

Batterham et al. (1978) compared eight protein concentrates on a total lysine basis in lysine-deficient diets for pigs during the 20-45 kg growth phase. Growth rates and feed efficiencies were similar for pigs fed fish meal, skim-milk powder, rapeseed and soybean meal. However their performance was superior to that of pigs fed cotton seed meal, meat meal and sunflower meal. It was found that the availability of lysine in rapeseed meal was 34% greater than in cotton seed meal.

The growth responses of pigs in this study indicated that the availability of lysine in cotton seed meal, meat meal and sunflower meal was reduced by about 60% compared to that in the other protein concentrates.

Corn protein has been shown to be limiting in lysine and tryptophan. Supplementation of corn diets with lysine causes an imbalance (Baker et al. 1969) which depresses feed intake and rate of gain. The imbalance can be overcome by tryptophan supplementation. A response to lysine supplementation in low protein all-corn diets can be obtained only by simultaneous addition of tryptophan (Gallow and Pond 1968). The relative value of opaque-2 corn and other types of corn in relation to the performance of growing pigs has been investigated by Cromwell et al. (1967), Kornegay et al. (1975), and Wahlstrom et al. (1977). Opaque-2 corn (high lysine corn) though superior to normal corn in lysine content, has been found to be first limiting in lysine. Growth performance of pigs on all-corn diets using opaque-2 corn has been found to be inferior to the performance of pigs fed 18% protein corn-soybean meal diets.

Potassium Requirements in Swine Diets

Potassium should not pose any nutritional problem in swine feeding since most common feedstuffs used in swine diets contain more potassium than that required by all classes of pigs. Potassium is the principal intracellular cation in the body and plays an important role in the maintenance of osmotic pressure and acid-base balance. Most cells are

able to maintain high intracellular potassium concentrations even at lower concentrations of the ion in extracellular fluids.

The potassium requirement for growing (5-20 kg) pigs is listed at 0.26%, (N.R.C., 1979). The need for potassium was recognized as early as 1940. In experiments by Hughes and Ittner (1942) at the California Experimental Station at Davis, pigs fed diets that did not include skim-milk powder were found to lose appetite, scour and vomit. Some pigs were weak in their hind quarters and could not rise. Since casein was present in the purified basal diet, it was suspected that the necessary nutrient was present in the whey. When whey was added to the diet an improvement took place in appetite and growth. Later, potassium was substituted for the whey powder with equally good results. The fact was then established that potassium was necessary for the pig. The minimum potassium requirement for the young pig was found to be between 0.08 and 0.15 percent.

The response of the young pig to different levels of potassium was further investigated by Jensen et al. (1961). Growth rate and feed efficiency of pigs weaned at 14 and 18 days were improved by supplementing potassium up to 0.3% of the diet. The optimum levels of supplemental potassium were 0.26 and 0.22 percent. Since the control diets contained 0.15% potassium, the average optimum level indicated by the young pig was 0.26% of the diet. After 5-6 days on the experimental diets, pigs fed the low potassium diet exhibited poor appetite, slow growth, rough hair coats and became emaciated, less active and unsteady on their legs. Two pigs died after 35 days. Electrocardiograms

at 28 days on the deficient diet, showed marked cardiac impairment, suggesting that potassium markedly affects cardiac function.

Similar results were obtained by Cox et al. (1966). The cardiac function of the young pig (14-21 days of age) was found to be abnormal when feeding 0.007% potassium diets. The abnormalities included increased wave intervals and depolarization of the ventricles. The usual symptoms of anorexia, rough hair coat, emaciation and ataxia were also exhibited. Rate of gain, feed efficiency and daily feed intake were also adversely affected. Pigs on the potassium deficient diet ate only 0.16 kg of the diet per day.

The effects of excess potassium has been investigated in new-born piglets by McCance and Widdowson (1958). When new-born piglets were given evaporated cow's milk containing more sodium, chloride and potassium than sow's milk, they developed hypertonic expansion of the extracellular fluids. Human infants have also been found to react in the same way. In this experiment, the pigs were given water and sow's milk with or without added potassium chloride. Administration of potassium chloride in the water led to progressive retention of potassium, raised blood sugar and paralysis.

Excess potassium was found to exert an ameliorative effect on magnesium deficiency (Grace and O'Dell 1970). In a diet that was moderately deficient in magnesium, increasing the dietary level of potassium above the requirement stimulated growth rate in guinea pigs. At 0.05% and 0.1% levels of magnesium, increasing the potassium level from 0.4% to 1.6%, significantly increased the growth rate but there

was no effect at 0.01% and 0.3% magnesium. At high levels, potassium was found to decrease mortality by reducing deaths from 75% to 50% at the 0.01% magnesium level and from 35% to zero when the diet contained 0.05% magnesium. A deficiency of magnesium in the diet was found by Seta et al. (1965) to produce a decrease in both the magnesium and potassium levels in plasma and cardiac muscle. However dietary potassium deficiency produced an increase in plasma magnesium, a decrease in plasma potassium and a decrease in cardiac muscle magnesium and potassium. The decrease in intracellular potassium in magnesium deficiency, despite potassium adequacy in the diet, is due to a defect in ion transport brought about by an impairment in the energy yielding reactions. This causes a failure to maintain the concentration gradient between the intracellular and extracellular potassium levels. Thus magnesium is necessary for the maintenance of potassium within the cells.

Other studies have been concerned with factors affecting the metabolism of potassium in pigs. Holmes and Grace (1975) found that at higher air temperature (33° C), urinary excretion of potassium increased when pigs were fed high levels of potassium (2.5 x maintenance). The effect of high ambient temperature on daily fecal mineral excretion and retention was non-significant. However the retention of potassium decreased ($P < 0.05$). Studies by Mraz et al. (1958), indicated that total and fecal excretion of K-42 were higher ($P < 0.01$) in pigs fed beet pulp than in those fed the basal diet. They postulated that the changes in the excretory patterns of potassium were due to the

beet pulp in the gut absorbing the potassium during its passage from the body fluids into the gut. If no material is present in the gut, the potassium passes back into the body fluids and is either excreted through the kidneys or recycled through the body.

Kwashiorkor, a syndrome of weanling children whose diet is low in protein in relation to its carbohydrate content, can be prevented and even cured by potassium supplementation when protein and/or lysine is also added to the diet (Hansen 1956, Senecal 1958, Barnes et al. 1961). In the poor developing countries, protein intake by children is often limited and baby foods (formulae) are usually diluted. Under these conditions, utilization of protein may be improved by potassium supplementation. Studies by Barnes et al. (1961), indicate that potassium increases protein absorption and retention in highly refined wheat. It was also found that the potassium requirement increased when the quality of refined wheat was improved by the addition of lysine.

Potassium-Lysine Requirement

The effect of potassium on lysine metabolism has been studied in rats, poultry and swine. One hypothesis is that during potassium deficiency, basic amino acids enter the muscle by diffusion and are accumulated due to electrostatic forces to maintain cation-anion balance. The basic amino acid level in the tissues is increased when the level of cations (Na and K) fails below that of the anions.

Brandt et al. (1960) found that muscle and kidney from rats with potassium deficiency alkalosis contained higher concentrations of

lysine, histidine and arginine than tissue taken from control animals. Induction of potassium deficiency brings about loss of potassium from the tissues. There is a gain of sodium in muscle tissue but the increase is not enough to replace the total amount of potassium lost. The cation deficit is made up by protons with a resultant intracellular acidosis or by certain amino acids which posses a positive net charge. The increase in the concentrations of basic amino acids during potassium deficiency occurs because they are passively trapped to serve as cations in the absence of sufficient sodium or other cations to replace the lost potassium.

On the other hand, studies by Eckel et al. (1958) showed no evidence of competition between lysine and potassium in the muscle or kidney of rats. The accumulation of basic amino acids though characteristic of potassium deficiency was found to occur without potassium depletion when plasma lysine level was raised through feeding lysine monohydrochloride in the diet. This indicated that the accumulation of basic amino acids does not lead to potassium depletion. The basic amino acids were transported into the muscle through an active metabolic process that is independent of potassium transport. This hypothesis is supported by the finding of Brandt et al. (1960) that there was a significant increase in histidine (which is the least likely of the three amino acids to have a positive charge) during a potassium deficiency alkalosis in rats. It would therefore appear that the need for cations is not the fundamental reason for the accumulation of all the basic amino acids during potassium deficiency.

Amino acid differences in muscle and liver were found by Gershoff et al. (1959) to be associated with lysine deficiency but not with the potassium content of the diet. They also found that variations in lysine but not potassium content of the diets resulted in marked changes in the potassium and sodium content of the skin, but not of the liver and muscle. Differences in growth were also related to the lysine but not the potassium content of the diets. Rats that received the lowest levels of lysine (0.28%) lost hair and showed alopecia on shoulders and hind quarters. These symptoms were more severe in rats receiving 0.14% potassium than in those receiving 0.72% potassium. This shows a protective effect of increased potassium in diets deficient in lysine.

Iacobellis et al. (1956) showed that administration of potassium chloride solution by stomach tube during 24 hours to potassium deficient rats resulted in normalization of the amino acid patterns. They hypothesized that the development of hypochloremic alkalosis found in potassium deficient rats is dependent upon a shift in the exchange of potassium. The loss of cellular potassium was found to be compensated in part by certain amino acids acting as cations.

Effect of Potassium on the Lysine-Arginine Antagonism

The nutritional interrelationships of electrolytes and amino acids have been reviewed by Austic and Calvert (1981). Although conflicting results have been obtained, there is increasing evidence, especially in the chicken, that potassium alleviates the lysine-arginine antagonism.

The lysine-arginine antagonism is characterized by the following: (i) the arginine requirement markedly increases when dietary concentrations of lysine are excessive; (ii) variation in intensity of the antagonisms differ in different species e.g. higher concentrations of dietary lysine are required to induce the antagonism in rats than in chicks; (iii) excess dietary lysine increases plasma and tissue lysine concentrations while decreasing the arginine concentration; (iv) lysine alters arginine utilization in chicks by increasing arginine degradation via renal arginase activity, increasing urinary loss of arginine and by decreasing synthesis of creatine; (v) excess lysine impairs growth by depressing appetite; (vi) excess arginine depresses growth when lysine is limiting.

Whereas there is agreement that potassium decreases the free lysine pools in plasma and tissue, there is controversy over how the lowered plasma potassium is brought about. Scott and Austic (1978) showed that potassium increased the rate of lysine degradation (increased $^{14}CO_2$ output) while Stutz et al. (1972) showed that potassium acetate supplementation promoted lysine anabolism rather than catabolism.

Results of experiments by Scott and Austic (1978) with single comb Leghorn chicks fed a purified diet containing 35% casein, showed that plasma arginine levels in the potassium supplemented group were not increased above the level of the basal group and that the amount of arginine and lysine excreted as intact amino acids was small. The plasma lysine was found to be reduced when chicks received supplemental potassium. They concluded that lysine and not arginine metabolism must

be altered by dietary potassium. The studies also showed that 1.8% potassium supplementation increased the lysine-α-ketoglutarate reductase activity, improved growth and increased feed consumption. Potassium supplementation thus decreases the lysine:arginine ratio i.e. alleviating the amino acid imbalance by increasing the lysine-α-ketoglutarate reductase activity, which in turn lowers the plasma and tissue concentration of lysine with little effect on arginine concentration. The potassium induced shift in lysine:arginine ratio stimulated feed intake and improved growth.

Studies by Stutz et al. (1972) indicated that the production of $^{14}CO_2$ peaked during the second hour after administration of ^{14}C labelled lysine regardless of the diet fed. Chicks fed the basal diet exhaled ^{14}C-carbon dioxide at a higher rate than those given the arginine and potassium supplements, showing that the supplements did not increase the oxidative degradation of lysine. The results also indicated that incorporation of radioactive lysine into tissue protein increased with potassium acetate supplementation. It was therefore concluded that the reduction in free lysine pool size relates to increased anabolism of the amino acid to form tissue proteins.

This theory appears to be supported by the findings of Garry et al. (1979) that sodium and potassium concentrations regulate protein synthesis in chick embryo fibroblast cultures. They found that protein synthesis was inhibited at the level of initiation of translation of the cell messenger ribonucleic acids (mRNAs). The inhibition was found to be correlated with an increase in the intracellular sodium concentrations and a decrease in intracellular potassium.

The response to arginine-lysine antagonism has been investigated in the chick by O'Dell and Savage (1966). Supplementation of diets with excess lysine so as to bring the lysine:arginine ratio to 2.2:1 and 2.6:1 caused severe growth depression and produced gross symptoms of arginine deficiency such as stilted gait and poor feathering. The high ratio of lysine to arginine in casein diets increased the arginine requirement of the chicks fed this protein as a source of amino acids. Supplementation of the casein diet with arginine improved growth. Growth depression due to addition of lysine to soybean meal protein was not counteracted by arginine alone but potassium acetate and glycine were also required.

Potassium Supplementation in Swine Diets

At low protein levels or when lysine is limiting, potassium has been found to spare lysine and improve performance of growing pigs (Leibholz et al. 1966, Mabuduike et al. 1980). On the other hand Miller et al. (1981) found that the performance of pigs either from 10-20 kg body weight or from 35-60 kg body weight was not significantly affected by addition of 0.1% potassium to the diet.

The studies by Leibholz et al. (1966) indicated that there was a significant increase in weight gains and feed efficiency when 2% potassium acetate was added to 16% and 20% protein diets but not to 24% protein diets. A highly significant increase in potassium concentration of plasma was also obtained but protein levels did not influence potassium concentration of plasma. Addition of potassium to the diets

was also found to reduce the basic amino acid concentration of plasma. Faster gains were obtained in pigs fed soybean meal and poorest gains in those fed fish meal as sources of protein. Soybean meal is higher in potassium and animals on diets in which soybean meal is the source of protein had higher potassium intake and a higher potassium concentration was reflected in their muscles.

Experiments by Mabuduike et al. (1980) indicated that when lysine was limiting for growth (0.4-0.5%), increasing the dietary sodium concentration from 0.16% to 0.9% or that of potassium from 0.25% to 1.5% significantly increased growth rate, food consumption and, except for sodium, the efficiency of feed utilization. Dietary potassium or sodium had no effect on pig performance when lysine was adequate (0.83-2.0%). It was found that high levels of dietary potassium decreased the plasma lysine concentrations only when lysine levels were adequate or excessive but not when lysine was limiting. The requirements for potassium for maximum growth and efficiency of feed utilization was 0.26-0.51% for pigs that received 0.8 and 2.0% lysine but was 0.51-0.81% for pigs receiving 0.43% lysine. Thus the potassium requirements are higher when lysine is deficient than when it is adequate in the diet.

MATERIALS AND METHODS

The study reported here comprised two experiments which were designed to determine the response of weanling pigs to different levels of supplemental potassium and lysine. Crossbred weanling pigs, having an initial average weight of approximately 8 kg were used in 3x2 factorial experiments. The pigs were allotted to outcome groups on the basis of weight and litter and these groups were randomly assigned to six treatments, three levels of potassium and two levels of lysine. Each treatment was replicated four times.

The experiments were conducted in the Animal Science Complex swine laboratory. The temperature in the laboratory was maintained between 24 and 27 C. Half of the pens had plastic floors while the other half had vinyl coated expanded metal flooring.

Trial I

One hundred and twenty pigs were used in this trial with five pigs per pen. The pigs were put on the experimental diets immediately following weaning and received the diets for 35 days. The experiment was conducted between 9th December 1980 and 20th January 1981. Each replication was started on different days in order to equalize average starting weights.

The pigs were fed ad libitum in metal feeders and water was provided by automatic nipples. The feed was mixed at the University Feed Unit and was in meal form.

The composition of the ingredients used in the diets and the vitamin/antibiotic premix are as shown in appendix tables 1 and 2. The

composition of the diets, their proximate analyses and amino acid analyses are shown in tables 1-3.

The dietary treatments contained either 0.85% lysine or 1.15% lysine with 0.0, 0.4 or 0.8% added potassium. The diets were as follows:

Diet 1 - Basal diet: 0.85% lysine without added potassium.

Diet 2 - Basal diet plus 0.3% lysine without added potassium.

Diet 3 - Diet 1 plus 0.4% potassium from potassium chloride.

Diet 4 - Diet 1 plus 0.8% potassium from potassium chloride.

Diet 5 - Diet 2 plus 0.4% potassium from potassium chloride.

Diet 6 - Diet 2 plus 0.8% potassium from potassium chloride.

TABLE 1. COMPOSITION OF DIETS (PERCENT) TRIAL 1.

Ingredients	Dietary treatments					
	1	2	3	4	5	6
Oat groats	40.0	40.0	40.0	40.0	40.0	40.0
Corn	35.0	34.6	34.2	33.4	33.8	33.0
Corn gluten meal	14.0	14.0	14.0	14.0	14.0	14.0
Meat meal	7.0	7.0	7.0	7.0	7.0	7.0
Fish meal	3.5	3.5	3.5	3.5	3.5	3.5
TM salt	0.3	0.3	0.3	0.3	0.3	0.3
Vitamin-antibiotic premix[a]	0.2	0.2	0.2	0.2	0.2	0.2
L-lysine-Hcl	--	0.4	--	--	0.4	0.4
Potassium chloride	--	--	0.8	1.6	0.8	1.6

[a]Composition shown in appendix table 2.

TABLE 2. CHEMICAL ANALYSIS OF DIETS (% DM BASIS) TRIAL 1.

	Diets					
	1	2	3	4	5	6
Crude protein	26.2	26.9	27.1	26.7	27.3	26.7
Crude fibre	1.8	1.73	1.84	1.79	1.69	1.83
Ether Extract	6.6	6.37	7.15	6.68	6.78	6.63
Ash	4.9	4.93	5.73	6.45	5.77	6.74
Nitrogen free extract	60.4	60.1	58.2	58.4	58.5	58.2
Potassium	0.45	0.45	0.96	1.36	0.99	1.36
Sodium	0.26	0.30	0.32	0.34	0.29	0.33

TABLE 3. AMINO ACID ANALYSES OF DIETS (PERCENT) TRIAL 1.

Amino acids	Diets					
	1	2	3	4	5	6
Lysine	0.89	1.29	0.98	0.97	1.40	1.28
Histidine	0.53	0.54	0.55	0.55	0.61	0.57
Ammonia	0.55	0.56	0.59	0.58	0.63	0.60
Arginine	1.43	1.46	1.35	1.46	1.50	1.43
Aspartic acid	1.81	1.99	1.83	1.96	1.85	1.81
Threonine	0.87	0.89	0.88	0.89	0.92	0.90
Serine	1.22	1.25	1.25	1.25	1.31	1.25
Glutamic acid	4.95	5.16	4.95	5.14	6.78	5.02
Proline	2.06	1.89	2.05	1.99	2.17	2.12
Glycine	1.34	1.45	1.35	1.43	1.40	1.39
Alanine	1.73	1.85	1.79	1.85	1.86	1.84
Cystine (half)	0.37	0.33	0.33	0.31	0.35	0.35
Valine	1.24	1.27	1.20	1.26	1.27	1.27
Methionine	0.49	0.51	0.48	0.50	0.50	0.53
Isoleucine	0.96	0.97	0.93	0.98	0.98	1.00
Leucine	2.93	3.03	2.92	2.98	3.04	2.99
Tyrosine	1.02	1.02	1.01	0.98	1.03	1.05
Phenylalanine	1.37	1.37	1.32	1.34	1.37	2.38

Pigs were weighed at one week intervals and feed was also weighed back at one week intervals to allow calculation of feed composition and feed efficiency on a weekly basis. At the end of each trial, the pigs were bled. About 10 ml of blood was obtained from the anterior vena cava of each pig and put into centrifuge tubes to which 2-3 drops of ammonium heparin had been added. The heparin was made to run down the walls of the collecting tubes so as to thoroughly and uniformly coat them. The blood and heparin were then mixed by slowly inverting the tube 2-3 times. The tubes were labelled, sealed with parafilm and stored in a bowl of ice until centrifugation.

Precautions were taken to obtain blood with minimum haemolysis. Ammonium heparin (Sherwood Med Industries, Inc.) was used in preference to other commercial heparins because it was electrolyte free. The content of sodium was less than 0.15%, that of potassium less than 0.01% and calcium less than 0.01% on a dry weight basis.

The heparinized blood was centrifuged at 3600 rpm for ten minutes. The blood plasma from each pen was pooled and samples taken for amino acid and potassium analyses. For the amino acid analysis, the plasma was deproteinized with a solution of 3.75% sulfasalicylic acid in sodium citrate buffer (pH 1.8). Eight ml of the solution was added to two ml of the plasma and the mixture was centrifuged at 10000 rmp for ten minutes. The samples were run on the short column of a modified amino acid analyzer (Beckman/Spinco Model 120B). The procedure followed was that of Spackman (1962). For the potassium analysis, the plasma samples were diluted one hundred times. An aliquot of 0.1 ml of the plasma was

added to 10 ml of distilled water. Potassium was determined on a Perkin Elmer 303 Atomic Absorption Spectrophotometer.

Statistical analysis of the pig, feed and blood data was carried out by the least squares analysis of variance outlined by Steel and Torrie (1960). A probability level of less than 0.05 was accepted as being significant and 0.01 as highly significant.

Trial II

In the second experiment, 96 pigs were allotted four pigs per pen to the same six treatments as in trial I. The pigs received the experimental diets for 32 days and as in the first experiment each replication was started on a different day in order to obtain similar starting weights. The trial was conducted between 13th February and 4th April 1981.

All the conditions were the same as for trial I except that wooden feeders were used and the feed was pelleted. Thus the flow of feed through the feeders was more even. Additional zinc was supplemented to prevent parakeratosis. Unlike the first trial, soybean meal was used to supply part of the protein. Composition of the diets is shown in table 4 and their analyses appear in table 5.

TABLE 4. COMPOSITION OF DIETS (PERCENT) TRIAL 2.

Ingredients[a]	Dietary treatments					
	1	2	3	4	5	6
Oat groats	50.0	50.0	50.0	50.0	50.0	50.0
Ground corn	34.0	33.6	33.2	32.8	32.4	32.0
Meat meal	7.0	7.0	7.0	7.0	7.0	7.0
Fish meal	3.5	3.5	3.5	3.5	3.5	3.5
Soybean meal	3.0	3.0	3.0	3.0	3.0	3.0
TM salt	0.3	0.3	0.3	0.3	0.3	0.3
Bentonite	2.0	2.0	2.0	2.0	2.0	2.0
L-lysine Hcl	--	0.4	--	0.4	--	0.4
Potassium chloride	--	--	0.8	0.8	1.6	1.6
Vitamin/antibiotic mix[b]	0.2	0.2	0.2	0.2	0.2	0.2

[a]Composition shown in appendix table 1.

[b]Composition shown in appendix table 2.

TABLE 5. PROXIMATE AND AMINO ACID ANALYSIS (% DM BASIS) TRIAL 2.

	Dietary treatments					
	1	2	3	4	5	6
Crude protein	20.0	20.7	20.7	20.6	21.2	20.2
Calcium	1.25	1.25	1.12	1.16	1.14	1.13
Phosphorus	0.83	0.92	0.80	0.84	0.82	0.81
Crude fibre	2.45	2.16	2.16	1.92	2.08	2.02
Ether extract	6.29	6.72	6.41	6.86	6.56	6.46
Ash	7.62	7.73	8.03	8.46	9.18	9.56
Nitrogen-free extract	63.7	62.7	62.7	62.2	60.9	61.7
Potassium	0.64	0.66	1.01	1.10	1.64	1.78
Lysine	1.00	1.41	0.89	1.40	1.00	1.23
Histidine	0.41	0.71	0.45	0.47	0.52	0.55
Arginine	1.35	1.43	1.61	1.40	1.50	1.31

RESULTS AND DISCUSSION

The results of the experiment are summarized in tables 6 and 7. The analyses of variance data are shown in tables 8, 9 and 10. During the course of the experiment, one pig developed parakeratosis and two others died. The dead pigs were taken to the Veterinary Diagnostic Laboratory for necropsy. Gross microscopic lesions characteristic of mulberry heart disease were found. Data were calculated only for those pigs completing the experiment.

The data obtained in this study indicated that there were no significant differences in average daily gain, final weight, feed consumption or feed per gain due to potassium supplementation of weanling pig diets. However, there were significant differences in daily gain and feed per gain between pigs fed diets containing 0.85% lysine and those fed 1.15% lysine. There were also significant trial differences for average daily gain, feed consumption, feed per gain, plasma potassium and plasma lysine concentrations. The blood plasma data indicated that plasma lysine levels increased ($P < 0.01$) with increasing levels of lysine in the diet while plasma potassium decreased ($P < 0.05$). Plasma potassium levels increased ($P < 0.01$) as increasing amounts of potassium were added to the diet. Dietary potassium had no effect on plasma lysine.

The highest daily gains were obtained by pigs fed 1.15% lysine in their diets. Potassium addition at this level of lysine did not improve daily gains. Average daily gains at 1.15% lysine were 0.39, 0.39 and

TABLE 6. EFFECT OF POTASSIUM SUPPLEMENTATION AT TWO LEVELS OF LYSINE.

Dietary treatment	1	2	3	4	5	6
Dietary lysine, %	0.85	0.85	0.85	1.15	1.15	1.15
Added potassium, %	0.0	0.4	0.8	0.0	0.4	0.8
Initial wt, kg	8.11	8.10	8.12	8.10	8.10	8.12
Final wt, kg	17.39	18.71	18.66	21.11	21.12	20.55
Avg. daily gain, kg	0.28	0.32	0.32	0.39	0.39	0.38
Avg. daily feed, kg	0.60	0.66	0.66	0.68	0.68	0.67
Feed/gain	2.17	2.17	2.20	1.76	1.74	1.82
Plasma lysine, mg %	4.14	4.09	3.77	5.31	5.20	5.11
Plasma potassium, meq/liter	5.36	5.97	6.23	5.40	5.74	6.12

TABLE 7. EFFECT OF LYSINE AND POTASSIUM LEVELS IN DIETS FOR GROWING PIGS.

Item	Dietary lysine, %		Added potassium, %		
	0.85	1.15	0.0	0.4	0.8
Initial wt, kg	8.10	8.10	8.10	8.10	8.12
Final wt, kg[a]	18.26	20.93	19.25	19.22	19.60
Avg. daily gain, kg[a]	0.31	0.39	0.34	0.36	0.35
Avg. daily feed, kg[b]	0.64	0.68	0.64	0.67	0.66
Feed/gain[a]	2.18	1.77	1.97	1.95	2.01
Plasma lysine, mg %[a]	4.00	5.20	4.73	4.64	4.44
Plasma potassium, meq/liter[bc]	5.86	5.75	5.38	5.85	6.17

[a]Lysine effect ($P < 0.01$)

[b]Lysine effect ($P < 0.05$)

[c]Potassium effect ($P < 0.01$)

TABLE 8. ANALYSIS OF VARIANCE FOR AVERAGE DAILY GAIN AND FINAL WEIGHT.

Source of variation	df	Mean squares	
		Average daily gain	Final weight
Replication	3	0.114*	135.00*
Lysine	1	1.623**	1825.29**
Lys x Rep	3	0.032	37.38
Potassium	2	0.034	38.12
Pot x Rep	6	0.024	27.00
Lys x Pot	2	0.076	75.21
Lys x Pot x Rep	6	0.006	8.24
Trial	1	3.762**	3177.31*
Rep x Tri	3	0.094*	105.62
Lys x Tri	1	0.031	53.15
Lys x Rep x Tri	3	0.018	21.48
Pot x Tri	2	0.011	10.35
Pot x Rep x Tri	6	0.005	5.17
Lys x Pot x Tri	2	0.042	40.89
Residual	6	0.041	48.96

*$P < 0.05$

**$P < 0.01$

TABLE 9. ANALYSIS OF VARIANCE FOR AVERAGE FEED CONSUMPTION AND FEED PER GAIN.

Source of variation	df	Mean squares: Average daily feed	Mean squares: Feed per gain
Replication	3	0.052	0.140
Lysine	1	0.090*	1.989**
Lysine x Replication	3	0.004	0.140
Potassium	2	0.016	0.012
Pot x Rep	6	0.007	0.030
Lys x Pot	2	0.033	0.003
Lys x Pot x Rep	6	0.010	0.046
Trial	1	0.301**	3.271**
Rep x Tri	3	0.014	0.261*
Lys x Tri	1	0.007	0.660**
Lys x Rep x Tri	3	0.020	0.180*
Pot x Tri	2	0.005	0.056
Pot x Rep x Tri	6	0.009	0.041
Lys x Pot x Tri	2	0.011	0.028
Residual	6	0.014	0.036

*$P < 0.05$

**$P < 0.01$

TABLE 10. ANALYSIS OF VARIANCE FOR PLASMA POTASSIUM AND LYSINE LEVELS.

Source of variation	df	Mean squares: Plasma potassium	Mean squares: Plasma lysine
Replication	3	1.476**	0.857
Lysine	1	0.128*	17.388**
Lys x Rep	3	0.024	0.651
Potassium	2	2.535**	0.347
Pot x Rep	6	0.074	1.006
Lys x Pot	2	0.073	0.055
Lys x Pot x Rep	6	0.286*	0.447
Trial	1	1.896**	20.137**
Rep x Tri	3	0.246*	1.727
Lys x Tri	1	0.000	0.454
Lys x Rep x Tri	3	0.026	0.409
Pot x Tri	2	0.043	0.641
Pot x Rep x Tri	6	0.076	0.874
Lys x Pot x Tri	2	0.009	0.333
Residual	6	0.036	0.618

*$P < 0.05$

**$P < 0.01$

0.37 kg per day for 0.0, 0.4 and 0.8% supplemental potassium, respectively. At 0.85% lysine, there was a slight improvement in daily gain with supplemental potassium. The daily gains were 0.28, 0.32 and 0.32 kg for 0.0, 0.4 and 0.8% supplemental potassium, respectively. The feed per gain ratio was also better at the 1.15% lysine level.

The results by treatment for each trial are presented in appendix table 3. There were highly significant differences in performance between the trials. In trial 1, the average daily gain for all treatments combined was 0.29 kg while for trial 2 it was 0.41 kilograms. The feed per gain for trial 1 was 2.24 while that for trial 2 was 1.72. The best gains in the first trial were obtained by pigs receiving 1.15% lysine with 0.4% added potassium. The gain for these pigs was 0.35 kg per day. In the second trial, those pigs receiving 1.15% lysine without added potassium gained the most; 0.46 kg per day. In both trials the poorest gains were obtained by those pigs fed diets with the minimum lysine and potassium levels.

In trial 1, the feed per gain ratios were 2.56 and 1.92 and in trial 2 feed per gain ratios were 1.8 and 1.63 for pigs receiving 0.85 and 1.15% lysine in the diets, respectively. The effect of potassium on feed per gain in the first trial were contradictory to the results obtained in the second trial. Although differences among potassium levels were small, in the first trial feed per gain ratios increased with increasing levels of potassium while in the second trial, the ratios decreased as potassium level increased.

Average daily gains were improved in both trials by raising the lysine levels in the diets from 0.85% to 1.15%. The average daily gains were 0.24 kg and 0.33 kg in the first trial and 0.37 kg and 0.44 kg in the second trial for pigs receiving 0.85 and 1.15% lysine diets, respectively. In both trials, average daily gains were highest when pigs received 0.4% added potassium in the diets.

Plasma lysine levels increased ($P < 0.01$) with increasing dietary lysine and tended to decrease ($P > 0.05$) with increasing potassium levels in the diet. Plasma lysine levels were 4.0 and 5.2 mg percent for pigs fed 0.85 and 1.15% lysine respectively. For pigs whose diets were supplemented with 0.4 and 0.8 percent potassium, the lysine levels were 4.6 and 4.4 mg percent, respectively. The lowest plasma lysine levels (3.8 mg%) were obtained in those pigs that received diets containing 0.85% lysine with 0.8% added potassium.

There was a tendency for the plasma potassium to decrease as the lysine level was increased in the diet. Plasma potassium values were 5.86 and 5.75 meq per liter for pigs fed diets of 0.85 and 1.15% lysine, respectively. There was an increase ($P < 0.01$) in the plasma potassium level as the dietary potassium was elevated. Pigs receiving diets with 0, 0.4 and 0.8 percent added potassium had 5.4, 5.9 and 6.2 meq per liter potassium in the plasma, respectively.

The plasma lysine and plasma potassium concentrations for the first trial were different ($P < 0.01$) from those obtained in the second trial. The mean plasma lysine concentration for the first trial was 3.96 mg% while that for the second trial was 5.25 mg percent. The mean

plasma potassium concentration for the first trial was 6.0 meq per liter while that for the second trial was 5.6 meq per liter. The trial differences may be attributed to the differences in composition between the diets in the first trial and those used in the second trial. Proximate and amino acid analyses show that the diets in the second trial had higher lysine and potassium contents. Additional zinc was supplemented to the diets in second trial. The feed used in the second trial was pelleted and better feeders were used.

The results in this study agree with the literature reviewed that increasing the dietary lysine levels elevates plasma lysine levels and increasing the dietary potassium levels will increase potassium and decrease lysine concentrations in the plasma. However, unlike the results of Leibholz et al. (1966), Mabuduike et al. (1980) and Miller et al. (1981), the data in this study showed no significant improvements in weight gains or feed efficiency due to potassium supplementation in the diets of growing pigs. However in the studies reviewed different levels of lysine and potassium were used in the diets and different potassium salts were used. Miller et al. (1981) obtained a response by adding 0.1% potassium to 0.7% lysine diets. Mabuduike et al. obtained a response only when the lysine was limiting for growth (0.4-0.5% of the diet). Leibholz et al. (1966) used potassium acetate at a 2% level instead of potassium chloride as used in this study. These factors may therefore influence the response of the young pigs to potassium supplementation.

Usually an increase in the plasma amino acid concentrations means the tissues are not utilizing the amino acids efficiently and lower plasma amino acid levels means more amino acids are being withdrawn from the plasma pool into the cells for protein synthesis i.e. there is a better utilization of the amino acids. On the other hand, variations in plasma amino acid levels have been attributed to the maintenance of cation/anion balance of the cells. The data from this study do not indicate good correlation between plasma lysine and growth performance. The data also indicated that added dietary lysine decreased ($P < 0.05$) the plasma potassium concentration. The variations in plasma lysine in this study were therefore more of a reflection of a cation/anion balance than better utilization of the lysine.

In pigs it has not yet been shown whether the decrease in plasma lysine with increasing dietary potassium is due to increased lysine catabolism, by increased activity of lysine ketoglutarate reductase, or increased protein synthesis making use of more lysine. From the literature reviewed, the lysine-arginine antagonism has not been shown in swine. It cannot therefore be said that potassium alleviates any amino acid antagonism in the pig. If potassium supplementation alleviates amino acid imbalances, such as excess lysine, then the action of potassium is through lysine catabolism. However since potassium has been found to spare lysine at levels below the requirements for optimum growth, it appears potassium improved the utilization of lysine.

SUMMARY AND CONCLUSIONS

The objective of this study was to determine the response of weanling pigs to potassium supplementation at two levels of dietary lysine. It was also designed to investigate the effects of potassium supplementation on plasma lysine and potassium concentrations.

The study comprised two trials. The basal diet contained 0.85% lysine and approximately 0.4% potassium. Supplementation with L-lysine monohydrochloride brought the lysine level to 1.15%. The 0.85% and 1.15% lysine diets were supplemented with 0.0, 0.4 or 0.8% potassium in the form of potassium chloride for a total of six treatments. However on chemical analysis, the diets were found to contain 0.96 and 1.3% lysine on the average.

Weanling pigs weighing about 8.0 kg were used in the study. One hundred and twenty pigs were used in the first trial and 96 pigs were used in the second trial. The pigs were allotted to the treatments on the basis of weight and litter group. There were five and four pigs per pen in the first and second trials, respectively, and each treatment was replicated four times. Trial 1 was conducted for 35 days and trial 2 for 32 days. At the end of each trial, blood was obtained for plasma analysis. The pigs and feed were weighed at weekly intervals.

The overall results of the study showed that potassium supplementation did not significantly improve weight gains or feed efficiency. However, potassium supplementation of the low lysine (0.85%) diet resulted in slightly improved gains of weanling pigs. On the other

hand, lysine addition to the basal diet to bring the total lysine to 1.15% of the diet, increased ($P < 0.01$) the weight gains and improved ($P < 0.01$) the feed efficiency. There were highly significant differences between the two trials in average daily gains, feed consumption and feed efficiency.

Potassium supplementation significantly increased plasma potassium levels and slightly lowered plasma lysine concentration. However the decrease in plasma lysine levels with increasing dietary potassium concentrations was nonsignificant ($P > 0.05$). Plasma lysine levels increased as dietary lysine increased from 0.85% to 1.15 percent. The increase in dietary lysine caused a decrease ($P < 0.05$) in plasma potassium levels.

The data obtained in this study do not indicate that potassium supplementation as potassium chloride, significantly improves the rate of gain and feed efficiency of weanling pigs by either sparing the lysine requirement at 0.85% level or enhancing its utilization at the 1.15% concentration. The response to lysine indicates that the lysine requirement of 8 to 20 kg pigs, as used in this study, may be above that recommended by the National Research Council. The low lysine level used in this study corresponds to recommendation for pigs in the 5-10 kg weight group (N.R.C., 1979). Variations in plasma lysine levels might have been due to maintenance of extracellular and intracellular cation balance and not because of efficiency of lysine utilization.

It is concluded from this study that unless the protein, lysine and/or potassium levels of the diet are below the requirements there is

no cause for potassium supplementation in weanling pig diets. Since most feeds used in swine diets contain potassium levels above those recommended by the National Research Council (1979), potassium supplementation in weanling pig diets may be unwarranted. The supplementation of lysine therefore still remains a major concern and takes precedence over potassium in the formulation of diets for weanling pigs.

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APPENDIX

TABLE 1. COMPOSITION OF INGREDIENTS (PERCENT)

Ingredient	Nutrient				
	Protein	Calcium	Phosphorus	Potassium	Lysine
Oat groats	16	0.07	0.43	0.34	0.60
Corn	9	0.02	0.28	0.30	0.25
Corn gluten meal	60	0.23	0.55	0.24	1.00
Meat meal	53	8.2	4.1	1.40	3.00
Fish meal	60	5.11	2.88	0.77	4.80
Soybean meal	44	0.29	0.62	2.0	2.90
L-lysine-Hcl	--			--	78.0
Potassium chloride	--			50.0	--

TABLE 2. VITAMIN-ADDITIVE PREMIX[a]

	Amount supplied per kg of feed	
	Trial 1	Trial 2
Vitamin A, IU	4400.0	4400.0
Vitamin D, IU	440.0	440.0
Vitamin E, IU	6.6	8.0
Vitamin K, mg	2.6	3.5
Riboflavin, mg	3.3	4.4
Pantothenic acid, mg	13.2	17.6
Niacin, mg	21.1	28.16
Choline, mg	66.0	176.0
Vitamin B_{12}, mcg	13.2	17.6
Selenium, mg	0.1	158.4
Penicillin, mg	55.0	55.0
Sulfamethazine, mg	110.0	110.0
Chlortetracycline, mg	110.0	110.0
Zinc, mg	--	88.0

[a]Premix added at 0.2% of the diet.

TABLE 3. RESULTS BY TREATMENT FOR EACH TRIAL.

Dietary treatment	1	2	3	4	5	6
Dietary lysine, %	0.85	0.85	0.85	1.15	1.15	1.15
Added potassium, %	0.0	0.4	0.8	0.0	0.4	0.8
Avg. daily gain, kg						
Trial 1	0.24	0.25	0.24	0.33	0.34	0.32
Trial 2	0.33	0.39	0.40	0.46	0.44	0.43
Avg. daily feed, kg						
Trial 1	0.58	0.61	0.64	0.63	0.64	0.64
Trial 2	0.62	0.71	0.68	0.74	0.71	0.71
Feed per gain						
Trial 1	2.46	2.55	2.68	1.91	1.85	1.99
Trial 2	1.89	1.80	1.72	1.62	1.62	1.64
Plasma lysine, mg %						
Trial 1	3.61	3.86	2.89	4.46	4.57	4.36
Trial 2	4.68	4.32	4.66	6.16	5.83	5.86
Plasma potassium, meq/liter						
Trial 1	5.61	6.19	6.36	5.59	6.00	6.27
Trial 2	5.12	5.76	6.10	5.21	5.48	5.97