A NUTRITIONAL EVALUATION OF RECYCLED SWINE WASTE

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ABSTRACT

A NUTRITIONAL EVALUATION OF RECYCLED SWINE WASTE

By Donald E. Orr, Jr.

Seven experiments involving 114 finishing pigs weighing 54 to 100 kg were conducted to evaluate dried swine feces (DSF), dried poultry waste (DPW) and oxidation ditch liquor (ODL) as sources of nutrients in swine finisher diets.

In experiment 1, 16 finishing pigs were randomly allotted to one of two rations. One group of pigs received a 13% crude protein, fortified corn-soybean meal ration. The other group received a ration of 78% corn and 22% DSF during the first 3 1/2 weeks of the trial and then 0.1% L-lysine and 0.1% DL-methionine were added to the diet for the remainder of the trial. The additional lysine and methionine were required to bring the corn-DSF ration up to N.R.C. minimum requirements for these amino acids. Pigs were fed to typical market weights and loin roasts were removed at slaughter to use in taste panel tests to determine flavor acceptability. Overall average daily gain was significantly higher ($P<0.01$) with the corn-soy group. Feed intake of the corn-DSF group was 93% of that of the corn-soy group, whereas feed efficiency was depressed to a greater extent with the corn-DSF group. Taste panel tests of loin

roasts revealed no significant difference between groups for flavor acceptability.

In experiment 2, three balance trials involving four barrows were conducted to determine the digestibility of nutrients, nitrogen balance and mineral balance for a corn-soybean meal diet, corn-DSF diet and corn-DSF diet containing supplemental lysine and methionine. Significantly higher daily fecal output ($P<0.01$) occurred from the two corn-DSF diets than from the corn-soy diet. Daily urine volume was also higher on the corn-DSF diets. The higher calcium level of the DSF diets resulted in significantly higher calcium intake ($P<0.01$) for the DSF groups. Although calcium retention relative to intake was significantly greater ($P<0.05$) for the corn-soy diet as compared to the corn-DSF diet with supplemental amino acids, due to the lower calcium intake of the corn-soy diet, absolute calcium retention was similar for all three dietary treatments. Daily phosphorus and magnesium balances indicated a similar pattern to that of the calcium balance for all treatments. Sodium retention relative to intake was similar for all three diets. Apparent digestibility and retention of potassium were significantly higher ($P<0.01$) on the corn-soy diet.

Apparent digestibility and retention of iron, zinc and manganese were improved with the addition of supplemental amino acids to the corn-DSF diet.

Nitrogen apparent digestibility and retention were significantly higher ($P<0.01$) in the corn-soy diet as compared to the DSF diets. Amino acid supplementation significantly improved ($P<0.01$) these same parameters with the corn-DSF diets. Energy balance was directly related to nitrogen balance of the respective diets.

In experiment 3, 32 finishing pigs were fed (1) conventional corn-soy, (2) 80% of ration 1 plus 20% DPW, (3) corn-limited soy plus 20% DPW plus vitamin-zinc-methionine premix and (4) corn-limited soy plus 20% DSF, salt and vitamin-trace mineral premix. Growth rate was significantly higher ($P<0.01$) on ration 1. Feed intake and feed efficiency were reduced with diets containing DPW and DSF. Higher dietary calcium levels occurred with the DPW diets due to elevated calcium levels of the DPW that originated from caged layers. Pig performance was poorest on ration 3. Poor availability of amino acids in DSF may have been the reason for poor performance on ration 4.

In experiment 4, eight finishing swine were used to evaluate a corn, limited soy diet containing 20% DSF and 4% corn oil to improve the energy density of the diet compared with a fortified corn-soy control diet. Daily gains slightly favored the control diet, but the difference was not statistically significant. Feed intakes were similar with feed efficiency being 9.5% poorer with the corn-DSF diet. The addition of supplemental energy to the DSF diet resulted in significant improvement in pig performance as compared to previous DSF diets.

In experiments 5 and 7, forty-eight finishing pigs were assigned to one of two treatments: (1) conventional fortified corn-soy diet or (2) corn-limited soy fortified only with vitamins A, D and E. Pigs on diet 1 received equal parts (weight basis) of dry feed and water. Pigs on diet 2 received equal parts (weight basis) of dry feed and ODL. ODL was pumped from the oxidation ditch at each feeding to be mixed with the diet. In experiment 7, these same diets were also offered *ad libitum* from a self-feeder in addition to being hand fed to two other lots. In experiment 5, average daily gain was only slightly higher for the corn-soy plus water diet, but was significantly higher ($P<0.01$) for the same diet in experiment 7 as compared to the corn-limited soy plus ODL. Average daily feed intake and feed efficiency were depressed slightly with the corn-limited soy plus ODL regime. Results from experiment 7 demonstrated that feed intake of the hand fed groups was similar to feed intake of the self-fed groups.

In experiment 6, six barrows were utilized in a double reversal designed balance trial to determine the digestibility of nutrients, nitrogen balance and mineral balance for the diets utilized in experiments 5 and 7. Results indicated significantly higher ($P<0.01$) daily fecal output with the ODL. The corn-soy-water diet had significantly higher ($P<0.01$) calcium, phosphorus, sodium and magnesium apparent digestibilities and retentions as compared to the

corn-limited soy-ODL diet. Potassium retentions were similar for both diets. Apparent digestibility of iron and zinc and relative retention of iron were similar for both diets, although zinc relative retention was higher on the corn-soy-water diet. Manganese and copper balances were significantly higher ($P<0.01$) for the corn-soy-water diet. Higher ($P<0.01$) nitrogen apparent digestibility occurred with the corn-soy-water diet, although nitrogen retention was similar for both diets. Dry matter and energy apparent digestibilities were significantly higher for the corn-soy-water diet.

From the experiments conducted, it could be concluded that finishing pigs will consume corn-soy rations containing up to 22% DSF at 90 to 95% of full appetite. Rate and efficiency of gain are depressed by the incorporation of DSF into corn-soy rations to replace all or most of the soybean meal. The incorporation of DSF into a finisher diet resulted in a depression of apparent digestibility and retention of dry matter, nitrogen, energy and most minerals; however, the addition of supplemental amino acids to the DSF diets significantly improved apparent digestibility of these nutrients. Elevated calcium levels, reduced amino acid availability and reduced energy digestibility of DSF and DPW (layer) would appear to be the primary factors affecting their utilization in swine diets. The addition of supplemental energy to DSF diets to restore the concentration of digestible energy should improve pig performance. No improvement in pig performance was observed for pigs receiving ODL in their diet and lower apparent digestibility coefficients for dry matter, protein, energy and minerals were obtained in balance trials utilizing ODL.

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TABLE OF CONTENTS

TABLE OF CONTENTS (Continued . . . .)

LIST OF TABLES

LIST OF TABLES (Continued . . . .)

I. INTRODUCTION

A major problem confronting the swine industry is waste management. This is a problem to the industry from both the standpoint of labor expenditure of disposing of the waste and from the standpoint of environmental pollution. With increased intensification of swine production, the problems associated with waste handling and odor control have demanded special consideration.

Logically, a system of animal waste management emphasizing waste utilization rather than disposal would be of value to the livestock producer. The refeeding of animal waste (feces) has been practiced by livestock raisers for many years. The practice of following steers with swine was known long ago as an efficient method of swine raising. Besides obtaining undigested corn, the hogs also utilized other nutrients of the cattle manure.

In confinement rearing of swine, slotted floors offer considerable advantage in labor saving over conventional solid floors. In the future, it is conceivable that an increasing number of swine will be raised on slotted floors. Any long range solution to management of the excrement accumulating beneath the slotted floors should emphasize waste utilization rather than waste disposal.

An approach to the waste handling and odor control problems has been the operation of an oxidation ditch containing a paddle wheel which incorporates oxygen into liquid swine wastes for the purpose of promoting aerobic microbial activity and reducing odors. Unfortunately, the operation of an oxidation ditch is expensive in terms of initial equipment investment, energy required for operation and maintenance. If waste products in the form of microbial protein and other nutrients contained in the oxidation ditch could be used, this might help to offset operational costs of the oxidation ditch in the future or help to justify waste handling investments.

The purpose of these studies was to evaluate dried swine feces (DSF), dehydrated poultry waste (DPW) and oxidation ditch liquor (ODL) as sources of nutrients in swine finisher rations.

II. REVIEW OF LITERATURE

A. Digestibility of Nutrients of Ingredients in the Swine Diet.

The efficiency of utilization of a swine diet with its resulting effect on animal performance is greatly dependent upon the nutrient digestibility of dietary ingredients.

Much research has been conducted in order to establish total and available nutrient requirements which permit the animal to perform adequately at a given stage of development. The ability to supply the nutrient needs for a particular animal varies among feedstuffs and depends heavily upon the complementary nature of the ingredient composition of a diet. Keys and DeBarthe (1974), feeding complete diets containing 70% wheat, milo, corn or barley, studied total digestion of various nutrient parameters. The milo diet had significantly lower total digestion of dry matter (73.7%), energy (72.6%) and crude protein (64.8%) then the other 3 diets. The corn diet provided total digestion coefficients for dry matter, energy and crude protein of 80.7%, 78.4% and 81.7%, respectively. Sihombing _et al_. (1969) demonstrated that apparent digestibility of crude protein tended to be higher in diets containing opaque - 2 corn as compared to diets containing normal corn. They noted that, in general, apparent digestibility of protein increased linearly with increasing increments of crude protein in the diets. In their experiments, apparent digestibility of fat was significantly lower in the opaque - 2 corn diets than in those containing normal corn, whereas apparent digestibility of dry matter was not consistently affected by corn source. Jensen et al. (1965) showed that milo, which contained 8.0% crude protein and was fortified with vitamins, minerals and antibiotic, was inadequate as the sole source of protein for finishing pigs averaging 55 kg initially. The addition of 0.25% lysine to this diet resulted in gains and gain/feed ratios equal to finishing pigs fed a 12% crude protein corn-soy diet.

In a study of the digestibility of rations containing different sources of supplementary protein for young pigs, Combs et al. (1963) reported that the apparent digestibility of protein of soybean meal, fish meal or dried skim milk was not different for these protein sources as the pigs grew older. They noted that maximum protein digestion occurred during the 7th to 8th week of age. Studies by Lloyd and Crampton (1955) and Whiting and Bezeau (1957) demonstrated that level of crude fiber along with level of crude protein in the diet affect the apparent digestibility of protein. Using the rat as an experimental animal, Sibbald et al. (1957) noted that the level of crude fiber in the diet limited nitrogen retention of the diet. They demonstrated that, at least in the case of the rat, this was due to nitrogen intake being limited by energy concentration in the diet. Studies by Crampton and Rutherford (1954) using the rat and Armstrong and Mitchell (1955) using the pig showed that fecal nitrogen of these growing animals is linearly related to the protein level of the diet fed over various ranges of dietary protein levels. Hendricks et al. (1969) conducted nitrogen balance studies with the baby pig and showed an increase in total urine volume, urine nitrogen and nitrogen retention as protein levels in the diet were increased. Kuryvial and Bowland (1962) showed that the apparent digestibility of crude protein tended to be higher with 45 kg pigs fed higher protein diets, although nitrogen retention decreased as protein levels in the diets increased. This would agree with studies by Greeley, Meade and Hanson (1964) which demonstrated that as dietary protein level increased, there was a highly significant linear trend toward reduced efficiency of utilization of digestible protein.

Zivkovic and Bowland (1963) used gilts fed different levels of energy and protein intake to investigate apparent digestibility of nutrients during growth, gestation and lactation. Apparent protein digestibility averaged 76% and did not vary between the physiological periods, but the apparent digestibility of other nutrients did vary. They showed that an increased level of protein in the diet tended to increase apparent digestibility of protein. Dammers (1965) also noted that the digestibility of protein by the pig was low when the diet had low protein content. He further concluded that the digestibility of most nutrients increased as the animals became older. Studies by McConnell et al. (1971) agree with previous research that nutrient digestibility improved with increasing age and that protein digestibility was somewhat higher when pigs were fed higher protein levels. These studies demonstrated that lean type pigs fed a higher protein diet retained similar amounts of nitrogen at body weights of 40 to 70 kg, but a lower amount of nitrogen was retained at 90 kg body weight. Daily nitrogen retention in fat type pigs fed a high protein diet decreased with increasing body weight. Daily nitrogen retention was similar in both fat and lean type pigs when a low protein diet was fed. In earlier studies, Bell and Loosli (1951) showed that the biological value of protein fed at a level of 10% in a diet decreased as the pigs increased in body weight.

Dietary amino acid levels and amino acid balance has been shown to affect nutrient digestibility and animal performance. Luce et al. (1964) conducted digestion trials with growing pigs and showed that dry matter, energy and nitrogen digestibility tended to decrease as the number of amino acids supplemented was increased. These workers related the digestibility depression to an amino acid imbalance. Baker et al.(1969) conducted trials with growing pigs to evaluate amino acid additions to a fortified corn diet.

Lysine supplementation at 0.2% of the diet caused a marked depression in feed intake and rate of gain. A similar level of supplemental methionine had no effect. Supplemental DL - tryptophan at 0.05% of the diet completely overcame the depression caused by the lysine supplementation. This data would suggest that tryptophan is the first-limiting amino acid and lysine is the second-limiting amino acid in corn protein. These data would tend to support the classical theory that amino acid imbalances can be induced most easily by supplementing a low protein diet with its second-limiting amino acid (Harper, 1964). Clawson (1967) reported that daily feed intake of growing pigs was not significantly influenced by protein level as long as amino acid balance was adequate. Jurgens _et_ _al_. (1967), feeding milo-soybean meal diets to growing-finishing pigs, showed that average daily gain and feed efficiency were higher when the pigs received a 16% crude protein diet than when a 12% crude protein diet was fed. These performance parameters were not significantly affected by the addition of 0.1% lysine to the diets. Standish and Bowland (1967) fed 3 to 9 week old pigs diets containing 12, 16 and 20% crude protein and 12 and 16% crude protein diets supplemented with lysine and methionine to equal those amino acid levels present in the 20% protein diet. These researchers found that each increment of protein resulted in increased rate of gain and that the amino acid supplemented 16% ration resulted in as rapid daily gain and as efficient feed utilization as did the 20% protein diet. Apparent digestibility of nitrogen was higher in the 20% protein diet than in the 12 or 16% protein diets and was found to increase with the amino acid additions to the low protein diets. Gallo and Pond (1968) utilized finishing pigs from 50 to 100 kg body weight to evaluate corn diets containing 10% crude protein supplemented with lysine and tryptophan. They found that pigs fed this diet gained more rapidly and efficiently than pigs fed the unsupplemented corn diets. Rate of gain and feed efficiency for the supplemented pigs were not significantly different from pigs fed a 12% crude protein corn-soy diet. Noland and Scott (1960) showed that protein levels in the diet linearly affected rate of gain of pigs from weaning to 34 kg, but had little effect on gains from 34 kg to market weight. They tested diets with crude protein levels of 12, 16 and 20% which were apparently all adequate to support acceptable daily gains.

In a more recent study, Brown et al. (1973) attempted to more narrowly define the requirement for lysine with the finishing pig. These Illinois workers concluded from their studies with the finishing pig that the lysine requirement for maximum daily gain was 0.48% of the diet, while 0.62% lysine was necessary for maximum gain/feed ratios. Regarding methionine supplementation, Huck and Brooks (1972) reported that methionine added to corn-soy diets increased the nitrogen digestibility for the growing pig, but not for the finishing pig. Other researchers have noted no benefit in performance from methionine additions to growing-finishing diets containing reduced protein levels and supplemental lysine (Miller, Orr and Ullrey, 1973; Orr, Miller and Ullrey, 1973; Wahlstrom and Libal, 1973).

An interrelated factor with protein and amino acid levels is the caloric density of the diet. Clawson (1967) using growing pigs noted that daily caloric intake was reduced by increasing levels of dietary calories when the dietary protein level was inadequate and was further depressed when an amino acid imbalance existed. No depression in caloric intake resulting from increasing caloric density occurred when low protein diets containing high quality protein were fed.

A number of researchers (Kuryvial and Bowland, 1962; Dammers, 1965; Boenker, Tribble and Pfander, 1969) reported that the fat content or gross energy level of a diet had no effect on the digestibility of the other components of the diet. Wagner et al. (1963) found that increasing energy levels for growing swine resulted in less feed required per unit of gain. Pond, Lowrey and Maner (1962) demonstrated that average daily gain of growing-finishing pigs was significantly reduced by the addition of 24.8% corn cobs to either a 10 or 18% crude protein ration. Apparent digestibilities of dry matter, nitrogen-free extract and crude protein were significantly reduced by the addition of corn cobs to the low protein diet. Zivkovic and Bowland (1963) found that the digestibilities of dry matter, crude protein and crude fiber were improved and the digestibility of nitrogen-free extract depressed when gilts received supplemental fat (15% added stabilized tallow) in their diet. Greeley et al. (1964) fed growing pigs 16% protein diets containing 0, 5, 10 or 15% stabilized lard, stabilized animal tallow or crude corn oil. They found that neither source nor level of dietary fat significantly affected apparent digestibility of protein or dry matter. Highly significant increases in apparent digestibility of energy resulted with increased levels of dietary tallow. Lowrey et al. (1962) showed that the addition of 10% stabilized beef tallow resulted in non-significantly increased weight gains for growing swine on high protein levels (19%) and non-significantly decreased gains when fed low protein levels (13%). The apparent protein digestibility of practical rations for growing swine was not influenced by the addition of fat to the diet. Using 45 kg pigs initially, Waterman et al. (1973) showed that a 3% tallow supplementation to a corn-soy finisher diet brought about a reduction in time to market weight by about 4 days. Metabolizable energy consumed per unit gain was reduced by about 4%. Six percent additional tallow to the diet gave no performance improvement. Jones and Pond (1964) showed that the inclusion of 12% corn oil in growing-finishing diets resulted in significantly faster gains to market weight when compared to pigs on corn-soy diets alone. However, Nordstrom et al. (1972) found that the addition of 3 or 12% refined corn oil to corn-soy grower diets or the utilization of corns containing 6.7 to 8.4% oil did not significantly affect rate of gain, but resulted in a highly significant decrease in feed/gain when corn oil was added to the diet.

Other nutrients have been shown to be required at minimum levels in a diet for acceptable pig performance and proper body development. The availability and utilization of these nutrients from different sources and at different dietary levels have been the subject of numerous research papers. Hansard, Lyle and Crowder (1961) showed that calcium absorption and retention were greatest in young pigs and decreased rapidly to 5 months of age. Using pigs weighing 45 kg, these workers found calcium apparent digestibility to be 42%. Stockland and Blaylock (1973) showed that the calcium requirement of growing-finishing pigs from 27 to 91 kg was about 0.30% of the diet for maximum gain and feed efficiency. The phosphorus requirement for swine at these weights was found to be 0.45% for maximum performance as well as maximum skeletal development. Studies by Vipperman, Peo and Cunningham (1974) indicated that the utilization of calcium appeared to be less affected by the calcium to phosphorus ratios than was the case with phosphorus utilization. These investigators noted that as dietary phosphorus increased, urinary calcium was depressed while calcium retention was improved. They noted that nitrogen retention was affected greater by dietary phosphorus level than by dietary calcium level. Morgan et al. (1969) showed that increased dietary calcium improved calcium retention while reducing phosphorus retention. No effect was shown on zinc retention. They showed that about 50% of the calcium and phosphorus ingested was retained by the pigs, but only about 10% of the ingested zinc was retained by the growing barrows. Combs and Wallace (1962) demonstrated that with growing pigs fed 0.40 and 0.88% dietary calcium, the higher calcium level significantly depressed growth rate. Studies with the baby pig by Miller et al. (1962) where the phosphorus level was maintained at 0.5% indicated that a dietary calcium level of 0.4% appeared sufficient for normal growth rate and feed utilization. However, maximum calcium retention occurred at 1.0% dietary calcium. N.R.C. (1968) recommendations for the finishing pig are 0.50% dietary calcium and 0.40% dietary phosphorus.

The availability of calcium and phosphorus from different feed sources has been the subject of numerous research studies. Chapman et al. (1955) showed that growing-finishing swine did not utilize plant phosphorus as efficiently as inorganic phosphorus, as indicated by a significantly poorer feed efficiency and depressed feed intake when fed the former phosphorus sources. These workers noted a significant linear increase in daily gains and feed efficiency when the phosphorus from plant sources was reduced as a percent of the total ration with inorganic phosphorus being added to maintain 0.5% total phosphorus in the diet. Taylor (1965), discussing the availability of calcium and phosphorus from plant materials, noted that plant phytates influence calcium utilization in two ways: by interferring with calcium absorption by forming insoluble calcium phytate and by failing to provide inorganic phosphate equivalent to their organic phosphate content. In early studies with corn-soy diets containing 0.30% phosphorus, Plumlee _et al_. (1958) noted highly significant increases in daily gain and serum phosphorus values with the addition of 0.15% phosphorus from either dicalcium phosphate or phosphoric acid. Libal _et al_. (1969) showed that calcium and phosphorus levels did not adversely affect daily gains when calcium was near the N.R.C. requirements or below. These workers also noted that increasing phosphorus in 0.10% increments from 0.30% to 0.70% of the diet had a linear effect on daily gain. Bayley and Thompson (1969) determined that the biological availability for phytate phosphorus was 20 to 30% for a 27 kg pig. Other workers had previously found values of 18 to 24% (Besecker _et al_., 1967) and 30 to 60% (Noland, Funderburg and Johnson, 1968) for the biological availability for phytate phosphorus with the growing pig. Tonroy _et al_. (1973) showed the apparent digestibility of phosphorus in sorghum grain to be 4.5% and 1.9% for the 0.3% and 0.5% total dietary phosphorus levels, respectively. His studies showed this parameter for soybean meal to be 27.0%. The apparent digestibility of phosphorus from dicalcium phosphate in a blood fibrin diet was 49.4%. Peeler (1972), in summarizing the work of several researchers, noted that the soluble phosphates such as sodium phosphate, phosphoric acid and monocalcium phosphate have the highest biological availability, followed closely by dicalcium phosphate. Next in order were defluorinated phosphate, steamed bone meal, low fluorine rock phosphate and, finally, soft phosphate with the lowest availability. In mineral balance studies with the baby pig, Miller _et al_. (1964) showed that increasing the dietary phosphorus levels to 0.5% resulted in increased total phosphorus retention and percentage phosphorus retention. Cromwell _et al_. (1970), using growing-finishing pigs, showed significantly slower gains with grower diets containing 0.38% phosphorus and finisher diets containing 0.30% phosphorus compared to diets having higher phosphorus levels. Work by Lehmann and Pollak (1941) and McCance, Widdowson and Lehmann (1942) suggested that increased protein or amino acid levels might increase the absorption of calcium. Using baby pigs in mineral balance studies, Hendricks _et al_. (1969) did not show any significant differences in mineral retention due to protein level or dietary vitamin D level. Studies with tallow in swine rations by Newman _et al_. (1967) showed that the added tallow had no consistent effects on calcium digestibility, but depressed the apparent digestibility of dietary phosphorus. This is contrary to findings by Tillman and Brethour (1958) with sheep that the inclusion of 7.5% corn oil did not significantly affect apparent digestibility of dietary phosphorus, but did significantly reduce the apparent digestibility of dietary calcium.

Concerning the addition of water to dry diets and its effect upon nutrient utilization, Rerat and Fevrier (1965) showed that digestibility and utilization of nitrogen for swine diets were not altered by degree of dilution with water. Becker et al. (1963) showed that finishing swine showed increased body weight gains and feed efficiency when water was added to the diet at ratios of 1:1 or less on a weight basis. However, Barber, Braude and Mitchell (1963) and Kornegay and VanderNoot (1968) found no improvement in daily gains and feed efficiency for swine with similar additions of water to the diet.

B. Production of Wastes by Swine.

Many investigators have attempted to quantitate the daily production of wastes from various types and sizes of swine. Muehling (1971) has presented data suggesting the average daily manure production (feces and urine) per 45 kg of live body weight to be approximately 3.64 kg. This author presents a summary of data on the waste production of hogs of various ages and weights. For growing-finishing pigs, live weight (kg) and approximate daily manure production (kg of liquid and solids), respectively, are as follows: 18, 1.8; 45, 3.6; 68, 6.2; 95, 8.0. For sows and boars, live weight (kg) and approximate daily manure production (kg of wet solids), respectively, are: 136, 10.9; 227, 18.2. The approximate daily manure production (liquids and solids) for a typical sow and litter is 14.5 kg. Muehling (1969) presents average figures from various sources as 3.5 kg of total wet manure and 0.45 kg of dry matter produced per 45 kg pig per day. Conrad and Mayrose (1971) characterized daily waste production of growing-finishing swine as 5 to 8% of their live weight per day of which 10 to 15% is dry matter. Using averages of these values, these researchers show that a 45 kg pig could be expected to produce 2.9 kg of total wet manure daily and 0.36 kg of dry matter. Taiganides and Hazen (1966) found the average daily manure production for a 45 kg pig to be 2.3 kg per day, which is somewhat lower than values presented by other investigators. For the same size pig, Schmid and Lipper (1969) found daily manure production to be 4.1 kg per day. Taiganides _et_ _al_. (1964) showed manure production with swine to be 5% of body weight and the manure produced contained 17% total solids on a wet basis. Ngoddy _et_ _al_. (1971), using growing-finishing pigs, found daily manure production rate to be 5% of body weight, but these researchers found total solids to be only 10% (wet basis) of the daily manure production. These latter results were obtained from pigs housed in individual metabolism cages and fed typical fortified corn-soy rations.

Conrad and Mayrose (1971) illustrated the approach of basing manure production on the amount of feed fed. They note that with a 45 kg pig consuming 2.5 kg of air-dry feed daily and having a dry matter digestibility of 84%, fecal dry matter would be 0.40 kg. With gestating swine, these Purdue researchers pointed out that a corn-soybean meal diet had an average dry matter digestibility coefficient of 87% when 2.22 kg was fed daily and 88.5% when 1.8 kg was fed daily. They noted that diets higher in fiber with lower dry matter digestibility coefficients result in more fecal dry matter with pigs of any age. They concluded that 16% of the average feed to a swine enterprise would be a good estimate of fecal dry matter production. O'Callaghan et al. (1971) measured daily fecal and urinary production of growing-finishing pigs using 3 different feeding regimes. They found that manure production to total input ratio was influenced by feeding regime. This ranged from 0.6 for floor feeding and pipeline feeding regimes at a water to meal ratio of 2.5 to 1 to approximately 0.7 for pipeline feeding at a water to meal ratio of 4 to 1. These researchers also noted that total solids of the manure was influenced by feeding regime. This ranged from approximately 9.5% for floor feeding and pipeline feeding at a water to meal ratio of 2.5 to 1 to approximately 5.6% for pipeline feeding at a water to meal ratio of 4 to 1. These feeding methods can be expected to vary the urine output considerably. N.R.C. (1968) states that pigs will voluntarily consume an average of 2.0 to 2.5 times as much water as dry matter.

Other factors affecting the production of swine wastes from a quantitative standpoint are temperature, humidity, feed wastage from self feeders and water wastage. The total amount of liquid in a swine unit can be influenced more by the amount of wastage from the many pressure waterers in a confinement system than by any other single factor (Muehling, 1971).

C. Methods of Waste Handling

With the trend toward confinement raising of swine during all stages of production, the burden of waste handling falls upon the operator of the swine production system. Prior to the trend of confinement raising, swine were usually maintained on pasture or dirt lots and wastes were deposited on the soil by the animals. Muehling (1971) noted that before 1950, hogs were raised in small groups, utilizing portable houses on clean pastures. The pasture lots were rotated to provide clean ground for the pigs. This author noted that very few pollution problems existed with these practices. However, during the next 10 to 20 years many producers increased their hog numbers to better utilize their equipment capacity and managerial ability. This precipitated the trend toward confinement rearing on a large scale.

Muehling (1971) has presented a description of waste handling from several swine production systems.

Pasture system

As mentioned previously, this method of raising swine has been used the longest of all the systems and there are still a large percent of hogs raised by this method. This system requires a minimum amount of capital investment for facilities, especially permanent facilities. It is best adapted to areas of rough, rolling land unsuitable for growing cash crops. Little labor is required for handling wastes, although for this system to work most efficiently, the land must be rotated every few years to prevent parasite and disease problems. If vegetation is lacking, water pollution may occur following heavy rainfall if wastes are carried into streams. Gains with this system may not equal those obtained with confinement systems (Conrad and Mayrose, 1971).

Solid floor confinement

This confinement system requires the lowest amount of initial investment of all confinement systems. However, bedding must usually be used with this type of system. This is necessary since the wastes must usually be handled as solids and some bedding is required to make it suitable to handle with conventional equipment (Muehling, 1971). This production method requires the most labor for waste handling. From farrowing to 21 days, an average of 80 minutes per litter was required when the sow and litter were confined in a crate on a solid concrete floor, which was considerably higher than the other systems tested (Daniel _et al_., 1967). Cleaning and bedding time was 5 to 8 times higher with solid concrete floor growing-finishing facilities (Kadlec _et al_., 1966) when compared with slotted floor systems.

Slotted floors with pit

With slotted floors, the manure must be handled as a liquid. This type of waste handling system is efficient from the standpoint of ease of cleaning. No bedding is used in this system. For farrowing, nursery and growing-finishing systems, this method requires the least amount of labor (Daniel _et al_., 1967 and Kadlec _et al_., 1966). Construction costs of this type of facility are higher than the previous systems discussed and adequate ventilation is required because this facility is usually completely enclosed. Manure from this system is handled in liquid form. The major problems with spreading liquid manure on the land are the odors during and immediately following spreading, and the danger of pollution from runoff on rolling land, particularly when rainy weather follows or when the manure is spread on frozen ground (Muehling, 1971). Kesler and Hinton (1966) found total hauling and spreading to be the lowest net cost method of disposing of liquid hog manure from slotted floor confinement facilities when cropland was available to use the manure to replace commercial fertilizer.

Waste lagoons

Lagoons have been used for treatment of liquid hog wastes because of their ease of operation with expanding swine operations, and, perhaps more important, a lack of acceptable alternatives (Muehling, 1971). This author noted that many lagoons were anaerobic due to overloading with wastes. These lagoons did have the ability to break down organic matter, but the major disadvantages were the undesirable odors released and the higher temperature required for optimum operation. Fertility value of the waste is lost with this method. Kesler and Hinton (1966) found this method to have the highest net cost for disposing of hog manure. This was primarily due to the large recommended size of lagoon necessary to satisfactorily digest the hog wastes.

Oxidation ditch

This system is a mechanical method of aerobically treating liquid wastes. According to Muehling (1971), this method has attracted attention because it has the capability of reducing odors. Volatile solids are oxidized and gases are minimized with this system (Jones, Day and Dale, 1970). The aerobic bacteria use the organic matter in the waste as food for their metabolic processes, thereby reducing the biologically degradable organic material to stable products, with carbon dioxide and water as the major by-products (Miner, 1971). However, installation and operating costs as well as required maintenance are major limitations associated with this waste handling method (Conrad and Mayrose, 1971). Furthermore, hauling or lagooning of the overflow material is necessary.

Hydraulic manure removal

Smith and Hazen (1967) have shown that a flushing gutter system can minimize odors within a confinement building when the manure is flushed from the house several times a day. The manure is washed into a lagoon or storage pit before the production of anaerobic gases from the solids has a chance to increase greatly. This system has been applied to slotted floored buildings by Miller and Hansen (1973). Due to the large demand for water and the excessive amount of liquid wastes produced, normally some type of recycling of liquid is required for the flushing process. Conrad and Mayrose (1971) have speculated that this system in conjunction with an aerated lagoon will be used more in the future combined with recycling of the liquid for flushing and utilization of the effluent for irrigation of cropland.

D. Nutritional Value of Animal Waste

1. Poultry waste

Before the poultry manure or litter can be successfully mixed into animal diets, the manure must have its moisture content reduced to a maximum level of 15% (Blair and Knight, 1973). Further moisture reduction will increase the length of time which the manure can be safely stored. Poultry manure has been safely dried with heat at temperatures ranging from 149 to 385 degrees C (Sheppard et al., 1971). Their data show an inverse relationship between the drying temperature and the resulting nitrogen content of the dried poultry waste. Couch (1974) designated the manure from caged layers as "poultry battery manure", that from poultry houses where birds are maintained on litter as "poultry house litter," and poultry house litter which has been ensiled for a period of 6 weeks as "broiler litter silage." He further pointed out that any of the above types of poultry waste may be air dried or dried with heat. Blair (1974) noted that dried poultry waste (DPW) contained a high content of nitrogen of which only about one-third is true protein and the remainder is non-protein nitrogen, mainly uric acid, which is of no value to poultry or other non-ruminants. Muhrer and Carroll (1964) showed that uric acid is utilized by rumen microorganisms and is a better source of nitrogen for the ruminant than urea. Thus, DPW has the potential to serve as an excellent protein source for the ruminant. Blair (1974) stated that DPW is variable in composition due to moisture content, variation in the composition of the feed, variable feed spillage into the manure, decreases in the stage of lay of hens and feather shedding. He noted that the protein and amino acid levels of DPW are roughly equivalent to a cereal such as barley. Numerous researchers have analyzed the nutrient composition of various dried poultry manure samples and their results have been summarized by Blair and Knight (1973). Dried poultry waste has a high ash content with calcium and phosphorus having the highest concentration of the minerals (Young and Nesheim, 1972). Parker, Perkins and Fuller (1959) showed that 94% of the phosphorus is available for poultry. The primary deficiency in poultry waste is the low metabolizable energy content. This parameter has been estimated to be from 660 to 1290 kcal M.E./kg (Polin et al., 1971; Hodgetts, 1971; Young and Nesheim, 1972; Nesheim, 1972).

In feeding studies with chicks, Flegal and Zindel (1970, 1971) fed broiler type chicks 5, 10 and 20% dried poultry manure in their diets. Feed conversion and gains were depressed when 20% poultry waste was included in the diet. These researchers found that this depression in performance could be prevented by the addition of 4.5% fat to the diet illustrating that the depression of weight gains and feed conversion resulted from the decreased energy content of the diet containing poultry manure. Calvert, Morgan and Eby (1971) confirmed this finding in their work with dried poultry manure in chick diets. Their results indicated depressed growth rates when the product was included in the diet. Lee and Blair (1972) reported that poultry manure could serve as a source of amino acids to substitute for glutamic acid in a glutamic acid low diet. These researchers showed that the nitrogen in uric acid was completely unavailable and might even be toxic for the growing chick.

Michigan researchers studied the feasibility of using dried poultry manure as an ingredient in laying hen diets. Flegal and Zindel (1970) included 10, 20, 30 and 40% poultry manure in a ration for caged layers with and without added calcium, phosphorus, fat and methionine. They noted that the dried poultry manure had an adverse effect on feed conversion and was not corrected by the addition of fat to the diet containing 40% dried poultry manure. The low energy content of the poultry manure was apparent in these studies. Flegal and Dorn (1971) recycled dried poultry waste through caged layers for 14 cycles of 12 days each and reported that there were few differences in nutrient composition of the manure, although there was a slight trend in accumulation of calcium and phosphorus. Quisenberry and Bradley (1969) fed levels of 10 and 20% of dried poultry wastes to laying hens and noted no depression on performance or egg production. However, all diets in this study were adjusted, isonitrogenously and isocalorically. Nesheim (1972) fed layers on a ration where 22.5% dried poultry manure was substituted for corn. He noted that the hens could increase their feed intake by 14%, but they could not maintain the level of caloric intake which the control hens had. This resulted in a higher feed conversion ratio due to the poultry manure addition to the diet. On the assumption that all the phosphorus was available, this Cornell researcher showed that the poultry manure would, by computer analysis, be a selected ingredient for layer diets until it reached a cost of $26 per 908 kg. Young and Nesheim (1972) found that 30% of the dry matter of DPW was digested at levels up to 25% of the total laying diet. Ousterhout and Presser (1971) obtained a dry matter digestibility of 25% for poultry manure fed to laying hens. Blair and Lee (1973) demonstrated that the laying hen was able to utilize some of the essential amino acids in dried poultry manure.

Dried poultry manure or litter has been successfully incorporated into ruminant diets by many researchers. Noland, Ford and Ray (1955) conducted feeding trials with gestating-lactating ewes fed diets in which ground broiler house litter was used to replace conventional protein concentrates. Ewes fed the ground broiler litter performed as well as those fed soybean meal. These same researchers found that fattening steers fed the chicken litter did not gain as rapidly as those fed cottonseed meal when both groups were pair-fed for equal feed intake, but nearly equal rates of gain were obtained for both groups of steers when the total feed intake of the litter-fed steers was increased by 15%. The crude protein content in this study and studies by other researchers using broiler litter and caged layer manure has averaged 28% or higher (Noland *et al*., 1955; El-Sabban *et al*., 1970; Fontenot *et al*., 1966; Fontenot *et al*., 1971a). Bhattacharya and Fontenot (1965) used semi-purified diets containing 25, 50 and 100% nitrogen components derived from poultry litter for nitrogen balance studies with sheep. They demonstrated that when 25 or 50% of the dietary nitrogen was supplied from the poultry litter, nitrogen retention was not significantly lower than when isolated soybean protein supplied all of the dietary nitrogen. A positive nitrogen balance was obtained with the diet having 100% of its nitrogen derived from the poultry litter. El Sabban *et al*. (1970) noted a trend of higher nitrogen retention when sheep were fed diets containing autoclaved or cooked caged layer manure as the only source of nitrogen as compared to soybean meal. These authors did report a trend toward lower apparent digestibility of nitrogen with sheep fed diets containing poultry manure as compared to those fed diets containing soybean meal. Other researchers have reported similar lower digestibilities for feces rations than for soybean meal or barley rations (Lowman and Knight, 1970 and Tinnimit *et al*., 1972). Bucholtz *et al*. (1971) and Smith and Calvert (1972) reported similar nitrogen retention with sheep fed dried poultry waste and soybean meal as supplemental nitrogen sources. Brugman *et al*. (1968) found the apparent digestibility of energy in laying house litter for cattle to be 59.2%. The low energy value of poultry wastes is caused, in part, by a fairly high ash content (Brugman _et al_., 1964; Bhattacharya and Fontenot, 1966; El-Sabban _et al_., 1970). Fontenot _et al_. (1966) showed that daily gain of steers fed a fattening ration containing 25% peanut hull or wood shaving broiler litter was similar to gains for steers fed a control diet. Drake, McClure and Fontenot (1965) fed poultry litter with four base materials, peanut hulls, corncobs, grass hay and soybean hulls, and noted similar performance in fattening steers. El-Sabban _et al_. (1970) reported that performance and carcass quality of cattle fed rations supplemented with autoclaved and dried caged layer manure were similar as for cattle fed soybean meal. Bucholtz _et al_. (1971) reported relatively poor performance of beef animals fed dried poultry waste as 32% of the ration compared to the use of soybean meal. These workers noted that milk production from cows receiving about 20% of their total protein from dried poultry waste was equal to or above that of cows receiving similar proportions of supplemental protein from non-protein nitrogen in silage or soybean meal. Similar results were obtained by Bull and Reid (1971) and Thomas and Zindel (1971). Oliphant (1974) reported that when dried poultry waste was substituted for conventional protein sources in beef rations, performance was directly related with the protein content of the poultry manure.

A limited number of researchers have fed dried poultry waste to pigs. Geri (1968) used growing pigs in three trials to test the effects of substituting dried poultry manure for bran. Up to 22 kg live weight, the pigs received manure at a level of 7% in the feed and from 22 kg received manure at a level of 10%. Growth rates were generally similar, but feed efficiency was poorer with manure in the diet. Phelps (1969) showed poorer feed efficiency resulted when dried poultry house litter was included in the diet of growing-finishing pigs. Perez-Aleman _et al_. (1971) fed dried poultry manure as an addition to a conventional diet at levels of 10, 20 and 30% to pigs from 23 to 85 kg body weight. Their results showed significant linear relationships between the manure levels and growth rate and feed efficiency. For every 10% addition of manure, growth was reduced by 0.02 kg per day and feed efficiency by 0.25 units.

2. _Ruminant waste_

Historically, cattle manure has been utilized as a source of B-complex vitamins for other animals. Hammond (1942) used cattle manure as a source of certain vitamins for growing chicks and also (Hammond, 1944) substituted cow manure for alfalfa meal in poultry diets. Bohstedt, Grummer and Ross (1943) used cattle manure as a source of B-vitamins in rations for pigs. Anthony and Nix (1962) washed manure from cattle fed high energy rations and housed on concrete. The liquid phase was discarded and the washed fiber was blended with a basal mixture. Excellent gains were obtained when the diet was fed to yearling fattening steers. Anthony (1966) reported that combining whole feedlot feces with concentrates (40:60 ratio) in finishing steer diets resulted in lowered performance and digestion coefficients compared to diets containing corn and cottonseed meal. Further experiments by Anthony (1966, 1967, 1968 and 1969) showed the use of cattle manure and ground coastal bermudagrass hay for making a high dry matter silage designated wastelage. These reports indicate equal or nearly equal gains with a corn-wastelage diet as compared to steers on a conventional high concentrate diet. He reported that wastelage produces satisfactory performance in breeding ewes and beef cows when supplemented with vitamin A. Anthony (1970) showed that ground shelled corn and manure rations supported gains similar to cattle fed feeds without manure, although total daily dry matter intakes were higher for the manure-fed groups. Air dried cattle manure has been successfully utilized in pullet diets and catfish diets (Durham *et al*., 1966). Digestibility studies with sheep using dried cattle feces, dried poultry feces and dried swine feces revealed similar apparent digestibilities of dry matter, but significantly lower nitrogen digestibility with the cattle feces diet when compared to the other diets tested (Tinnimit *et al*., 1972).

3. Swine waste

Anthony (1971) in summarizing animal waste research noted that the published research on the feeding of swine waste was far less extensive than for poultry waste. With the confinement of swine and resulting collection of swine wastes, the potential of this byproduct needed to be pursued. Smith (1973) noted that the nitrogen in feces from nonruminant animals should be more useful as a protein source since the digesta undergoes gastric digestion, followed by an increase in microorganisms in the lower part of the gut which escape digestion. In the case of the ruminant, the digesta undergoes a microbial fermentation followed by gastric digestion. Harmon (1974) pointed out that the nutrient analyses of swine waste change rapidly with time after excretion. He presented data showing the changes in amino acid composition of swine feces under different conditions. Early studies by Diggs, Baker and James (1965) showed that dried swine feces added at low levels (15%) to a fortified corn-soybean meal finishing diet supported similar weight gains and feed efficiency as a 14% crude protein basal diet when fed to finishing pigs. At 30% of the diet dried swine feces reduced both gains and feed efficiency. Daily feed intake of the diet containing 30% dried feces was 26% higher compared to intake of the basal diet. In balance trials using animal feces to furnish 65 to 89% of the dietary nitrogen, Tinnimit _et al_. (1972)

fed a diet containing 32% dried swine feces to sheep. Dry matter and nitrogen digestibilities were lower compared to values obtained with sheep fed diets containing soybean meal. Nitrogen retentions were similar for sheep receiving dried beef, poultry or swine feces in their diets, but all were lower compared to sheep receiving the soybean meal as the principal nitrogen source in the diet.

Illinois researchers have conducted many studies with products of the oxidation ditch. Initial studies by Harmon, Jensen and Baker (1969) and Harmon _et_ _al_. (1972b) involved the refeeding of solids collected from a swine building oxidation ditch after the liquid portion had been drained from the ditch. The oxidation ditch residue (ODR) solids were dried by spreading in a thin layer at 40 C. The latter paper by these authors describes the nutrient composition of the ODR which contained 27.7% crude protein. Results showed that the protein of ODR could replace one-third to one-half of the protein of casein or soybean meal and permit similar weight gains with weanling rats. Gain/feed ratio decreased as ODR was increased in the diets. No depression in feed intake by the addition of ODR to the diets was experienced. ODR diets were significantly lower in protein and energy digestibilities compared to a casein basal diet. The addition of lysine or tryptophan individually to a corn-ODR diet had no influence on gains while the combination of these two amino acids significantly increased gain and gain/feed. These authors suggested that these amino acids were most limiting and nearly equally limiting in the ODR diet. Baird and Young (1973) showed that dried sediment from a swine oxidation ditch that analyzed 10 to 12% crude protein and 35 to 45% crude fiber was of no value in a swine diet.

Holmes et al. (1971) have shown that most of the crude protein in the contents of an oxidation ditch are contained in the smaller sized particles. An increase in amino acid concentration was noted as particle size decreased (Harmon, 1972 and Harmon et al., 1972a). These authors noted that these data strongly suggest that single cell protein is responsible for enhancing the nutritive value of swine waste. Additional studies by the Illinois researchers (Harmon, 1972; Harmon et al., 1972a; Harmon et al., 1973a) included the collection of solids from an oxidation ditch by isolating solids from a continuous sample of liquid into an anaerobically-maintained vat. Solids were carried to the surface of the material in the vat by gases, collected, dried and fed to rats and swine as a substitute for corn or soybean meal in the diets. When substituted at levels from 10 to 30% of the diet, weight gains and feed efficiency were reduced at all levels of substitution with this anaerobically formed product.

In later studies the Illinois workers made no attempt to isolate solids from the liquid of the oxidation ditch mixed liquor (ODML). In these experiments the ODML was considered as a source of water (Harmon _et_ _al_., 1971, 1973a,b). The nutrient content of ODML is characterized by Harmon _et_ _al_. (1973b). The ODML contained approximately 3% dry matter. Amino acid concentrations as a percent of dry matter were increased as compared to the amino acid composition of ODR in previous studies. The ODML or water was mixed with a 12% crude protein corn-soybean meal fortified diet in a ratio of two parts liquid to one part feed at the time of feeding. Water was available to all groups by access to automatic waterers. For five replications, a total of 76 finishing swine were fed twice daily in open troughs. Although treatment differences were small, gain and feed efficiency values were significantly greater for pigs receiving ODML. These authors noted that protein intake and lysine intake increased approximately 3% and 0.1%, respectively, for finishing pigs receiving the ODML. No evidence of liver or lymphatic damage was found due to consumption of the ODML. In a similar study Harmon _et_ _al_. (1973a) added water or ODML to corn alone as a diet for finishing swine. Performance of the pigs was quite low and no treatment differences were observed. These workers suggested that severe amino acid deficiencies existed on both treatments. Further studies by Harmon _et_ _al_. (1973b) were conducted in which all the water available for pigs in half of the pens was provided as ODML. In these experiments the ODML was pumped from the ditch into shallow troughs for 20 seconds during every 20 minutes. The initial flow flushed out any liquid remaining in the trough, while the ODML flowing as the pump stopped remained in the trough. Control pigs had access to automatic waterers. A 12% crude protein corn-soybean meal fortified diet was available from self feeders for each treatment. Daily gain and feed efficiency were greater for pigs receiving the ODML.

E. Problems with Waste Recycling

While the main consideration for recycling animal wastes back into animal diets would be nutritional in nature, the presence of undesirable constituents in these wastes must be considered. Scott et al. (1969) pointed out several nonnutritive feed additives that pose potential problems in recycling animal waste as feed. Many of these additives have been discussed in detail according to class of animal by Smith et al. (1971). The additives of greatest concern would appear to be antibiotics, arsenicals and hormones. Messer et al. (1971) and Webb and Fontenot (1972) found residues of several common coccidiostats, antibiotics and arsenic in poultry litter from broiler operations. In experiments by these researchers where litter containing a coccidiostat was fed to steers at a level of 25 or 50% of the ration, no difference in tissue residues of the coccidiostat was found when steers were fed for either 121 or 198 days. Significant increases in liver arsenic levels were found with steers fed litter containing 17ppm arsenic (Long, Bratzler and Frear, 1969). Studies by Calvert (1973) with arsenic from arsanilic acid fed to sheep have shown that an average of 87% of the ingested arsenic was in the feces. Fontenot et al. (1971b) showed copper toxicity in ewes which were fed diets containing 25 or 50% broiler litter for 137 days. Woodside (1972) reported that when sheep were grazed on grass heavily contaminated with pig slurry from pigs fed high copper diets, no toxicity was noted although individual sheep did show abnormally high S.G.O.T. levels indicating accelerated liver cell destruction. Hedges, Kornegay and Martens (1973) noted a trend toward higher copper levels in corn plants raised on soil where liquid manure had been spread from finishing pigs receiving 250 ppm of copper in their diet. Griel, Kradel and Wickersham (1969) reported abortions in beef cows resulting from the intake of poultry litter showing excessive estrogenic activity. El Sabban et al. (1970) fed dried poultry waste to steers and noted no increase in chlorinated hydrocarbon levels in the fat of the steers. With the swine oxidation ditch, Harmon (1974) has noted a condition where nitrate levels reached 5000 ppm in the ODML. The ditch had been anaerobic for several weeks and then was aerated for a period of time without adding manure. Death losses due to nitrate toxicity were experienced with pigs consuming the liquid. This author also reported another occasion where a study was terminated prematurely due to ascarid infestation in pigs consuming ODML. This was caused from a recycling of ascarid eggs back into the pigs resulting in lung and liver damage. With proper preventative measures for internal parasites, the problem did not occur again. Ariail, Humenik and Kriz (1971) studied the effect of antibiotics and heavy metals on swine waste biodegradation. They concluded that copper had the greatest effect on microbial inhibition. Due to the feeding of high levels of copper in certain swine diets, measures would need to be taken to prevent this waste from being recycled back to the animals as a portion of the diet.

Disease problems have not been reported due to the feeding of poultry litter. Messer et al. (1971) reported that while bacteria in poultry wastes does pose a potential disease problem, mild heat treatment destroys many of the pathogens. Fontenot et al. (1971a) found that poultry litter can be sterilized by processing at 150 C for 3 hours or longer. Zindel (1970) showed that some bacteria were present after drying poultry manure, but the bacteria were not of significant importance and may indicate a recontamination after the drying process. While Meyer et al. (1971) and Robinson, Saxon and Baxter (1971) showed that Salmonella survived aerobic and anaerobic swine waste treatment for prolonged periods, the former researchers found that anaerobic digestion inactivated swine enterovirus after a period of 4 days.

The feeding of poultry wastes to ruminants has not been found to cause undesirable flavors in the meat (El Sabban et al., 1970; Fontenot et al., 1966; Fontenot et al., 1971a) or milk (Bucholtz et al., 1971; Bull and Reid, 1971; Thomas and Zindel, 1971). Flegal, Goan and Zindel (1970) showed that dried poultry feces fed to laying hens at levels up to 30% of the diet had no significant effect on the taste of the resulting eggs. Diggs et al. (1965) found no undesirable flavor with pork from finishing pigs which had received dried swine feces as a portion of the diet.

III. EXPERIMENTAL PROCEDURE

A. Introduction

Five feeding trials and two digestion trials with finishing swine were conducted to evaluate dried swine feces (DSF), dried poultry waste (DPW) and oxidation ditch liquor (ODL) as sources of nutrients in swine finisher diets. These experiments were:

Experiment 1. Feeding trial utilizing DSF in swine finisher diets.

Experiment 2. Balance trial utilizing DSF in swine finisher diets.

Experiment 3. Feeding trial utilizing DSF and DPW in swine finisher diets.

Experiment 4. Feeding trial utilizing DSF in swine finisher diets containing supplemental energy.

Experiment 5. Feeding trial utilizing ODL in swine finisher diets.

Experiment 6. Balance trial utilizing ODL in swine finisher diets.

Experiment 7. Feeding trial utilizing ODL in swine finisher diets.

The experimental animals used in these studies were Yorkshire, Hampshire and Yorkshire-Hampshire crossbred pigs

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obtained from the Michigan State University swine research herd. All pigs were randomly allotted from weight, sex and litter outcome groups to the experimental treatments.

All feeding trials were conducted in a completely enclosed, environmentally controlled building containing fully slotted floors. Floor space allotted per pig was adequate for the duration of the feeding trials. Feed was provided _ad libitum_ using self feeders in feeding trial experiments 1, 3 and 4. Animals were hand fed twice daily from troughs in experiment 5. Two lots were provided feed _ad libitum_ using self feeders with the remaining two lots being hand fed twice daily from troughs in experiment 7. All pigs in the feeding trials had free access to water during the experiment. The animals were weighed initially and biweekly thereafter with feed consumption being determined for each weight period.

The balance trials were conducted in a well ventilated metabolism area with thermostatically controlled hot water heat. The pigs were housed in individual stainless steel-lined metabolism cages. The pigs were individually fed 2 times daily an amount of feed and water which they would consume within a 5 to 10 minute period. The feed intake data were adjusted for any refused feed by drying this material to air-dryness, weighing it and subtracting this amount from the total offered. Urine was collected in 6N hydrochloric acid separate from the feces. The total amount voided was measured and a 100 ml aliquot was stored in acid-washed polyethylene bottles at 4 C for subsequent analysis. Feces were collected separately from urine by means of a fine screen placed above the collection tray. Total fecal collections were partially dried in a low temperature oven and spread on trays to air dry before being weighed, finely ground and stored in air tight polyethylene bags for analysis.

The feces for the dried swine feces (DSF) were obtained from growing-finishing swine housed at the Michigan State University Swine Farm. These feces were collected by gathering the fecal material contained on the slats of a fully slotted floored building. This procedure served to separate urine from feces and, thus, avoid the collection of feces containing high levels of urea from urine. No feces were collected from swine receiving high levels of copper in their diets. The poultry feces utilized in these studies as dried poultry waste (DPW) were collected from pullets housed in cages and fed a cage laying ration during their first year of egg production. A commercial excreta dryer[1] located at the Michigan State University Poultry Farm was used to dehydrate the swine and poultry feces used in these experiments. The moisture content of the excreta leaving the machine ranged from 5 to 15%, which

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[1]Manufactured by Allendale Industries, Inc., Allendale, Michigan.

was sufficiently low to insure safe storage. Analyses of the nutrient composition of DSF and DPW are shown in Table 1.

Concerning the studies (experiments 5, 6 and 7) involving oxidation ditch liquor (ODL), this product was collected from two similar oxidation ditches which were covered with slotted floors upon which growing-finishing swine were fed a fortified corn-soybean meal diet. The oxidation ditches had been in continuous operation for 2 years prior to the initiation of these experiments.

B. Experiments

1. Experiment 1. Feeding trial utilizing DSF in swine finisher diets.

Sixteen purebred and crossbred finishing pigs weighing 55 kg were assigned to one of the two rations shown in Table 2. One group of pigs received a corn-soybean meal finisher ration. The other group received a ration of 78% corn and 22% DSF during the first 3½ weeks of the trial and then 0.1% L-lysine and 0.1% DL-methionine were added for the remainder of the trial. The DSF used in this trial analyzed 23.9% crude protein. The amino acid composition of the DSF used in experiments 1 and 2 is presented in Table 3. In this trial and all succeeding trials the diets were formulated to attempt to meet the minimum N.R.C. (1968) dietary recommendations for finishing pigs. All pigs were fed to 80 to 100 kg final weights. One pig on the corn-DSF ration was removed after a feeding period of 18 days due to weakness and poor appetite. At the termination of the experiment

TABLE 1. Nutrient composition of dried swine feces (DSF) and dehydrated poultry waste (DPW)

Nutrient	DSF 1	DSF 2	DPW[1]
Total nitrogen, %	3.48	3.44	3.87
Protein-nitrogen, %	-	-	1.73
Non-protein-nitrogen,%	-	-	2.14
Crude protein, %	21.8	21.5	24.2
Calcium, %	2.8	2.2	7.8
Phosphorus, %	1.8	1.5	2.5
Sulfur, %	1.0	1.1	-
Potassium, %	1.2	0.9	1.9
Sodium, %	0.3	0.2	0.9
Chlorine, %	-	-	1.0
Magnesium, %	0.1	0.1	0.5
Manganese, ppm	213	141	310
Iron, ppm	513	397	2570
Zinc, ppm	432	586	423
Copper, ppm	117	98	51

[1]Analysis of DPW from Flegal and Zindel (1970).

TABLE 2. Composition of diets used in experiment 1

Ingredient	Corn-soy	Corn-DSF
Corn, shelled, ground	85.5	77.7
Soybean meal, dehulled solvent (49% CP)	11.5	-
Dried swine feces[1]	-	22.0
L-lysine (50%)	-	0.2
DL-methionine (98%)	-	0.1
Salt	0.5	-
Limestone, ground	1.0	-
Dicalcium phosphate	1.0	-
VTM premix[2]	0.5	-
	100.0	100.0
Analyses: (air-dry basis)		
Crude protein, %[3]	13.0	12.1
Lysine, %[3]	0.57	0.50
Methionine + cystine, %[3]	0.46	0.40
Calcium, %[4]	0.69	0.98
Phosphorus, %[4]	0.50	0.71
Potassium, %[4]	0.63	0.66
Sodium, %[4]	0.21	0.12
Magnesium, %[4]	0.15	0.25
Manganese, ppm[4]	54	90
Iron, ppm[4]	113	156
Zinc, ppm[4]	95	160
Copper, ppm[4]	21	30

[1]See Appendix A, Table A-1 for composition.

[2]MSU vitamin-trace mineral premix. See Appendix A, Table A-2.

[3]Calculated.

[4]Analyzed.

TABLE 3. Amino acid composition of dried swine feces (DSF)[1] - experiments 1 and 2

Amino acid	%
Lysine	1.11
Histidine	0.40
Arginine	0.67
Valine	1.04
Threonine	0.80
Methionine	0.58
Cystine	0.12
Isoleucine	1.03
Leucine	1.57
Phenylalanine	0.87
Glutamic acid	3.37
Aspartic acid	1.37
Serine	0.58
Proline	0.91
Glycine	1.51
Tyrosine	0.65
Alanine	1.14

[1]Analyzed.

4 pigs from each treatment were slaughtered at the Michigan State University Meats Laboratory. A 25 cm loin section behind the 10th rib was removed from each pig. The loin roasts were used in taste panel tests to determine flavor acceptability. The flavor tests were conducted in the Michigan State University Food Science Laboratories using a nine point hedonic scale for flavor acceptability.

2. Experiment 2. Balance trial utilizing DSF in swine finisher diets.

Three balance trials involving 4 purebred and crossbred barrows averaging 78 to 90 kg body weight were conducted to determine the digestibility of nutrients, nitrogen balance and mineral balance for the diets presented in Table 4. The diets tested were corn-soybean meal grower, corn-DSF finisher and corn-DSF finisher containing additional lysine and methionine. Four-day collection periods were conducted with the first two diets while a three-day collection period was conducted with the corn-DSF plus lysine and methionine diet. The pigs were offered 1 kg of feed and 1 l of water twice daily during the course of the collection period. At least a five-day adjustment period on the test diet preceded each collection period.

3. Experiment 3. Feeding trial utilizing DSF and DPW in swine finisher diets.

Thirty-two purebred and crossbred finishing pigs averaging 68 kg body weight were assigned to one of the four rations shown in Table 5. Ration 1 was a conventional 13%

TABLE 4. Composition of diets used in experiment 2

Ingredient	Corn-soy grower	Corn-DSF	Corn-DSF + .1% Lys + .1% Met
Corn, shelled, ground	79.0	78.0	77.7
Soybean meal, dehulled solvent (49% CP)	18.0	-	-
Dried swine feces[1]	-	22.0	22.0
L-lysine (50%)	-	-	0.2
DL-methionine (98%)	-	-	0.1
Salt	0.5	-	-
Limestone, ground	1.0	-	-
Dicalcium phosphate	1.0	-	-
VTM premix[2]	0.5	-	-
	100.0	100.0	100.0
Analyses: (air-dry basis)			
Crude protein, %[4]	14.8	11.2	12.3
Lysine, %[3]	0.76	0.40	0.50
Methionine + cystine, %[3]	0.53	0.30	0.40
Gross energy, kcal/kg[4]	3861	3842	3911
Ether extract, %[4]	3.24	4.95	4.95
Ash, %[4]	4.02	4.94	4.91
Calcium, %[4]	0.69	1.09	0.99
Phosphorus, %[4]	0.51	0.71	0.71
Potassium, %[4]	0.75	0.64	0.66
Sodium, %[4]	0.22	0.11	0.12
Magnesium, %[4]	0.15	0.26	0.25
Manganese, ppm[4]	57	89	87
Iron, ppm[4]	100	156	156
Zinc, ppm[4]	96	138	147
Copper, ppm[4]	20	33	33

[1]See Appendix A, Table A-1.

[2]See Appendix A, Table A-2.

[3]Calculated.

[4]Analyzed.

TABLE 5. Composition of diets used in experiment 3

Ingredient	Ration 1	Ration 2	Ration 3	Ration 4
Corn, shelled, ground	85.5	70.3	75.0	75.0
Soybean meal, dehulled solvent (49% CP)	11.5	9.2	4.0	4.0
Dried swine feces	-	-	-	20.0
Dried poultry waste[1]	-	20.0	20.0	-
Salt	0.5	-	-	0.5
Limestone, ground	1.0	-	-	-
Dicalcium phosphate	1.0	-	-	-
VTM premix[2]	0.5	0.5	-	0.5
Vit., Zn, Met premix[3]	-	-	1.0	-
	100.0	100.0	100.0	100.0
Analyses: (air-dry basis)				
Crude protein, %[5]	12.8	14.3	12.2	11.5
Lysine, %[4]	0.57	0.54	0.38	0.50
Methionine + cystine, %[4]	0.46	0.41	0.48	0.43
Gross energy, kcal/kg[5]	3850	3610	3820	3860
Ether extract, %[5]	3.46	3.51	3.38	4.78
Ash, %[5]	3.30	6.14	5.59	6.01
Calcium, %[5]	0.67	1.41	1.40	1.16
Phosphorus, %[5]	0.52	0.78	0.74	0.80
Potassium, %[5]	0.61	0.90	0.75	0.65
Sodium, %[5]	0.23	0.14	0.15	0.30
Magnesium, %[5]	0.14	0.22	0.21	0.26
Manganese, ppm[5]	47	91	56	120
Iron, ppm[5]	92	145	135	198
Zinc, ppm[5]	111	152	161	199
Copper, ppm[5]	19	24	10	37

[1]See Appendix A, Table A-3 for composition.

[2]See Appendix A, Table A-2 for composition.

[3]See Appendix A, Table A-4 for composition.

[4]Calculated.

[5]Analyzed.

crude protein corn-soybean meal finisher. Ration 2 was essentially 80% of ration 1 plus 20% DPW. Ration 3 was a corn-limited soy-20% DPW ration plus a vitamin-zinc-methionine premix. Ration 4 was a corn-limited soy-20% DSF diet plus salt and the vitamin-trace mineral premix. The length of the feeding trial was 28 days. The purpose of this experiment was to evaluate the performance of finishing pigs as affected by the source of nutrients in the ration.

4. <u>Experiment 4</u>. <u>Feeding trial utilizing DSF in swine finisher diets containing supplemental energy</u>

A 28-day feeding trial was conducted using 8 purebred and crossbred finishing pigs with an initial average body weight of 58 kg. This trial was conducted to evaluate a diet consisting of corn, limited soy, 20% DSF and containing 4% corn oil to improve the energy density of the diet compared to a corn-soy finisher control diet (Table 6). Flegal and Zindel (1970) showed an improvement in weight gains and feed efficiency with broiler-type chicks fed a ration containing 20% DPW plus supplemental fat as compared to a similar diet which did not contain added fat. Supplemental vitamin E was added to the diet containing 4% corn oil.

5. <u>Experiment 5</u>. <u>Feeding trial utilizing ODL in swine finisher diets</u>

Sixteen purebred and crossbred finishing pigs weighing 65 kg were assigned to one of the two diets shown in Table 7. One group (1) received a conventional corn-soy

TABLE 6. Composition of diets used in experiment 4

Ingredient	Corn-soy	Corn-DSF-soy + supp. fat
Corn, shelled, ground	85.5	58.0
Soybean meal, dehulled, solvent (49% CP)	11.5	10.0
Dried swine feces	-	20.0
Corn oil	-	4.0
Corn sugar	-	5.0
Limestone, ground	1.0	0.5
Dicalcium phosphate	1.0	0.5
Salt	0.5	0.5
Vitamin E[1]	-	1.0
VTM premix[2]	0.5	0.5
	100.0	100.0
Analyses: (air-dry basis)		
Crude protein, %[4]	12.0	14.2
Lysine, %[3]	0.57	0.68
Methionine + cystine, %[3]	0.46	0.55
Gross energy, kcal/kg[4]	3890	3910
Ether extract, %[4]	3.30	7.95
Ash, %[4]	3.41	6.13
Calcium, %[4]	0.66	1.46
Phosphorus, %[4]	0.49	0.76
Potassium, %[4]	0.59	0.80
Sodium, %[4]	0.19	0.30
Magnesium, %[4]	0.14	0.25
Manganese, ppm[4]	50	124
Iron, ppm[4]	86	207
Zinc, ppm[4]	85	178
Copper, ppm[4]	17	31

[1]Contained 4400 IU of vitamin E per kg of premix.

[2]See Appendix A, Table A-2 for composition.

[3]Calculated.

[4]Analyzed.

TABLE 7. Composition of dry feed used in experiments 5, 6 and 7 with water or ODL

Ingredient	Corn-soy finisher	Corn-limited soy finisher
Corn, shelled, ground	85.5	90.5
Soybean, meal, dehulled solvent (49% CP)	11.5	9.0
Limestone, ground	1.0	-
Dicalcium phosphate	1.0	-
Salt	0.5	-
VTM premix[1]	0.5	-
Vit. A,D, E premix[2]	-	0.5
	100.0	100.0
Analyses: (air-dry basis)		
Crude protein, %[4]	13.0	12.4
Lysine, %[3]	0.57	0.50
Methionine + cystine, %[3]	0.46	0.40
Gross energy, kcal/kg[4]	3867	3924
Ether extract, %[4]	3.59	3.66
Ash, %[4]	3.59	1.71
Calcium, %[4]	0.68	0.08
Phosphorus, %[4]	0.51	0.31
Potassium, %[4]	0.57	0.56
Sodium, %[4]	0.24	0.02
Magnesium, %[4]	0.15	0.11
Manganese, ppm[4]	46	11
Iron, ppm[4]	118	42
Zinc, ppm[4]	96	28
Copper, ppm[4]	17	8

[1]See Appendix A, Table A-2 for composition.

[2]Supplied 660,000 IU of vitamin A, 132,000 IU of vitamin D_2 and 4,400 IU of vitamin E per kg of premix.

[3]Calculated.

[4]Analyzed.

finisher fortified with vitamins and minerals, while the other group (2) received a diet containing corn, limited soy and fortified with vitamins A,D and E. Pigs on the conventional corn-soy finisher diet received equal parts (weight basis) of the feed and water. Pigs on the corn-limited soy diet received equal parts (weight basis) of the feed and ODL. Each lot was fed twice daily on a group basis using troughs. ODL was pumped from the west oxidation-ditch at each feeding to be mixed with the corn-limited soy diet. The nutrient composition and amino acid composition of ODL are presented in Tables 8 and 9, respectively. One pig on the corn-limited soy, plus ODL diet was removed 13 days after the initiation of the experiment due to listlessness and poor appetite. Duration of this experiment was 49 days.

6. Experiment 6. Balance trial utilizing ODL in swine finisher diets

Six crossbred barrows with an average body weight of 93 kg were utilized in a double reversal designed balance trial to determine the digestibility of nutrients, nitrogen balance and mineral balance for the diets presented in Table 7. The diets were as described in experiment 5. Three-day collection periods were utilized with at least a seven-day adjustment period on the test diet preceding the collection. The pigs were offered 1 kg of feed and 1 kg of water or ODL, depending on the test diet, twice daily during the course of the collection period. Water was provided to each group between feedings in the feeding trough connected to the metabolism cage.

7. Experiment 7. Feeding trial utilizing ODL in swine finisher diets

Upon completion of experiment 5, it was concluded that the diets of that experiment should also be fed to pigs using self feeders without adding water or ODL to the respective diets presented in Table 7. This would make possible the determination of feed intake on *ad libitum* feeding of the diets and the determination of animal performance on the given diets with no water or ODL addition. Therefore, 32 finishing pigs were assigned to one of four lots in experiment 7. Average initial weight of the pigs was 65 kg. The trial lasted 49 days. Lot 1 was similar to lot 1 in experiment 5 with the pigs being fed the conventional corn-soy finisher plus water. Lot 2 was similar to lot 2 in experiment 5 using the corn-limited soy plus ODL on an equal weight basis. Lots 1 and 2 were fed twice daily from troughs. Lot 3 was fed the conventional corn-soy finisher only, using a self feeder. Lot 4 received the corn-limited soy finisher diet from a self feeder. Additional water was available *ad libitum* for each lot.

C. Chemical Analyses

1. Feed and feces

Feed samples were ground twice through a screen with 2 mm diameter openings in a Wiley mill.[1] Prior to and after

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[1]Thomas-Wiley Mill, Model ED-5, Arthur H. Thomas Co., Philadelphia, Pa.

TABLE 8. Nutrient composition of ODL[1]

Item	East ditch	West ditch
Dry matter, %	2.20	2.42
Crude protein, %	0.54	0.59
Crude protein (freeze dried), %[2]	24.47	24.22
Gross energy (freeze dried), kcal/kg[2]	-	2492
Ether extract (freeze dried), %[2]	-	2.68
Ash (freeze dried), %[2]	-	29.49
Calcium, %	0.08	0.10
Phosphorus, %	0.07	0.09
Potassium, %	0.09	0.08
Sodium, %	0.05	0.06
Magnesium, %	0.03	0.04
Manganese, ppm	10	14
Iron, ppm	25	29
Zinc, ppm	14	13
Copper, ppm	6	2

[1]Analyzed.

[2]Contained 10% moisture.

TABLE 9. Amino acid composition of oxidation ditch liquor[1]

	East ditch, %		West ditch, %	
Amino acid	Liquid	Freeze-dried[2]	Liquid	Freeze-dried[2]
Lysine	.035	1.57	.040	1.64
Histidine	.015	0.70	.017	0.69
Arginine	.028	1.26	.040	1.64
Threonine	.026	1.18	.030	1.25
Cystine	.007	0.31	.008	0.32
Valine	.042	1.90	.044	1.83
Methionine	.013	0.59	.014	0.60
Isoleucine	.035	1.61	.035	1.47
Leucine	.045	2.06	.053	2.20
Tyrosine	.019	0.87	.022	0.89
Phenylalanine	.035	1.58	.042	1.73

[1]Analyzed.

[2]Contained 10% moisture.

grinding they were stored in air-tight polyethylene bags at 4 C.

Feces were ground with a hand grist mill[1] following air drying on trays. They were again ground once through a 2 mm diameter screen in a Wiley mill. The samples were stored in the same manner as the feed samples.

[1]Quaker City Mill, Philadelphia, Pa.

Crude protein was determined by a semi-micro Kjeldahl technique. Dry matter was determined by drying in a vacuum oven for 16 hours at 90 C. Gross energy was determined by the use of a Parr adiabatic oxygen bomb calorimeter.[1] Ether extract was performed using a dried sample and extracting with anhydrous ethyl ether for 6 hours in a Goldfisch Fat Extractor.[2] Dry, fat free samples were ashed in a muffle furnace at 600 C for 18 hours.

The distribution of amino acids in the DSF and ODL was determined on acid hydrolysates by resin column chromatography. About 10 mg of the purified protein was weighed into 25 ml screw-cap (teflon-lined) tubes together with norleucine as an internal standard. The sealed tubes were autoclaved at 121 C for 16 hours to hydrolyze the protein. Thereafter, the tube contents were filtered through No. 1 Whatman paper and HCl was removed from the filtrate by successive evaporations in a flash evaporator. The residual amino acids were dissolved in a buffer of pH 2.0 composed of 0.3 N lithium hydroxide and 0.05 M citrate, and then applied to the amino acid analyzer[3] as described by Makdani, Huber, and Bergen (1971).

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[1]Parr Corp., Moline, Ill.

[2]Laboratory Construction Co., Kansas City, Mo.

[3]TSM-1 Amino acid analyzer, Technicon Corp., Tarrytown, N.Y.

Approximately 1 gm of air dry feed and 0.5 gm of air dry feces were digested first in 60 ml of concentrated nitric acid and second in 8 ml of concentrated perchloric acid in a wet ashing procedure for mineral analyses. The samples were previously weighed into an acid-washed 250 ml Phillips beaker. The first digestion was heated on a hot plate to near dryness and cooled. In the second digestion the contents were protected from excessively rapid evaporation by a small watch glass. The samples were heated again to near dryness, cooled and diluted to volume with deionized, distilled water. Standards were prepared in a like manner. All minerals except phosphorus were determined using an Instrumentation Laboratories, Inc.,[1] Model 453 atomic absorption spectrophotometer. Sodium and potassium were measured using emission spectrophotometry with the instrument set at wavelengths of 589.0 nm and 766.5 nm, respectively, for these two minerals. Other minerals measured by atomic absorption spectrophotometry and their respective wavelengths (nm) were: calcium, 422.7; copper, 324.7; iron, 248.3; magnesium, 285.2; manganese, 279.5; zinc, 213.9. Samples analyzed for calcium and magnesium were diluted with 10,000 ppm strontium chloride to suppress phosphate interference. All phosphorus determinations were made by the

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[1]Instrumentation Laboratories, Inc., Lexington, Mass.

colorimetric method of Gomorri (1942). The optical density was determined on a Coleman Junior II spectrophotometer[1] at 700 nm following a 45-minute incubation period.

2. Urine.

Urinary nitrogen was determined by the semi-micro Kjeldahl method. Urinary energy was determined by drying the sample and then burning the sample with the Parr adiabatic oxygen bomb calorimeter. Twenty milliliters of urine were pipetted into a 250 ml Phillips beaker and mineral digests were prepared as described previously utilizing 30 ml of concentrated nitric acid and 4 ml of 72% perchloric acid. The method and specifications of mineral determinations were as described previously.

D. Statistical Analyses

All data from the experiments were subjected to analysis of variance on a CDC[2] 6500 computer at the Michigan State University Computer Laboratory Center. The only exception to this was the taste panel test which was subjected to least squares analysis on a CDC 3600 computer at the same location. Treatment differences within experiments were determined by the multiple range test of Duncan (1955).

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[1]Coleman Instruments Corp., Maywood, Ill.

[2]Control Data Corp., Minneapolis, Minn.

IV. RESULTS AND DISCUSSION

A. Experiment 1: Feeding trial utilizing DSF in swine finisher diets.

Pig performance and taste panel data are presented in Table 10. The corn-DSF ration was formulated such that DSF would provide supplemental protein, minerals and vitamins to the grain portion of the diet. During the first 24 days of the trial, the corn-soy group gained significantly faster ($P<0.05$) than the corn-DSF group. An amino acid analysis of the DSF after the initiation of the trial indicated that additional lysine and methionine were required to bring the corn-DSF ration up to N.R.C. minimum requirements for these amino acids. On day 24 of the trial, 0.1% L-lysine and 0.1% DL-methionine were added to the corn-DSF ration for the remainder of the trial. Average daily gain for the period of day 24 to day 65 significantly ($P<0.05$) favored the corn-soy treatment. Body weight after 24 days was significantly greater for the corn-soy group ($P<0.05$). Overall performance indicated that the corn-DSF pigs ate well, with feed intake being 93% of that of the corn-soy group. Final body weight and overall average daily gain were significantly higher in the corn-soy group ($P<0.01$), which differs from the results of Diggs et al. (1965) who showed similar gains with or without 15% DSF additions to a

TABLE 10. Summary of pig performance and taste panel test from experiment 1

Item	Corn-soy ration	Corn-DSF ration	
No. of pigs	8	7	±SE[1]
Initial weight, kg	55.4	54.3	1.36
24 day weight, kg[2]	72.9[a]	65.2	2.34
Final weight, kg	99.2[aa]	82.0	4.03
0-24 day ADG, kg	0.73[a]	0.45	0.07
24-65 day ADG, kg	0.64[a]	0.41	0.06
0-65 day ADG, kg	0.67[aa]	0.43	0.05
Avg. daily feed, kg	2.25	2.10	
Feed/gain	3.36	4.88	
Taste panel score[3]	7.15	6.95	0.06

[1]Standard error of the mean.

[2]Time of supplemental amino acid additions to the corn-DSF diet.

[3]Flavor test: 1 = dislike extremely, 9 = like extremely.

[a]Significantly greater than least value ($P<0.05$);

[aa]$P<0.01$.

basal ration. It should be pointed out, however, that Diggs et al. (1965) fed 15% DSF in a complete ration, whereas in the present study the diet consisted of 22% DSF and 78% corn. Feed efficiency was much poorer with the corn-DSF group. These results are similar to those obtained by Harmon (1972), Harmon et al.(1972a) and Harmon et al. (1973a) when feeding an anaerobically-maintained waste to rats and swine. They also experienced reduced gains and feed efficiency at substitution rates of 10 to 30% of the diet.

Taste panel tests of flavor acceptability revealed no significant differences using loin roasts from pigs of both treatment groups. This would substantiate earlier reports by Diggs et al. (1965) that the DSF imparts no undesirable flavor to the meat, as determined by a taste panel.

B. Experiment 2: Balance trial utilizing DSF in swine finisher diets.

Analyses of the diets fed in this balance study revealed that the corn-DSF diets contained higher levels of calcium, phosphorus, magnesium, manganese, iron, zinc and copper than the corn-soy diet, whereas the latter was higher in sodium and potassium levels (Table 4).

Data from the balance trial (Table 11) indicate significantly higher daily fecal output ($P<0.01$) from the two corn-DSF diets than from the corn-soy diet. Daily urine output was significantly greater ($P<0.01$) for the pigs receiving the corn-DSF diet with supplemental amino acids than for those on the corn-soy diet. Daily urine

TABLE 11. Summary of balance trial in experiment 2

Item	Corn-soy	Corn-DSF	Corn-DSF +.1% Lys +.1% Met	
No. of pigs	4	4	4	±SE[1]
Daily feed intake, g	1930	1929	1975	33
Daily feces, g	194	426[aa]	394[aa]	21
Daily urine, ml	1085	1553[a]	1630[aa]	105
Ca balance, daily[2]				
Ca intake, g	13.23	21.08[bb]	19.49[aa]	0.27
Fecal Ca, g	6.89	13.16[aa]	13.19[aa]	0.71
Fecal Ca, %	52	62	68[a]	4
Urinary Ca, g	0.16	0.17	0.29[b]	0.03
Urinary Ca, %	1.2	0.8	1.5[a]	0.2
Ca retention, g	6.18	7.76	6.01	0.72
Ca retention, %	47[a]	37	31	4
Ca apparent digest, %	48[a]	38	32	4
P balance, daily[2]				
P intake, g	9.77	13.74[aa]	14.05[aa]	0.19
Fecal P, g	5.10	8.63[aa]	8.50[aa]	0.41
Fecal P, %	52	63	61	3
Urinary P, g	0.25	0.69[aa]	0.61[aa]	0.06
Urinary P, %	3	5[a]	4[a]	0.5
P retention, g	4.42	4.42	4.94	0.35
P retention, %	45[b]	32	35	3
P apparent digest, %	48	37	39	3
Na balance, daily[2]				
Na intake, g	4.22[bb]	2.09	2.36[a]	0.06
Fecal Na, g	0.49	0.63	0.71	0.07
Fecal Na, %	12	30[aa]	30[aa]	3
Urinary Na, g	2.58[bb]	1.13	1.09	0.21
Urinary Na, %	61	54	46	5
Na retention, g	1.15[aa,b]	0.33	0.56	0.14
Na retention, %	27	16	24	5
Na apparent digest, %	88[bb]	70	70	3

[1]Standard error of the mean.

[2]All percent values are in relation to intake.

[a]Significantly greater than least value ($P<0.05$); [aa]$P<0.01$.

[b]Significantly greater than least two values ($P<0.05$); [bb]$P<0.01$.

TABLE 11. (Continued . . . .)

Item	Corn-soy	Corn-DSF	Corn-DSF +.1% Lys +.1% Met	
No. of pigs	4	4	4	±SE[1]
K balance, daily[2]				
K intake, g	14.42[bb]	12.30	13.03	0.24
Fecal K, g	2.72	4.12[aa]	4.47[aa]	0.11
Fecal K, %	19	33[aa]	34[aa]	1
Urinary K, g	2.37	3.05	3.62[aa]	0.23
Urinary K, %	16	25[aa]	28[aa]	2
K retention, g	9.32[bb]	5.13	4.94	0.27
K retention, %	65[bb]	42	38	2
K apparent digest, %	81[bb]	67	66	1
Mg balance, daily[2]				
Mg intake, g	2.96	5.05[aa]	4.92[aa]	0.06
Fecal Mg, g	1.86	3.55[aa]	3.37[aa]	0.15
Fecal Mg, %	63	70	68	3
Urinary Mg, g	0.23	0.49[aa]	0.52[aa]	0.03
Urinary Mg, %	8	10	11	1
Mg retention, g	0.87	1.01	1.03	0.11
Mg retention, %	29[b]	20	21	2
Mg apparent digest, %	37	30	32	3
Fe balance, daily[2]				
Fe intake, mg	193.72	301.37[aa]	308.65[aa]	3.96
Fecal Fe, mg	133.97	257.29[bb]	213.19[aa]	8.56
Fecal Fe, %	69	85[bb]	69	3
Urinary Fe, mg	2.31[a]	1.42	2.49[a]	0.28
Urinary Fe, %	1.2[a]	0.5	0.8	0.1
Fe retention, mg	57.44	42.66	92.97[aa,b]	8.93
Fe retention, %	30[aa]	14	30[aa]	3
Fe apparent digest, %	31[aa]	15	31[aa]	3

[1]Standard error of the mean.

[2]All percent values are in relation to intake.

[a]Significantly greater than least value ($P<0.05$); [aa]$P<0.01$.

[b]Significantly greater than least two values ($P<0.05$); [bb]$P<0.01$).

TABLE 11. (Continued . . . .)

Item	Corn-soy	Corn-DSF	Corn-DSF +.1% Lys +.1% Met	
No. of pigs	4	4	4	±SE[1]
Zn balance, daily[2]				
Zn intake, mg	185.02	266.05[aa]	291.17[bb]	3.65
Fecal Zn, mg	116.16	256.31[aa,b]	225.29[aa]	8.66
Fecal Zn, %	63	96[bb]	77[aa]	3
Urinary Zn, mg	4.01	2.89	3.14	0.68
Urinary Zn, %	2.2[b]	1.1	1.1	0.29
Zn retention, mg	64.85[aa]	6.86	62.75[aa]	8.57
Zn retention, %	35[aa,b]	3	22[aa]	3
Zn apparent digest, %	37[bb]	4	23[aa]	3
Mn balance, daily[2]				
Mn intake, mg	110.23	172.11[aa]	172.46[aa]	2.25
Fecal Mn. mg	92.24	166.10[bb]	132.74[aa]	5.02
Fecal Mn, %	84	97[aa,b]	77	3
Urinary Mn, mg	1.46	1.27	1.37	0.29
Urinary Mn, %	1.3	0.7	0.8	0.2
Mn retention, mg	16.53	4.74	38.35[bb]	4.32
Mn retention, %	15[a]	3	22[aa]	3
Mn apparent digest, %	16[a]	3	23[aa]	3
Cu balance, daily[2]				
Cu intake, mg	36.15	64.42[aa]	64.32[aa]	1.10
Fecal Cu, mg	24.50	51.85[aa]	55.98[aa]	1.80
Fecal Cu, %	68	80[a]	87[aa]	3
Urinary Cu, mg	1.70	3.15	2.14	0.38
Urinary Cu, %	5	5	3	1
Cu retention, mg	9.95	9.43	6.21	1.83
Cu retention, %	27[aa,b]	15[a]	10	3
Cu apparent digest, %	32[aa,b]	20	13	3

[1]Standard error of the mean.

[2]All percent values are in relation to intake.

[a]Significantly greater than least value (P<0.05); [aa]P<0.01.

[b]Significantly greater than least two values (P<0.05); [bb]P<0.01.

TABLE 11. (Continued . . .)

Item	Corn-soy	Corn-DSF	Corn-DSF +.1% Lys +.1% Met	±SE[1]
No. of pigs	4	4	4	
N balance, daily[6]				
N intake,g	45.65[bb]	34.33	38.71[aa]	0.74
Fecal N,g	5.91	11.77[aa]	10.57[aa]	0.49
Fecal N,%	13	34[bb]	27[aa]	1
Urinary N,g	16.12	13.30	13.72	0.77
Urinary N,%	35	39	36	2
N retention,g	23.62[bb]	9.27	14.42[aa]	0.57
N retention,%	52[bb]	27	37[aa]	2
N apparent digest,%	87[bb]	66	73[aa]	1
Biological value,app.	59[aa,b]	41	51[a]	2
Net protein utilization, app.	52[bb]	27	37[aa]	2
Dry matter balance,daily[6]				
DM intake,g	1679	1688	1727	29
Fecal DM,g	182	391[aa]	351[aa]	18
Fecal DM,%	11	23[aa]	20[aa]	1
DM apparent digest,%	89[bb]	77	80	1
Energy balance,daily[6]				
Energy intake,kcal[2]	7453	7410	7724	128
Fecal energy,kcal	872	1884[aa]	1673[aa]	88
Urinary energy,kcal	113	104	140	21
Digestible energy, kcal[3]	6581[bb]	5526	6051[aa]	98
Digestible energy,%	88[bb]	75	78[a]	1
Metabolizable energy, kcal[4]	6468[bb]	5422	5911[aa]	92
Metabolizable energy,%	87[bb]	73	77[a]	1
N-corrected ME,kcal[5]	6292[bb]	5353	5804[aa]	88
N-corrected ME, %	84[bb]	72	75[a]	1

[1]Standard error of the mean.

[2]Gross energy, kcal/kg = 3862, 3841, 3911, respectively.

[3]DE, kcal/kg = 3410, 2865, 3064, respectively.

[4]ME, kcal/kg = 3351, 2811, 2993, respectively.

[5]N-corr. ME, kcal/kg = 3260, 2775, 2939, respectively.

[6]All percent values are in relation to intake.

[a]Significantly greater than least value ($P<0.05$); [aa]$P<0.01$.

[b]Significantly greater than least two values ($P<0.05$); [bb]$P<0.01$.

volume was significantly higher (P<0.05) with pigs on the corn-DSF treatment than for those receiving corn-soy.

The higher calcium level of the DSF diets resulted in significantly higher dietary calcium intake (P<0.01) for the DSF groups than the corn-soy group. In turn, this resulted in higher absolute fecal calcium excretion (P<0.01) and reduced absorption (P<0.05) with the corn-DSF diets as compared to the corn-soy diets. Urinary calcium excretion was small for all treatments in terms of absolute or relative excretion levels. Although calcium retention relative to intake was significantly greater (P<0.05) for the corn-soy diet as compared to the corn-DSF diet with supplemental amino acids, due to the lower calcium intake level of the corn-soy diet, absolute calcium retention was similar for all three dietary treatments.

The daily phosphorus balance (Table 11) followed a somewhat similar pattern to that of calcium balance for all treatments. Daily phosphorus intake and absolute fecal excretion were significantly higher (P<0.01) for the pigs on the two DSF diets. However, phosphorus relative absorption and relative fecal excretion were somewhat similar for all treatments. Relative urinary phosphorus excretion was significantly higher (P<0.05) with the DSF diets. Absolute phosphorus retentions were similar for all diets, although phosphorus retention relative to intake was higher for the corn-soy diet (P<0.05).

The daily magnesium balance (Table 11) indicates a similar pattern of absorption and retention as was found for calcium and phosphorus. The lower absorption and relative retention values for Mg with the DSF diets may be a reflection of the higher calcium and phosphorus levels of these diets, which are known to decrease magnesium absorption or increase excretion (O'Dell, 1960). Absolute magnesium retentions of all three diets were similar.

While the sodium levels of the DSF diets (Table 4) analyzed only slightly half or more of the level contained in the corn-soy diet, the sodium levels of the former diets were of the same magnitude as the sodium in the optimum dietary salt level of 0.30% which Hagsten and Perry (1974) found for growing swine. The low sodium levels found in DSF diets are due to the separation of the urine (which contains high levels of sodium) from the feces at the time of harvesting the solid excreta prior to drying. As a result of the above, sodium intake (Table 11) on the corn-soy diet was significantly greater ($P<0.01$) than from the DSF diets. Sodium apparent digestibility was significantly higher ($P<0.01$) on the corn-soy diet, as was absolute sodium retention, when compared to the DSF diets. Sodium retention relative to intake was similar for all three diets.

While potassium intake (Table 11) was significantly greater ($P<0.01$) with the corn-soy diet, fecal and urinary potassium excretions were significantly greater ($P<0.01$) on the DSF diets. As a result, apparent digestibility, absolute and relative retention of potassium were significantly higher (P<0.01) on the corn-soy diet.

Much more variation between treatments occurred in the iron, zinc and manganese balance studies (Table 11). Although a similar pattern of absorption and retention of these minerals was noted for each diet, the most obvious difference appeared to be the improvement in apparent digestibility and retention of these minerals with the addition of the supplemental amino acids to the corn-DSF diet.

Copper intake was significantly higher (P<0.01) from the DSF diets (Table 11). With this mineral, the apparent digestibility and relative retention were not improved with the additional amino acids to the DSF diet, but these parameters were actually slightly decreased. Absolute copper retention was similar for all diets.

Regarding the mineral balance studies, it is quite evident that the utilization of these minerals was variable in many cases among the diets. The corn-soy diet did utilize a trace mineral premix which contained mineral forms of known acceptable availability. No trace mineral premix was added to the DSF diets due to the high mineral content of the DSF. However, these minerals contained in DSF may not all be in highly available forms, which would ultimately affect their absorption and utilization by the pig. Some mineral levels in DSF are in excess and this would, in turn, affect utilization of other interrelated minerals.

Nitrogen balance was affected by diet. Nitrogen apparent digestibility, absolute retention and relative retention were significantly higher ($P<0.01$) in the corn-soy diet as compared to the two DSF diets. The corn-DSF with supplemental amino acids was significantly higher ($P<0.01$) in these same parameters as compared to the corn-DSF diets. Apparent biological value and apparent net protein utilization were significantly higher ($P<0.01$) in the corn-soy diet as compared to the corn-DSF diet. The corn-DSF with supplemental amino acids was significantly higher in apparent biological value ($P<0.05$) and apparent net protein utilization ($P<0.01$) as compared to the corn-DSF diet.

Apparent biological value (ABV) and apparent net protein utilization (ANPU) were determined by the following formulas:

$$\text{ABV} = \frac{\text{N intake} - (\text{fecal N} + \text{urinary N})}{\text{N intake} - \text{fecal N}} \times 100$$

$$\text{ANPU} = \frac{\text{N intake} - (\text{fecal N} + \text{urinary N})}{\text{N intake}} \times 100$$

$$\text{or} = \text{App. Dig. of N} \times \text{ABV}$$

Dry matter balance indicated a significantly higher ($P<0.01$) apparent digestibility of dry matter for the corn-soy diet as compared to the DSF diets. There was a direct relationship in results of the energy balance as compared to the nitrogen balance with the respective diets. Digestible

energy, metabolizable energy and nitrogen-corrected metabolizable energy were significantly higher ($P<0.01$) for the corn-soy diet as compared to the two DSF diets. The corn-DSF diet containing supplemental lysine and methionine had significantly higher absolute ($P<0.01$) and relative ($P<0.05$) levels of these same energy classifications as compared to the corn-DSF diet.

C. Experiment 3: Feeding trial utilizing DSF and DPW in swine finisher diets.

Pig performance data are presented in Table 12. Pigs on ration 2 (80% basal plus 20% DPW) consumed 15% less average daily feed than those on ration 1 (corn-soy basal), whereas feed efficiency on ration 2 was 82% relative to the feed efficiency of ration 1. Average daily gain was significantly higher ($P<0.01$) on ration 1 compared to ration 2, with average final weight being slightly higher on the former diet. Both elevated dietary calcium and a possible subminimal level of methionine plus cystine in ration 2 may have contributed to the poor performance of ration 2. Although the calcium to phosphorus ratio of ration 2 was slightly less than 2:1, absolute calcium level of this diet was well over 1% of the diet. This high calcium level of ration 2 results from the high calcium content of the DPW that originated from caged layers, which are fed high calcium diets for egg production.

Rations 3 and 4 were similar in ingredient make-up by having a corn-limited soy base, except that ration 3 contained 20% DPW and ration 4 contained 20% DSF. Average daily gain on ration 1 was significantly higher (P<0.01) than on ration 3 or ration 4. Average daily feed intake of ration 3 and ration 4 were 79% and 91%, respectively, relative to ration 1 and feed efficiency of the DPW and DSF rations was very poor compared to ration 1. Pigs on ration 3 had the poorest performance in this trial, which was probably due to the high dietary calcium and low dietary lysine.

TABLE 12. Summary of pig performance from experiment 3

Item	Ration 1 Corn-soy basal	Ration 2 80% basal +20% DPW	Ration 3 Corn-DPW + lim.soy	Ration 4 Corn-DSF + lim.soy	
No. of pigs	8	8	8	8	±SE[1]
Initial weight,kg	68.0	67.7	68.1	68.7	1.58
Final weight,kg	85.7	80.1	77.8	80.4	2.30
Avg. daily gain, kg	0.66[aa]	0.46	0.36	0.43	0.05
Avg. daily feed, kg	2.44	2.08	1.92	2.21	
Feed/gain	3.70	4.52	5.33	5.13	

[1]Standard error of the mean.

[aa]Significantly greater than all other values (P<0.01).

Poor performance of pigs on ration 4 was most likely due to the elevated calcium and marginal methionine plus cystine level of the diet. Poor availability of other amino acids in DSF may also have been a factor.

Pig performance on ration 2 followed the same trend as reported by Perez-Aleman et al. (1971) when DPW was included as an addition to a conventional diet. These researchers experienced depressed gains and feed efficiency with DPW additions, although these depressions were of a smaller magnitude than was the case with pigs on ration 2.

D. Experiment 4: Feeding trial utilizing DSF in swine finisher diets containing supplemental energy.

Pig performance data are presented in Table 13. The corn-DSF-soy diet in this experiment contained supplemental corn oil along with being fortified with dicalcium phosphate, ground limestone, salt and vitamin-trace mineral premix. Average daily gain and final weight slightly favored the corn-soy control diet over the corn-DSF diet, although these differences were not statistically significant nor did they approach significance. The average daily feed intakes were similar for the two diets. Feed efficiency of the corn-DSF was 9.5% poorer than that obtained with the control diet.

Although daily gains, feed intake and feed efficiency for the DSF group were slightly lower as compared to the control diet, the former shows definite improvement over

TABLE 13. Summary of pig performance from experiment 4

Item	Corn-soy	Corn-DSF-soy + supp. fat	
No. of pigs	4	4	±SE[1]
Initial weight, kg	58.2	57.7	1.44
Final weight, kg	78.3	75.0	2.42
Avg. daily gain, kg	0.72	0.62	0.09
Avg. daily feed, kg	2.47	2.35	
Feed/gain	3.43	3.79	

[1]Standard error of the mean.

results of previous feeding trials using DSF diets without corn oil. The addition of supplemental energy to these diets containing DSF to restore the concentration of digestible energy should improve pig performance on these diets. It should be noted that the DSF diet in this trial did contain improved levels of lysine and methionine plus cystine, but it also had an elevated level of calcium due to the addition of dicalcium phosphate and limestone to the diet. The results of experiment 4 are consistent with those reported by Flegal and Zindel (1970) where broiler-type chicks fed a ration containing 20% DPW plus supplemental fat showed an increase in weight gains and feed efficiency as compared to the same diet without the supplemental fat.

E. Experiment 5: Feeding trial utilizing ODL in swine finisher diets.

Pig performance data are presented in Table 14. Final weights were similar for both treatments. Average daily gain was slightly higher ($P<0.11$) for the corn-soy plus water (lot 1) as compared to the corn-limited soy plus ODL (lot 2). Average daily feed and feed efficiency of lot 2 were both 93% relative to that of lot 1 on the control diet.

The nutrient levels in the diet of lot 2 were determined by adding the nutrient level of the dry feed and the nutrient level of the ODL. These can be seen in Tables 7 and 8. The diet of corn-limited soy plus ODL was equal or exceeded the nutrient levels of the control diet with only a few exceptions. The most obvious deficiency was calcium which was present at a level of 0.18%. N.R.C. (1968) lists the calcium requirement for the finishing pig at 0.50%.

TABLE 14. Summary of pig performance from experiment 5

Item	Corn-soy + water (1)	Corn-lim. soy + ODL (2)	
No. of pigs	8	7	±SE[1]
Initial weight,kg	64.0	65.1	0.72
Final Weight, kg	99.6	95.7	2.32
Avg.daily gain, kg	0.73	0.63	0.04
Avg.daily feed,kg	3.16	2.93	
Feed/gain	4.33	4.65	

[1]Standard error of the mean.

This was perhaps the most important single factor which influenced pig performance on the ODL diet. The level of sodium in the ODL diet was 0.08% while N.R.C. (1968) lists the requirement for growing pigs at 0.10%. This difference would not seem to have a great affect on performance. Levels of zinc and iron in the ODL diet were 40 ppm and 70 ppm, respectively, while N.R.C. (1968) lists the minimum requirement for these minerals at 50 ppm and 80 ppm, respectively. Due to the lower zinc level in the DSF diet, the reduced calcium content of the DSF diet permitted these pigs to perform without any signs of parakeratosis occurring due to a zinc deficiency. No structural problems were noted in the ODL lot due to a lower calcium intake.

F. Experiment 6: Balance trial utilizing ODL in swine finisher diets.

Composition of the diets fed in this balance trial are presented in Tables 7 and 8. Data from the balance trial (Table 15) show significantly higher ($P<0.01$) daily fecal output with the ODL diet. Calcium intake was significantly higher ($P<0.01$) on the corn-soy-water diet due to the higher calcium level of that diet. Percent urinary calcium excretions were similar for both diets, but percent fecal calcium excretion relative to intake was significantly higher ($P<0.01$) from the corn-limited soy-ODL diet. This would not have been expected with the low calcium intake level. This resulted in a significantly lower ($P<0.01$) apparent digestibility of calcium on the ODL diet. This may

TABLE 15. Summary of balance trial in experiment 6

Item	Corn-soy + water	Corn-lim.soy + ODL	
No. of pigs	6	5[2]	±SE[1]
Daily feed intake, g	2000	1952	27
Daily feces, g	169	246[aa]	13
Daily urine, ml	2469	1623	311
Ca balance, daily[3]			
Ca intake, g	13.55[aa]	3.44	0.05
Fecal Ca, g	5.12[aa]	2.81	0.43
Fecal Ca, %	38	82[aa]	4
Urinary Ca, g	0.40[a]	0.09	0.09
Urinary Ca, %	3.0	2.5	0.8
Ca retention, g	8.03[aa]	0.54	0.44
Ca retention, %	59[aa]	16	4
Ca apparent digest,%	62[aa]	18	4
P balance, daily[3]			
P intake, g	10.20[aa]	7.64	0.11
Fecal P, g	4.11	4.50	0.25
Fecal P, %	40	59[aa]	3
Urinary P, g	0.34	0.46	0.06
Urinary P, %	3.3	6.1	0.9
P retention, g	5.76[aa]	2.68	0.24
P retention, %	56[aa]	35	3
P apparent digest,%	60[aa]	41	3
Na balance, daily[3]			
Na intake, g	4.88[aa]	1.52	0.02
Fecal Na, g	0.52	0.43	0.05
Fecal Na, %	11	28[aa]	2
Urinary Na, g	3.34[aa]	0.39	0.18
Urinary Na, %	68[aa]	26	5
Na retention, g	1.03	0.70	0.17
Na retention, %	21	46[aa]	5
Na apparent digest,%	89[aa]	72	2

[1]Standard error of the mean.

[2]One pig was removed due to rectal prolapse at the initiation of the collection period.

[3]All percent values are in relation to intake.

[a]Significantly greater than least value (P<0.05); [aa]P<0.01.

TABLE 15 (Continued . . . .)

Item	Corn-soy + water	Corn-lim.soy + ODL	
No. of pigs	6	5	±SE[1]
K balance, daily[2]			
K intake, g	11.44	12.61[aa]	0.17
Fecal K, g	1.78	4.17[aa]	0.20
Fecal K, %	16	33[aa]	2
Urinary K, g	6.02	3.79	0.73
Urinary K, %	52[a]	30	6
K retention, g	3.65	4.66	0.77
K retention, %	32	37	6
K apparent digest,%	84[aa]	67	2
Mg balance, daily[2]			
Mg intake, g	3.07[a]	2.91	0.04
Fecal Mg, g	1.45	2.19[aa]	0.11
Fecal Mg, %	47	75[aa]	3
Urinary Mg, g	0.32[aa]	0.21	0.02
Urinary Mg, %	10.4[aa]	7.3	0.6
Mg retention, g	1.31[aa]	0.50	0.11
Mg retention, %	43[aa]	17	4
Mg apparent digest,%	53[aa]	25	3
Fe balance, daily[2]			
Fe intake, mg	236.08[aa]	137.44	1.90
Fecal Fe, mg	141.38[aa]	73.81	7.94
Fecal Fe, %	60	54	3
Urinary Fe, mg	1.56	1.29	0.18
Urinary Fe, %	0.66	0.95	0.12
Fe retention, mg	93.14[a]	62.33	7.83
Fe retention, %	39	45	3
Fe apparent digest,%	40	46	3

[1]Standard error of the mean.

[2]All percent values are in relation to intake.

[a]Significantly greater than least value (P<0.05);

[aa]P<0.01.

TABLE 15 (Continued . . . .)

Item	Corn-soy + water	Corn-lim. soy + ODL	
No. of pigs	6	5	±SE[1]
Zn balance, daily[2]			
Zn intake, mg	192.50[aa]	79.69	1.10
Fecal Zn, mg	104.80[aa]	53.26	5.05
Fecal Zn, %	54	67	5
Urinary Zn, mg	1.86	2.81[a]	0.30
Urinary Zn, %	1.0	3.6[aa]	0.4
Zn retention, mg	85.84[aa]	23.61	5.41
Zn retention, %	45[a]	29	5
Zn apparent digest,%	46	33	5
Mn balance, daily[2]			
Mn intake, mg	92.82[aa]	48.07	0.67
Fecal Mn, mg	66.85[aa]	44.08	2.82
Fecal Mn, %	72	92[aa]	4
Urinary Mn, mg	0.87[a]	0.47	0.09
Urinary Mn, %	0.9	1.0	0.2
Mn retention, mg	25.11[aa]	3.52	2.72
Mn retention, %	27[aa]	7	4
Mn apparent digest,%	28[aa]	8	4
Cu balance, daily[2]			
Cu intake, mg	33.68[aa]	21.66	0.30
Fecal Cu, mg	17.62	17.54	1.00
Fecal Cu, %	52	81[aa]	4
Urinary Cu, mg	0.45	1.29[aa]	0.17
Urinary Cu, %	1.3	6.1[aa]	0.9
Cu retention, mg	15.62[aa]	2.83	0.89
Cu retention, %	46[aa]	13	3
Cu apparent digest,%	48[aa]	19	4

[1]Standard error of the mean.

[2]All percent values are in relation to intake.

[a]Significantly greater than least value ($P<0.05$);

[aa]$P<0.01$.

TABLE 15 (Continued . . . .)

Item	Corn-soy + water	Corn-lim.soy + ODL	
No. of pigs	6	5	±SE[1]
N balance, daily[6]			
N intake, g	41.29[aa]	38.26	0.50
Fecal N, g	5.34	8.87[aa]	0.50
Fecal N, %	13	23[aa]	1
Urinary N, g	18.21[a]	14.43	1.06
Urinary N, %	44	38	3
N retention, g	17.74	14.96	1.09
N retention, %	43	39	3
N apparent digest,%	87[aa]	77	1
Biological value,app.	49	51	3
Net protein utilization, app.	43	39	3
Dry matter balance, daily[6]			
DM intake, g	1753	1732	23
Fecal DM, g	154	217[aa]	11
Fecal DM, %	8.8	12.5[aa]	0.6
DM apparent digest,%	91.2[aa]	87.5	0.6
Energy balance, daily[6]			
Energy intake,kcal[2]	7734	7775	108
Fecal energy, kcal	802	1193[aa]	63
Urinary energy,kcal	140	131	10
Digestible energy,kcal[3]	6933[a]	6583	80
Digestible energy, %	90[aa]	85	1
Metabolizable energy, kcal[4]	6793[a]	6452	83
Metabolizable energy,%	88[aa]	83	1
N-corrected ME,kcal[5]	6661[a]	6341	85
N-corrected ME, %	86[aa]	82	1

[1]Standard error of the mean.

[2]Gross energy, kcal/kg= 3867 and 3983, respectively.

[3]DE, kcal/kg= 3467 and 3372, respectively.

[4]ME, kcal/kg= 3397 and 3305, respectively.

[5]N-corr. ME, kcal/kg= 3331 and 3248, respectively.

[6]All percent values are in relation to intake.

[a]Significantly greater than least value (P<0.05);

[aa]P<0.01.

be due to several reasons. The calcium may be in a complexed-form which has a low availability for the pig. The magnesium and phosphorus levels of the ODL diet are near the normal levels in a finisher diet and may be inhibiting normal calcium absorption due to the low calcium level present. Calcium retention was significantly higher ($P<0.01$) with the corn-soy-water diet.

Phosphorus intake (Table 15) was significantly higher ($P<0.01$) on the corn-soy-water diet with resulting phosphorus apparent digestibility and retention being significantly higher ($P<0.01$) on the same diet. As was the case with the calcium balance, phosphorus apparent digestibility was significantly lower ($P<0.01$) on the corn-limited soy-ODL diet. This decrease may have been caused by the form of the phosphorus or by the lower dietary calcium level, which may have been too low to permit efficient utilization of the phosphorus in the ODL diet.

Sodium intake and apparent digestibility (Table 15) were significantly higher ($P<0.01$) with the corn-soy-water diet. Absolute sodium retention was similar for both diets. The lower apparent digestibility of sodium from the ODL diet may have been affected by the potassium intake, which was significantly higher ($P<0.01$) on the ODL diet. Apparent digestibility of potassium was higher ($P<0.01$) for the corn-soy-water diet, but absolute and relative retentions were similar for both diets.

Magnesium balance data (Table 15) indicated significantly higher ($P<0.01$) apparent digestibility and retention with the corn-soy-water diet. The lower apparent digestibility of magnesium from the ODL diet may be due to the calcium and phosphorus levels present in the diet which were discussed previously. It is also possible that the magnesium was present in a form which had a poor availability.

Iron intake (Table 15) was significantly higher ($P<0.01$) on the corn-soy-water diet, which also had a higher ($P<0.05$) absolute iron retention. Apparent digestibility and relative retention were similar for both diets. A similar pattern of zinc utilization was found. Apparent digestibility of zinc was similar for both diets, but relative retention was significantly higher ($P<0.05$) for the corn-soy-water diet.

Manganese and copper balances followed similar patterns with the two diets (Table 15). Daily intake, apparent digestibility, absolute and relative retentions were significantly higher ($P<0.01$) for the corn-soy-water diet with both minerals. There was more variability in the data for these two minerals than was the case for many of the other minerals.

Nitrogen balance data (Table 15) indicated a significantly higher ($P<0.01$) nitrogen apparent digestibility for the corn-soy-water diet. Nitrogen retentions were similar for both diets, as were biological value and net protein utilization. Dry matter apparent digestibility was significantly higher ($P<0.01$) with the corn-soy-water diet, which was a reflection of the lower fecal output from that diet. This was also reflected in significantly higher ($P<0.01$) fecal energy with the ODL diet (Table 15). This contributed to the corn-soy-water diet being significantly higher in digestible energy, metabolizable energy and nitrogen-corrected metabolizable energy, as measured from the absolute ($P<0.05$) or relative values ($P<0.01$).

G. Experiment 7. Feeding trial utilizing ODL in swine finisher diets.

Pig performance data are presented in Table 16. Average final weights of lots 1 and 3 on the corn-soy control diet were similar, with both lots being significantly heavier ($P<0.05$) than lots 2 and 4 on the corn-limited soy diet, with or without ODL. Average daily gains of lots 1 and 3 were significantly higher ($P<0.01$) than gains of lots 2 and 4 in this trial. This had not been shown in experiment 5. Daily gains of lots 1 and 3 were the same. Daily gains of lots 2 and 4 were similar.

A question raised from experiment 5 was whether or not the hand fed pigs were consuming feed at near _ad libitum_ intake. Experiment 7 demonstrated this quite well. Lot 1, the hand fed diet of corn-soy-water, had almost exactly the same daily feed intake as did lot 3, the self fed diet of corn-soy. Moreover, feed efficiencies of the two lots were

TABLE 16. Summary of pig performance from experiment 7.

Item	Hand fed: Corn-soy + water Lot 1	Hand fed: Corn-lim. soy + ODL Lot 2	Self fed: Corn-soy Lot 3	Self fed: Corn-lim.soy Lot 4	
No. of pigs	8	8	8	8	±SE[1]
Initial weight,kg	65.4	64.8	65.1	65.7	1.36
Final weight, kg	98.0[a]	86.6	97.4[a]	86.2	3.37
Avg.daily gain,kg	0.66[aa]	0.44	0.66[aa]	0.42	0.05
Avg.daily feed,kg	2.71	2.33	2.64	2.13	
Feed/gain	4.11	5.30	4.00	5.07	

[1]Standard error of the mean.

[a]Significantly greater than least two values (P<0.05);

[aa]P<0.01.

similar. Feed consumptions of lots 2 and 4 were also quite similar, with lot 2, the hand fed lot, having a slightly higher average daily feed consumption. Feed efficiency of these two lots also showed a similar trend, but the efficiencies obtained with the corn-limited soy diet were lower than those obtained from the corn-soy diet.

It is quite evident that the corn-limited soy diet hindered performance in this experiment. This is quite likely due to the lower calcium content of that diet, along with an altered interrelationship of calcium with several of the other dietary minerals. Since this experiment utilized ODL from the east ditch which contained wastes from pigs fed diets having elevated dietary copper levels, it is possible that microbial protein synthesis may have been reduced in this ditch such that the ODL had a reduced nutrient content. Ariail _et_ _al_. (1971) demonstrated the inhibitory effect which copper had on microbial synthesis and it is possible that this effect was present in experiment 7. These results are not consistent with those obtained from feeding ODML by Harmon _et_ _al_. (1971, 1973a,b). They found significantly higher gains and efficiencies for pigs receiving ODML. Such results were not seen in these experiments, although results from experiment 5 would appear to be encouraging as to the utilization of ODL in swine diets.

CONCLUSIONS

Within the limits of the experimental conditions and procedures of the seven experiments presented herein, the results of this study have led the author to make the following conclusions:

1. Finishing pigs will consume corn-soy rations containing up to 22% dried swine feces (DSF) at 90 to 95% of full appetite.

2. Rate and efficiency of gain are depressed by the incorporation of DSF into corn-soy rations to replace all or most of the soybean meal.

3. The incorporation of DSF into a finisher diet resulted in a depression of apparent digestibility and retention of dry matter, nitrogen, energy and most minerals; however, the addition of supplemental amino acids to the DSF diets significantly improved apparent digestibility of nitrogen, energy and several minerals.

4. Elevated calcium levels, reduced amino acid availability and reduced digestibility of energy of DSF and dehydrated poultry (layer) waste (DPW) would appear to be the prime factors affecting their utilization in swine diets.

5. The addition of supplemental energy to diets containing DSF to restore the concentration of digestible energy should improve pig performance.

6. No improvement in pig performance was observed for pigs receiving oxidation ditch liquor (ODL) in their diet.

7. Diets containing ODL resulted in lower apparent digestibility coefficients for dry matter, protein, energy and minerals in balance trials.

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APPENDIX

TABLE A-1. Chemical analyses of DSF- experiments 1 and 2.

Nutrient	(air-dry basis)
Crude protein, %	23.9
Ether Extract, %	9.5
Ash, %	15.0
Calcium, %	4.02
Phosphorus, %	2.26
Potassium, %	1.52
Sodium, %	0.30
Magnesium, %	0.81
Manganese, ppm	404
Iron, ppm	794
Zinc, ppm	543
Copper, ppm	104

TABLE A-2. Michigan State University vitamin-trace mineral premix.

Nutrient	Amount in 4.54 kg of premix[1]
Vitamin A, million	3.0 I.U.
Vitamin D_2, million	0.6 I.U.
Vitamin E, thousand	10.0 I.U.
Riboflavin	3.0 g
Nicotinic acid	16.0 g
D-pantothenic acid	12.0 g
Choline chloride	100.0 g
Vitamin B_{12}	18.0 mg
Zinc	68.0 g
Manganese	34.0 g
Iodine	2.5 g
Copper	9.0 g
Iron	54.0 g
Antioxidant[2]	45.0 g
Carrier (ground yellow corn) to bring total to 4.54 kg.	

[1]Mixed into diet at rate of 0.5%.

[2]Butylated hydroxyanisole (BHA) and/or butylated hydroxytoluene (BHT).

TABLE A-3. Chemical analyses of DPW-experiment 3.

Nutrient	(air-dry basis)
Crude protein, %	19.22
Ether extract, %	2.94
Ash, %	22.62
Gross energy, kcal/kg	3090
Calcium, %	6.44
Phosphorus, %	2.56
Potassium, %	2.03
Sodium, %	0.62
Magnesium, %	0.58
Manganese, ppm	260
Iron, ppm	482
Zinc, ppm	279
Copper, ppm	37

TABLE A-4. Premix supplied the following to ration 3 - experiment 3.

Nutrient	Amount/kg of complete diet
Riboflavin, mg	8.8
Pantothenic acid, mg	17.6
Niacin, mg	39.6
Choline chloride, mg	396.0
Vitamin B_{12}, mcg	26.4
Vitamin A, IU	3960.0
Vitamin D_2, IU	1782.0
Vitamin E, IU	22.0
Zinc, ppm	110.0
DL-methionine, %	0.1