EFFECT OF SEWAGE SLUDGE DIETS FED SWINE ON NUTRIENT
DIGESTIBILITY, REPRODUCTION, GROWTH AND MINERALS IN TISSUES

BY

J. JEAN BEAUDOUIN

A DISSERTATION PRESENTED TO THE GRADUATE COUNCIL
OF THE UNIVERSITY OF FLORIDA IN
PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

UNIVERSITY OF FLORIDA

1981

This dissertation is dedicated to my wife
Winie, for her love, understanding, and patience
during the course of endeavour, and to my
Mother for her faith in my potential.

ACKNOWLEDGEMENTS

The author owes a most sincere debt of gratitude to Dr. R. L. Shirley of the Graduate Supervisory Committee, for his continuous support and guidance during the course of this endeavor. The writer thanks Drs. H. D. Wallace and G. E. Combs for providing facilities to carry out the metabolism trial, and Dr. D. L. Hammell, formerly of the Agricultural Research Center in Live Oak, where most of the experiments were conducted, for his cooperation and great aid in conducting this study. Special thanks are extended to Drs. D. S. Anthony, G. T. Edds, A. Z. Palmer and P. H. Smith for serving as members of the Graduate Supervisory Committee and to Professor J. F. Easley and Dr. H. Breland (Soil Science Department) for their aid in carrying out many laboratory analyses.

The writer greatly appreciates the help and cooperation of Mr. Stacey Geiger, in charge of the University of Florida Sewage Plant, for providing the sewage utilized in the investigation. The manuscript was typed by Ms. Patricia Beville, to whom the author is sincerely grateful.

TABLE OF CONTENTS

	Page
ACKNOWLEDGEMENTS	iii
LIST OF TABLES	v
ABSTRACT	vi
INTRODUCTION	1
REVIEW OF LITERATURE	3
Methods of waste disposal	3
Sanitary landfill	4
Incineration	4
Pyrolysis	5
Ocean dumping	5
Composting	6
Land application of sewage sludge	7
Metal uptake by plants grown on sludge amended soil	9
Use of sludge as a fertilizer	12
Nutritive value of sewage sludge as a feed ingredient	14
Mineral uptake in tissues when animals are fed sludge	15
Effect of sludge-containing diets on animal performance	16
Indirect effect of sludge on animal feeding	17
MATERIALS AND METHODS	19
Metabolism Trial	19
Data Collection	21
Reproduction and Weanling Pig Performance	24
Growing and Finishing Trial	25
Procedure for Mineral Analyses in Tissues	26
Statistical Analysis	27
RESULTS AND DISCUSSION	28
Digestibility Trial	28
Mineral Concentration in Tissues	30
Reproductive Performance of Gilts Fed University of Florida Sewage Sludge	31
Growing-Finishing Swine Performance	35
Mineral Accumulation in Milk and Tissues of Sows	35
Minerals in Weanling Pig Tissues	38
Minerals in Growing-Finishing Swine	41
Adverse Effect of Some Minerals in Tissues	45
SUMMARY AND CONCLUSIONS	48
BIBLIOGRAPHY	50
BIOGRAPHICAL SKETCH	59

LIST OF TABLES

TABLE	PAGE
1 BASAL DIETS FED DURING METABOLISM TRIAL, GESTATION-LACTATION, GROWING AND FINISHING PERIODS	20
2 PROXIMATE ANALYSES OF SEWAGE SLUDGE AND DIETS	22
3 MINERAL COMPOSITION OF SLUDGE AND DIETS	23
4 DIGESTIBILITY OF DRY MATTER, ORGANIC MATTER, CRUDE PROTEIN, ETHER EXTRACT, CRUDE FIBER, NITROGEN-FREE-EXTRACT (NFE), TOTAL DIGESTIBLE NUTRIENTS (TDN), METABOLIZABLE ENERGY (ME), AND NITROGEN RETAINED IN SEWAGE SLUDGE DIETS FED SWINE	29
5 MINERALS IN TISSUES OF PIGS IN METABOLISM TRIAL	32
6 REPRODUCTIVE PERFORMANCE OF SOWS DURING FIRST AND SECOND LITTERS ON DIETS CONTAINING 0, 10 AND 20 PERCENT SEWAGE SLUDGE	34
7 PERFORMANCE OF FIRST AND SECOND LITTER OFFSPRING FED GROWING AND FINISHING DIETS THAT CONTAINED 0, 10 AND 20 PERCENT SEWAGE SLUDGE	36
8 EFFECT OF SEWAGE SLUDGE IN DIETS FED SOWS ON CONCENTRATION OF MINERALS IN MILK AND SELECTED TISSUES WHEN THEY WERE SLAUGHTERED	37
9 MINERALS IN WEANLING PIG TISSUES OF FIRST AND SECOND LITTERS	39
10 MINERALS IN TISSUES OF GROWING-FINISHING SWINE FROM FIRST AND SECOND LITTERS FED DIETS CONTAINING SEWAGE SLUDGE (SIX PER TREATMENT)	42

Abstract of Dissertation Presented to the Graduate Council
of the University of Florida in Partial Fulfillment of the Requirements
for the Degree of Doctor of Philosophy

EFFECT OF SEWAGE SLUDGE DIETS FED SWINE ON NUTRIENT
DIGESTIBILITY, REPRODUCTION, GROWTH AND MINERALS IN TISSUES

By

J. JEAN BEAUDOUIN

March 1981

Chairman: Dr. R. L. Shirley
Major Department: Animal Science

Twelve female swine were fed in a 3X4 crossover design metabolism trial corn-soybean grower diets that contained 0, 10 or 20% sewage sludge over three 19-day periods. The mean values for total digestible nutrients were 79.4, 73.7 and 55%; those for metabolizable energy were 3.36, 2.25 and 1.15 Mcal/kg diet; and those for nitrogen retained were 42.8, 44.0 and 25.3%, respectively. Sewage sludge (0, 10, 20%) diets were fed to 31 sows approximately equally divided into the dietary groups during their first two pregnancies, and to their offspring from weaning until market weight. More live pigs were farrowed and weaned per litter from sows fed 20% sludge diets than from the control group. However, 21-day weaning weights of pigs were lower from sows fed the sludge-containing diets. Offspring of both first and second litters fed growing and finishing diets containing sludge from weaning until market weight had decreased daily weight gains and feed efficiency. There were

no increases in nine elements (lead, cadmium, nickel, zinc, chromium, manganese, iron, copper and aluminum) in sow's milk or blood. Offspring of sows fed sludge diets showed increases of several elements in selected tissues at weaning and after consuming sludge diets until market weight.

INTRODUCTION

The explosive increase in world population especially in urban areas is responsible for the increasing problem of sewage sludge disposal which is a major ecological and economic burden. Concern for quality of the environment has significantly increased the economic cost of traditional disposal options (Smith et al., 1979). With the growing concern over land, stream or ocean disposal, of sludges, alternate methods of disposal warrant evaluation (Farrel, 1974). One of these methods is recycling of wastes thereby reclaiming the nutrients they contain for animal production.

Sewage sludge consists of organic and inorganic matter from human and industrial sources and needs to be evaluated for its possible effects if consumed by livestock and wild animals when disposed of on grazing fields and timberlands. While nutrient organic matter and minerals present in sewage sludge may be utilized by livestock, it is suggested that microorganisms, heavy metals and other toxic compounds occurring in municipal sewages might pose health hazards to animals consuming them. Much concern about accumulation of heavy metals in animal products had been expressed (Hackler et al. 1957). Pal (1980) suggested a complete characterization of sewage solids for toxic metals, individual drugs, pesticides and other organic chemicals as well as pathogenic agents to assess the health risk associated with continuous application of sewage sludge on farms and forests.

Sewage sludge utilization on land is considered by many to be the best solution to the municipal sludge problem. Chaney (1975) reported that sewage solids appeared to be very valuable in revegetation and reclamation of land disturbed by urban development, mining and road construction and that, if properly used, the sludge can transform these disturbed lands into an environment suitable for plant growth.

Sludge from sewage plants has commonly been used in landfill (Engelbrecht and Amirhor, 1976). It can also be put back into the soil, fertilizing crops needed to feed livestock (Cambel, 1971; Decker et al., 1980; Manning and Spitko, 1980). However, sewage sludge may be a source of nutrients that would be more valuable if used directly as animal feed rather than as fertilizer (Smith et al., 1980).

Sewage sludge has been fed to rats (Kindzell et al., 1976; Smith and Staples, 1976), fish (Natarajan and Varghese, 1978; Sing and Ferns, 1978), laying hens (Damron et al., 1980), sheep (Smith et al., 1976a; Smith et al., 1977a), cattle (Kienholz et al., 1976a; Smith et al., 1979; Bertrand et al., 1980; Smith et al., 1980) and swine (Beaudouin et al., 1977; White et al., 1980; Edds et al., 1980).

The objectives of the present experiments were to evaluate the effect of sewage sludge in diets fed swine on:

- a) reproductive performance
- b) rate of growth
- c) total digestible nutrients (TDN), metabolizable energy (ME) and nitrogen balance in a metabolism trial
- d) accumulation of potentially toxic minerals in tissue of swine consuming sludge-containing diets

REVIEW OF LITERATURE

Sewage sludge can be defined as the total organic and inorganic wastes generated by human and commercial sources and removed from wastewater at treatment plants. The waste treatment is based on the need to remove objectionable substances in the wastewater prior to its release in the general environment (Waller, 1976). It is estimated (Bastian, 1977) that close to 5 million dry tons of sewage sludge are produced each year and the amount might double in the next five years. Land available for landfill disposal of the solid waste material is diminishing. With new federal regulations in water management and air pollution control, the disposal of sewage waste in a manner consistent with environmental criteria has become urgent and difficult.

Methods of waste disposal: The most popular methods of sludge disposal in the United States are landfilling, ocean dumping, incineration, pyrolysis, composting and landspreading. All methods of disposal are costly and Montague (1975) reported some comparative costs of sludge disposal. Costs for incineration and heat dried sludges are approximately \$50/ton; drying for fertilizer, \$5/ton; disposal at sea, \$32/ton; landfilling, \$25/ton; liquid sludge spreading and stripmine reclamation \$15 and \$16/ton, respectively. Landspreading of the liquid sludge is one of the most attractive alternatives from an economical and hopefully from the environmental standpoint. Montague (1975) compared its cost of disposal in this manner with the cost of ocean disposal by

the coastal megalopoli and the "out of sight out of mind" philosophy associated with this practice.

Sanitary landfill: This procedure is defined by the American Society of Civil Engineers (1959) as a method of disposing refuse on land without creating nuisances or hazards to public health or safety. The refuse should be confined to the smallest practical area, reduced to the smallest practical volume and it should be covered with a layer of earth at the end of each day of operation or at more frequent intervals if necessary. Objectionable materials like toxic metals, toxic organic chemicals, and pathogenic microorganisms may be present in sufficient concentration to be hazardous (Farrell, 1974).

High concentration of pathogens and chemicals in the raw sewage sludge may prohibit disposal in landfill or to agricultural land. The landfill should be in a site above the highest seasonal level of the water table and should not be subject to flooding (Clayton and Huie, 1973). The site should be located where groundwater contamination is not possible, and any leachate should be collected and treated (Farrell, 1974).

Incineration: As a disposal method, incineration is the process of reduction of combustible waste to inert residues by high temperature burning. The rapid increase in the production of solid waste and the steady exhaustion of available land within practical distance from population centers had generated a trend toward incineration as a major method of waste disposal, particularly in large communities. In recent years, the trend to incinerate waste in the United States rapidly increased and it was projected that by 1985, as much as 35% of the sludge would be disposed of in this manner (Farrell, 1974). But energy scarcity

and air pollution equipment with high operation expense required in most communities make incineration less attractive. However, Roesler (1977) reported that manufacturers of incinerators recognized this problem and have developed automated and semi-automated incinerators with the potential for improving performance, enhancing safety and saving fuel. Incineration also presents the problem of a residue which must be buried or otherwise disposed of. The ash resulting from the burning of sewage sludge can be converted into an environmentally acceptable material while conserving valuable resources. Gabler and Neylan (1977) reported that various investigators have shown an increasing interest in both the quantity of metals present in sludge ash and the most efficient means of extracting them as well as phosphorus. Gabler and Neyland (1977) concluded that for most cities, recovery costs may only be justified as part of the disposal cost.

Pyrolysis: This process involves destructive distillation of organic matter under heat and/or pressure in absence of oxygen and with a more positive control of the combustion process. But like incineration, it is not a total disposal method since most solid materials contain non-combustibles and have residual ash (Sittig, 1979; Chaney, 1975). The major difference between incineration and pyrolysis is that in the latter process three potentially useful energy rich substances are produced, i.e. a gas (methane), a liquid and a char (Vesilind, 1979).

Ocean dumping: The ocean dumping of sewage sludge has been a way of disposal in most coastal cities for years. But with environmental concern over floating materials (oil, grease) floating back to shore and discouraging recreational fishing and swimming as well as being a health

risk, it is possible that ocean dumping will likely not be allowed in the future (Vesilind, 1979).

Composting: A major attribute of composts is that it is an esthetically pleasing, easily handled material that can be used in urban environments without odor or nuisance problems (Epstein and Willson, 1974). Proper composting not only dewateres the sludge but also destroys disease organisms during the compost heating process. Toth (1973) defines the composting process as the procedure involving microbial conversion of waste organic residues into lignoprotein (humus) by thermophilic organisms under optimal condition. Toth (1973) also observed that compost improves the physical property of soil. It causes an increased aggregation which results in reductions in surface runoff, improvement in holding capacity, absorption of heat, aeration and reduction of water infiltration in light soil. Addition of sludge compost to sandy soils increases their ability to retain water and render them less droughty (Willson et al., 1976). Application of sludge or sludge compost has been found to increase the cation exchange capacity of soils by as much as threefold (Epstein et al., 1976). Sludge compost, when added to clay soils, reduces compaction and increases rooting depth. But the potential use of compost on land is limited to the extent to which the sludge is contaminated by heavy metals and industrial chemicals. Willson et al., (1976) pointed out that the chemical composition of compost depends on the composition of the sludge, which in turn depends on the extent of the wastewater treatment and particular type of contamination. One difficult problem with sludge is that it is not possible to guarantee the composition of either the liquid or the dried sludge

because of the varying nature of the sewage received and the treatment process (Ardern, 1976). In addition to the problem of toxic substances in composting sewage sludge, it is necessary to add extra nitrogen, potassium and phosphorus and keep the loading of the soil within a 10 to 20 tons limit. A higher load will allow CO_2 accumulation to stop the decomposition (Cárdenas and Varro, 1973; Satriana, 1974).

Hill and Montague (1975) observed that plants grown on compost plots had significantly lower zinc and cadmium contents than those grown on sludge treated plots. Composting of sewage sludge appears to be desirable not only from the standpoint of pathogen reduction (temperature has exceeded 70°C for over 14 days as reported by Hill and Montague, 1975) as well as odor control, drying by natural processes, ease of handling, lowering the nitrate levels, and reduced potential for metal uptake by plants. According to Willson et al. (1976), composting of good quality sludge, low in heavy metals, is the most acceptable way of applying sludge to land.

Land application of sewage sludge: Black (1974), Chaney (1975), Bastian and Whittington (1977) have reviewed potential hazards and problems as well as agricultural benefits of land treated with sewage products. Land application of sewage sludge remains a controversial area. Most discussions centered on application to agricultural lands for food crop production. The use of sludge on non-agricultural lands (stripmine reclamation, park, construction site) or non-food chain crop production (sod production) can be done without much controversy to recover nutrient and soil building properties of municipal sludge (Bastian and Whittington, 1977). Dean and Smith (1973) stated that for an idea such as recycling of urban sewage or sludge to the land to

be implemented, it must have public acceptance. In fact, public acceptance and health effect concerns are the two major impediments to the use of sewage sludge in agriculture. The ultimate disposal of sewage sludge by utilization on land is considered by many as the best solution available to municipal sludge problems. Black (1974) reported the favorable effect of sewage sludge on soil properties as being that of increased field moisture capacity, organic matter content and soil aggregation. Those factors tend to render the soil more suitable to plant growth, through improved aeration, greater ease of root penetration, increased rate of water infiltration and improved availability of nutrients.

The sludge can be applied to land as liquid or dried. forms. When used in liquid form, cost of drying the sludge is avoided. Upon applying sludge to pasture, Decker et al. (1980) observed excellent plant growth resulting from both liquid and composted sewage sludge. Forage quality was not reduced by the sludge fertilizer and forage acceptability by grazing animals was excellent. However, disposal or the application of raw sewage sludge has potential health and aesthetic problems. The material is odorous, highly biodegradable and bears pathogenic microorganisms typical of human excreta (Miner and Hazen, 1971). The potential hazard from metals in sludge is the most urgent problem in sludge utilization on land. There is potential hazard to the land, to animals that feed on crops, and to humans who eat both the crops and the animal (Farrell, 1976). There are currently no acceptable tolerances or limits for heavy metals and other contaminants in sludge for crops grown on sludge amended soils for human or animal foodstuffs (Bastian and Whittington, 1977). When sludge is used as an addition to

soil to grow crops in the food chain, it is important to consider the fact that sludge can contain varying amounts of pathogens, toxic metals, pesticides and industrial chemicals such as PCB's (polychlorinated biphenyls), according to Jelinek and Braude (1976). Although the utilization of sewage sludge as a resource to recover nutrients and other benefits has been encouraged, there are, however, conflicting opinions on the overall merit versus the potential risks associated with applying sludges to cropland (Bastian, 1977). Land cultivation of waste is a disposal technique by which wastes are mixed with the surface soil to promote microbial decomposition of the organic fraction (Bauer et al., 1977). Miller (1973) observed that frequent large applications of sewage sludge or a single massive application could result in an accumulation of organic matter which would adversely affect ion solubility and availability, plant growth or environmental quality.

Metal uptake by plants grown on sludge amended soil: Lutrick and Cornell (1980) observed that metal uptake by corn grown on sludge treated soil was proportional to the quantity added from the sludge and was directly associated with soil pH. When liquefied, irradiated, digested sludge was applied to soil, Manning and Spitko (1980) found that with the exception of lead, which exceeded normal concentration only in lettuce, concentrations of all other metals were within normal range observed for plants grown without sludge. Naylor et al. (1980) showed that uptake of cadmium into corn grain grown on sludge amended soil was only slightly greater than that of corn grown on a control site. However, there was a significant increase in the cadmium content of the corn leaves over the control plants. No contamination of surface water or ground water was detected. Corn grown on a sludge fertilized field had

significantly more Ca, P, K, Mg, Zn, Cd, Ni, Cu, and Fe, and less Mn than a standard corn (Hansen et al., 1976). Loehr et al. (1979) concluded that aluminum, iron and manganese levels in sludge were usually of no environmental concern. They are not toxic as long as low pH is avoided and good aeration of the soil is maintained. Lead toxicity in sludge was found to decrease when incorporated into a neutral soil. Loehr et al. (1979) suggested, that a good management practice designed to prevent production of crops with toxic cadmium concentration, would be to maintain a 1:100 cadmium to zinc ratio. The Food and Drug Administration (FDA) has set some limitations on the application of sludge to land used to grow human and animal foods in order to protect public health. The sludge should not contain more than 20 ppm of cadmium, 1,000 ppm of lead or 10 ppm of PCB (polychlorinated biphenyl) on a dry weight basis (Jelinek and Braude, 1976). Goldstein (1979) suggested these heavy metal limits for croplands: zinc, 1,500 ppm; copper, 750 ppm; lead, 500 ppm; chromium, 500 ppm; nickel, 150 ppm; and cadmium, 50 ppm. The heavy metals occurring in amounts that are significant to agriculture include zinc, copper, nickel, cadmium, mercury and lead. It has been proven (Otte and Laconde, 1977) that repeated sludge applications result in increased surface accumulation of cadmium, copper, nickel and zinc in sludge treated fields. In fact, Jelinek and Braude (1976) observed a cadmium increase in grains and soybeans as a result of repeated applications of cadmium-containing sludge. Chaney (1975) reported some concerns by agronomists who feared that the disposal of some sludges on agricultural land may impair crop growth because of their heavy metals content or may endanger the food chain through excessive accumulation of these metals in the crop's edible portion. Metals such

as copper, zinc, nickel can be toxic to vegetation if they are applied in excessive concentration. Other metals, cadmium for instance, may accumulate in animals and humans, where they act as cumulative toxins (Sidle, 1977). The toxicology of cadmium is recognized as a serious cumulative disease in man, first described in Japan as Itai-Itai or Ouch-Ouch disease and characterized by deformities, muscular atrophy and excruciating pain (Stevens, 1976). Sludge disposal in forested areas seems a viable alternative to farmland application since the vegetation is generally not harvested as edible crops (Sidle, 1977). The only means of food chain transfer would be through wildlife feeding on vegetation in the sludge treated areas and through the ground water recharge. Incidentally, nitrogen in the nitrate form is implicated in methemoglobinemia, a current condition in infants in areas with high nitrate drinking water (Waller, 1976). But according to Dean and Smith (1973), a long history of successful use of sludge as a soil amendment in agriculture indicated that hazards are slight and probably are easily controlled by appropriate farm practices. Results of experiments on using sludge on calcareous soils did not differ whether the sewage products are thermoradiation treated or untreated. However, thermoradiation treatment greatly facilitates handling of the raw sewage for experimentation because pathogens are eliminated and objectionable odors almost completely eliminated (McCaslin and Titman, 1977). Adrian (1973) reported that when digested sludge is dried on sand beds, it takes many weeks to months to provide time for a significant die-off of pathogens. However, one has to be cautious. Hoffmann and Bertrand (1980) identified non-lactose fermenting, gram negative bacteria from dry University of Florida sludge. They also isolated two groups of *Salmonella enteritidis*

from feces of animals fed on a sludge amended diet. Mineral toxicity is also a serious problem. For example, cumulative cadmium ingestion causes renal tubular dysfunction (Franconi syndrome) in man (Chaney, 1980). Ryan (1978) indicated that cadmium toxicity could occur in animals consuming food and feed crops produced on soil treated with large amounts of sewage sludge, high in cadmium, the metal adhering to the edible plant surface. But Schauer et al. (1978) estimated that food chain accumulations of many heavy metals, with the exception of cadmium, do not appear to present a problem because they are toxic to plants in lower concentrations than those detrimental to animal or human health.

Use of sludge as a fertilizer: Liquid sludge, as applied to land, contains major fertilizer elements, mainly nitrogen, potassium and phosphorus. The dry weight percentage of each depends on the sewage and the sludge treatment plant operation (Hill and Montague, 1975). Peterson et al., (1973) found the following amounts of mineral nutrients in sludge:

Mineral nutrient percentages of dry sludge solids.

Total N	3.5 - 6.4%	Organic N	2.0 - 4.5%
Total P	.3 - 3.9%	P ₂ O ₅	1.8 - 3.7%
Total K	.2 - .7%	K ₂ O	.24 - .84%

Micronutrients such as iron, manganese, copper, zinc and boron were also determined. Dried sludge can be a very good fertilizer and soil conditioner but the cost of drying the sludge is high and the end-product must be sold to make the operation economical (Vesilind, 1979). Blok (1976) reported that in 1975, a total of 160,000 tons of dried sludge were produced in Houston, Chicago, Milwaukee and Winston-Salem. Most of them were used in Florida for turfgrass, citrus industry, nurseries and

vegetable industry. Blok (1976) even mentioned that citrus groves on an organic versus synthetic fertilizer program are better able to withstand freeze and droughts. Some cities sell the sludge to fertilizer manufacturers who incorporate it into specialty products and handle the marketing of the product (Styers, 1973). The value of the heat dried sludge is directly related to its nutrient content and its characteristics as a soil conditioner. Plant growth on calcareous soils in greenhouse was stimulated by digested sludge in comparison with nitrogen-phosphorus chemical fertilizers (Smith et al., 1976b). It is difficult to estimate the economic benefit of sludge application with that of commercial fertilizer (Reisner and Christensen, 1977), because of the varying chemical composition of the sludge as well as fluctuation of nutrient price. These authors estimated that one ton of dried sludge provides about 100 lbs each of nitrogen and phosphate and 5 pounds of potash. But to produce a marketable fertilizer, it is necessary to keep the nitrogen content as high as possible and minimize the moisture, ash, grease and cellulose (Garrett, 1974). Heat dried activated sludge must compete with other sources of organic nitrogen such as dried blood, fish scraps, tankage and cottonseed meal. Sewage sludge is often used in commercial fertilizers as an organic source or as a cheap bulking agent (Chaney, 1973). Digested sludge contains all the nutrients and trace elements required for plant growth. Three to four tons of sludge per acre provide adequate nitrogen and phosphorus for a healthy crop of corn (Black, 1974). But according to Martin and Baxter (1976), nitrogen, heavy metals, salts, and pathogen transmission are possible limitations to using sludge as a fertilizer. Excess nitrogen can be converted to nitrates contaminating surface or ground water supplies (Dean and Smith,

1973; Martin and Baxter, 1976). The shortage of fossil fuels used in the manufacturing of nitrogen fertilizer has tremendously increased the cost of commercial fertilizer. Savings from using sludge will likely increase as the cost of commercial fertilizers increases.

Nutritive value of sewage sludge as a feed ingredient: In an experiment using dried activated sewage sludge as a source of nitrogen for sheep, Hackler et al., (1957) found that sewage sludge has good nutritive value for animal feeding and presents little problems from pathogens. But the hazards of chemical toxicants, cultural stigma and low economic incentive precluded practical application. Nutrients in sewage solids are potentially more valuable as animal feed than as fertilizer, especially when fed to ruminants (Smith et al., 1979). Undigested sewage solids fed as a supplement in a fibrous diet to sheep and compared to one containing cottonseed meal had 40-60% digestible energy and approximately 50% digestible nitrogen (Smith et al., 1976a). Sewage solids had about 65 to 75% as much supplemental energy and nitrogen as cottonseed meal when fed in approximately isonitrogenous diets to sheep. In short-term trials with sheep and cattle, Smith et al. (1979) demonstrated that irradiated sewage solids from primary sludge provided nutritive energy and nitrogen worth at least half the value of cottonseed meal when fed with poor quality, fibrous feeds. Smith et al. (1980) concluded that raw sewage could be recycled as supplemental feed for ruminants subsisting on poor quality roughage at substantial nutritive benefits, without incurring undue risk from accumulation of heavy metals or halogenated hydrocarbons. Hackler et al. (1957) fed sheep a ration in which 18% of the nitrogen was supplied as dried activated sludge and

found nitrogen retention equivalent to that obtained with soybean meal and urea-containing rations of similar crude protein content (11-12%). The total nitrogen of the sludge-containing ration had a significantly lower apparent digestibility but a higher biological value.

In a feeding trial with three groups of lambs (basal versus 10% cottonseed meal (CSM) versus 20% thermoradiated, centrifuged undigested sewage solids), Smith et al. (1977b) observed that the amount of digested energy and digested nitrogen were greater for lambs fed 20% sludge than those fed the 10% cottonseed meal diet. The diets, when fed to steers, showed that both CSM and TRUS-C (thermoradiated, centrifuged, undigested sewage solids) tended to increase digestible energy and nitrogen over that of the basal diet.

Mineral uptake in tissues when animals are fed sludge: In long term feeding of diets that contained 20 or 30% of irradiated dried sewage sludge to sheep, tissue retention of selected trace minerals lightly increased over the control groups (Smith et al., 1979). However, only the increase in iron was considered biologically important. Bertrand et al. (1980) fed 500 g/head/day of dried Pensacola sludge to steers and observed a consistent decrease of liver tissue concentration of copper and some accumulation of lead in both liver and kidney. Accumulation of cadmium and lead in liver and kidney tissues were also observed when dried Chicago digested sludge replaced the Pensacola sludge in the diets. These authors found no significant increases in concentration of selected metals in liver and kidney of beef steers fed a diet that contained corn grain grown on land pretreated with a Pensacola liquid sludge. Kienholz et al. (1976a) fed steers feedlot diets that contained 15% dried sewage sludge for 95 days and observed a 10-fold

increase in lead and mercury and a 2-fold increase in cadmium and copper in their liver and kidney. In another experiment, Kienholz et al. (1976b) found that by adding 3.7 or 11.6% sludge to a diet, cadmium and lead increased in the kidney but there was a significant decrease in copper when 11.6% sludge was present in the diets. The sludge-containing diets significantly increased copper, cadmium and lead in liver tissues, but had no effect on zinc contents. Edds et al. (1978) fed a 50% dried sewage sludge diet to pigs and observed an increase in cadmium and lead in the kidney and liver. However, copper and zinc decreased in both tissues when sludge was fed. Accumulation of chromium, iron, nickel and lead in rainbow trout maintained on a diet containing 30% activated sludge was observed by Sing and Ferns (1978).

Effect of sludge-containing diets on animal performance: Smith et al. (1976b) fed rats sewage solids during growth periods and found no detrimental effect on subsequent reproductive performance. No recognizable lesions that were due to the dietary sludge were found in rats upon post-mortem examinations. However, the feed efficiency decreased with increasing levels of dietary sludge (0, 12.5, 25 and 50% sewage sludge). Bertrand et al. (1980) fed Chicago sewage sludge to steers at levels of 6% of the dry diet for 141 days and found, however, no differences in growth, feed efficiency or carcass quality measurements. Firth and Johnson (1955) included 5% dry activated sewage sludge in the diet of baby pigs without adverse effects on growth. However, 10% sludge inhibited growth and feed efficiency. These authors fed 10% sewage sludge in diets to baby chicks for a month without any evidence of adverse effects. Damron et al. (1980) fed Leghorn hens rations containing 0, 3.5 and 7%

dried Chicago sludge and found neither egg production, egg weights, daily feed intake, feed efficiency nor body weights significantly affected.

Indirect effect of sludge on animal feeding: Stoewsand et al. (1980) found hepatic necrosis in lambs fed corn silage grown on land covered with municipal sludge and cadmium and zinc were found to be higher in kidney and liver. Steers consuming forages produced on land covered with dried Pensacola sludge had a decrease in copper and zinc in liver (Edds et al., 1980). When these authors used corn grain harvested from soils previously amended with Pensacola liquid sludge to replace either 50% or 100% of corn from plots fertilized with commercial fertilizer in diets fed chicks, they found, with one exception, no significant differences in growth performance in three experimental groups. These diets had no detrimental effects on egg laying or hatchability when fed to hens. When freeze dried liver from swine that had been fed diets that contained 0, 10 or 20% dried University of Florida sewage sludge was included in diets fed mice, an increase in the lead content of the mice liver and muscle occurred with the 20% dried sewage sludge treatment (Kelley et al., 1980). Such tests are called relay feeding trials and are defined (Robens, 1980) as ones in which edible tissues obtained from animals fed potentially toxic feed ingredients, are subsequently fed to laboratory animals which are then observed for effect of accumulated toxicants on survival, lesions, reproduction or other parameters.

This review of the literature indicates that sewage sludge can be valuable as a fertilizing agent for crops as well as a feed ingredient

for animals. The potential for human or animal disease due to pathogenic organisms being transmitted in unprocessed or improperly managed sludge and the danger from heavy metal accumulation in some vital tissues limits its general acceptance.

MATERIALS AND METHODS

Metabolism Trial

This experiment was conducted at the Swine Research Unit of the University of Florida at Gainesville in order to study the effect of sewage sludge diets fed swine on total digestible nutrients (TDN), metabolizable energy (ME), nitrogen balance and minerals accumulation in tissues. Twelve crossbred gilts averaging 28 Kg in body weight were equally divided into three groups of four and fed corn-soybean grower diets (table 1) containing either 0, 10 or 20% sewage sludge over three nineteen-day periods in a crossover design metabolism trial. The pigs were randomly selected from several litters of the same age and weight that had not previously been fed sewage sludge diets. The sludge, aerobically digested in the University of Florida sewage plant and sun-air dried replaced corn grain in diets on an equal air-dry weight basis. Diets were marked with chromic oxide ($.1\% \text{Cr}_2\text{O}_3$), a reference substance used to calculate fecal output according to the equation:

$$\text{Fecal output} = \frac{\text{Total chromium intake, g}}{\text{gram chromium/gram dry matter of feces}}$$

The swine were adapted to the diets for nine days in pens and then confined to individual metabolism cages where feed intake was recorded and feces and urine collected for seven days. Determination of chromic oxide in swine feed and feces was done by the method of Christian and Coup (1954).

TABLE 1. BASAL DIETS FED DURING METABOLISM TRIAL, GESTATION-LACTATION, GROWING AND FINISHING PERIODS^a

Ingredient	Internat'l Ref. No. ^b	Gestation and lactation	Starting	Grower and metabolism	Finishing
Corn, grain, yellow, grnd (9.0%)	4-02-931	70.45	61.45	78.25	83.25
Oats, grain, grnd (12.7%)	4-03-315	10.0	0	0	0
Sugarcane, molasses, 79.5° brix	4-04-696	0	5.0	0	0
Soybean seed, dehulled, solvent extract	5-04-612	16.0	27.5	18.75	13.75
Animal fat	4-00-409	0	3.0	0	0
Phosphate, defluorinated ^c	6-01-780	2.5	2.0	1.50	1.50
Salt, iodized	6-04-151	.5	.5	.50	.50
Trace mineral premix ^d		.05	.05	.10	.10
Vitamin premix ^e		.5	.5	.50	.50
Limestone, ground	6-01-069	0	0	.40	.40

^a

Corn was replaced on air-dry weight basis by sewage sludge in 10 and 20 sludge diets fed swine.

^b

Atlas of Nutritional Data on United States and Canadian Feeds, 1971. Nat. Acad. of Sci., Washington, D.C.

^c

Courtesy of Occidental Petroleum Co., White Springs, FL.

^dProvided the following elements in mg per kg diet: zinc (ZnO), 200; iron (FeSO₄), 100; manganese (MnSO₄), 55; copper (Cu₂O), 11; iodine Ca(IO₃)₂, 1.5; and cobalt (CoCO₃), 1.0. Courtesy of Calcium Carbonate Company, Quincy, IL.^eProvided the following vitamins per kg diet: vitamin A, 11,025 IU; vitamin D, 5,513 IU; vitamin E, 22 IU; riboflavin, 11 mg; pantothenic acid, 27 mg; niacin, 55 mg; choline chloride, 1,102 mg; vitamin B₁₂, 49 mcg. Courtesy of Charles Pfizer and Company, Terre Haute, IN.

Proximate analysis constituents were determined in the sludge, diets (table 2), feces and urine by the AOAC (1975) procedures. Diets, sludge, feces and urine were analyzed for selected mineral concentration by atomic absorption spectrophotometry (Perkin Elmer Corporation, 1973). Gross energy was determined in an oxygen bomb calorimeter (Parr Instrument Company, 1960). The mineral composition of sludge and diets are presented on Table 3.

Data Collection

The pigs were weighed at the beginning and at the end of each fecal collection period. During the seven day period in the metabolism cages about 300 grams of feces were obtained each day per animal and kept in a sterile plastic bag. Feces was air-dried for four days, ground in a Wiley mill to pass a 10 mesh stainless steel screen. Approximately 300 grams of ground feces from each pig were saved for analyses. The urine was collected in bottles that contained 10 ml of toluene and 15 ml of concentrated hydrochloric acid and measured each day. An aliquot of 100 ml was saved from each animal and stored in a refrigerator until analyses were completed. All animals were allowed a 12-day adjustment period to the new diets before feces or urine collection were made in each period. Pigs fed the control diet in the last period were slaughtered one day after the conclusion of the experiment while corresponding ones fed the 10 or 20% sludge diets were fed the control diet for one or two weeks

TABLE 2. PROXIMATE ANALYSES OF SEWAGE SLUDGE AND DIETS

	Air dry matter %	Cr. protein %	Cr. fiber %	Proximate analyses ^a		Ash %
				Ether extract %	NFE ^b %	
Sludge ^c	91.9 (66-98)	25.9 (22-37)	4.3 (.7-15)	.46 (.01-1.1)	40.6 (9-47)	28.8 (27-57)
Metabolism trial:						
Control diets (grower)						
Period 1	85.9	17.6	6.0	1.1	60.5	5.9
Period 2	84.5	21.9	4.6	.4	64.7	8.4
Period 3	87.2	19.5	12.7	.7	55.5	11.7
Sludge diets, 10%						
Period 1	84.4	19.4	6.4	.6	66.2	7.4
Period 2	89.1	18.4	6.9	.4	66.3	8.1
Period 3	85.2	19.7	3.5	.4	64.9	11.5
Sludge diets, 20%						
Period 1	83.9	25.0	4.5	.6	63.2	6.8
Period 2	84.1	20.2	6.0	.3	65.1	8.5
Period 3	82.4	21.4	5.7	.6	61.9	10.5
Gestation-lactation diets						
Control	84.7	20.6	5.7	.8	66.3	6.7
Sludge, 10%	85.9	20.1	5.8	.4	65.4	8.3
Sludge, 20%	84.9	20.2	7.3	.5	60.8	11.2

^aPercentage on dry matter basis.^bNitrogen-free extract.^cMean and range of 22 samples.

TABLE 3. MINERAL COMPOSITION OF SLUDGE AND DIETS

Minerals, mg/kg dry matter	Pb	Cd	Ni	Zn	Cu	Cr	Mn	Fe	Al	Hg
Sludge	463	13	32	1190	512	213	274	10670	4436	54
Diets:										
Control	2	.3	4	189	12	2	75	344	419	.53
Sludge, 10%	31	1.3	5	265	42	16	90	1011	688	6.2
Sludge, 20%	66	2.2	8	381	80	32	118	1963	1045	5.2

respectively before slaughter. This was done to decrease the residual material of the sludge diets. Kidney, liver, spleen and skeletal muscle samples were cut with a stainless steel knife and frozen until analyzed for potentially toxic minerals. Blood was also collected in heparinized tubes and kept at 34°C until analyzed. Tissues and blood were analyzed for lead, mercury, cadmium, nickel, zinc, chromium, copper, manganese, iron, aluminum and magnesium by atomic absorption spectrophotometry (Perkin Elmer Corporation, 1973). Mercury was similarly analyzed in feed, feces and urine.

Reproduction and Weanling Pig Performance

An experiment was conducted at the swine unit of the Agricultural Research Center in Live Oak, Florida, that involved thirty-three Yorkshire-Hampshire crossbred gilts. The gilts weighed initially approximately 60 kg each and were allotted randomly and equally to corn-soybean gestation-lactation diets (table 1) that contained either 0, 10 or 20% sewage sludge. The sludge was air and sun-dried. Analysis values for protein and selected minerals are presented in tables 2 and 3, respectively. The added sludge replaced the ground corn in the diets on a dry weight basis. Feed and sludge samples were taken at each mixing of diets and analyzed for selected mineral content. During approximately twelve months of feeding the diets, two litters were obtained from each of the sows. The sows were fed from troughs in open pens on the ground except just prior to farrowing and during lactation until weaning when they were kept on concrete in farrowing pens and hand-fed. Ad libitum feed consumption by sows was not determined. After weaning, the sows

were returned to open pens on the ground. On day 7 of the first lactation, three sows randomly chosen from each dietary group were milked by hand after being injected with 1 ml of oxytocin. The milk was dried on a steam bath and ashed at 480°C overnight. Subsequently, the ash was dissolved in .1% HCl and analyzed for nine selected elements: lead, cadmium, copper, chromium, nickel, manganese, aluminum, iron and zinc. Six weanling pigs (three male, three female) of each dietary group from both first and second litters were killed by severing the jugular vein, and blood was collected in heparinized tubes. In addition, liver, kidney, spleen and muscle tissues were secured with a stainless steel blade and frozen immediately at -10°C. Samples were partially oxidized with nitric acid followed by dry ashing at 480°C. The ash was dissolved in aqueous hydrochloric acid and filtered through a No. 43 acid washed Whatman filter paper. The filtrate was volumetrically diluted to 100 ml with distilled water and analyzed for Pb, Cd, Cu, Cr, Ni, Mn, Al, Fe and Zn. At the conclusion of the reproduction phase, 18 sows, 6 from each dietary group, were randomly selected and slaughtered. Blood, liver, kidney, spleen and muscle were obtained and handled as above prior to analysis of the nine elements.

Growing and Finishing Trial

This trial was also conducted at the Agricultural Research Center in Live Oak, Florida. Seventy-two weanling pigs from each of the first and second litters were randomly selected and allotted to 18 pens according to weight, sex and litter number. There were two barrows and two gilts in each pen, none littermates. They were successively fed starter,

grower and finisher diets until they reached market weight (80 to 90 kg). All diets contained either 0, 10 or 20% sewage sludge. Individual weights and pen feed consumption data were obtained every two weeks for calculation of the average daily gain (ADG) and feed efficiency. The pens were equipped with wooden self-feeders and automatic drinking fountains. At market weight, 18 pigs (nine barrows, nine gilts), one from each pen, were randomly selected, and slaughtered. Blood, liver, kidney, spleen and muscle were secured and handled as described above prior to analyses of selected elements.

Procedure for Mineral Analyses in Tissues

Five to ten grams of tissue were dried overnight in an oven at 110°C for dry matter determination. The dried tissue was predigested with concentrated nitric acid on a hot plate until completely carbonized, then placed in a furnace where the temperature was gradually raised to 480°C and ashed overnight. The crucibles were allowed to cool in a dessicator and weighed. The ash was dissolved in concentrated nitric acid, filtered into a 100 ml volumetric flask and diluted to volume with distilled water according to the AOAC (1975). Selected elements were analyzed as described above. Feed, sludge and feces samples were air dried for three or four days in an oven at 60°C and ground in a stainless steel Wiley mill. Dry matter was then determined at 100°C followed by ashing at 480°C. The ash was dissolved in concentrated HCl and minerals analyzed by atomic absorption spectrophotometry as described above.

Statistical Analysis

In the metabolism trial significance of variation in values due to treatments were analyzed using the least significant difference (LSD) method of Steel and Torrie (1960). The data in all other treatments were tested for significance of variance by the SAS computer method (Barr et al., 1976). Duplicate analyses were made for each element in the various tissues.

RESULTS AND DISCUSSION

Digestibility Trial

Digestibility of crude protein, crude fiber, ash, ether extract and nitrogen-free extract as well as total digestible nutrients (TDN), metabolizable energy (ME) and nitrogen balance data are presented in table 4. Daily feed intake was slightly greater with the 20% sludge diet. Organic matter, TDN, ME, nitrogen retained and all proximate analyses nutrient values except for ether extract were decreased ($P < .05$) in digestibility when 20% sludge was included in the diet. However, values for dry matter, organic matter, crude protein and NFE digestibility as well as TDN, ME and N retained with the 10% sludge-containing diet were equivalent to those of the control diet. It is not apparent why more ether extractable material was present in the feces than in the diet; the diet ranged from .3 to 1.1% (table 2). The increased fecal lipid must have been of metabolic origin. The two sludge-containing diets did not differ significantly in digestibility of dry matter, crude protein, crude fiber or ME. The nutritive value of the sludge diets may have been influenced by the high level (23.8%) of ash present, which was largely sand from the sand-based drying beds of the sewage plant. The ash decreased the organic matter in the 20% sludge-containing diets by approximately 5%.

Average daily weight gains of swine were .69, .60 and .63 Kg with corresponding feed/gain ratio of 2.31, 2.62 and 2.77 for the 0, 10 and

TABLE 4. DIGESTIBILITY OF DRY MATTER, ORGANIC MATTER, CRUDE PROTEIN, ETHER EXTRACT, CRUDE FIBER, NITROGEN-FREE EXTRACT (NFE), TOTAL DIGESTIBLE NUTRIENTS (TDN), METABOLIZABLE ENERGY (ME), AND NITROGEN RETAINED IN SEWAGE SLUDGE DIETS FED SWINE^a

Item	Diets		
	Control	Sludge, 10%	Sludge, 20%
No. swine	12	12	12
Daily feed intake, kg, d.m.	1.59	1.57	1.74
Gain, kg/day	.69	.60	.63
Feed efficiency	2.31	2.62	2.77
Digestibility, %			
Dry matter	76.4 ^b	68.3 ^b	49.8 ^c
Organic matter	79.7 ^b	72.5 ^b	56.5 ^c
Crude protein	77.8 ^b	68.6 ^{bc}	58.2 ^c
Ether extract	-63.6 ^b	-42.9 ^c	-112.5 ^d
Crude fiber	69.7	70.3	63.9
NFE	82.8 ^b	78.2 ^b	61.7 ^c
TDN, %	64.7 ^b	62.3 ^b	53.6 ^c
ME, Mcal/kg	3.74 ^b	2.74 ^{bc}	1.88 ^c
Nitrogen retained, %	50.9 ^b	51.4 ^b	35.6 ^c
Nitrogen intake, g/day	19.1	18.4	24.05
Nitrogen in feces, g/day	4.02	5.7	10.0
Nitrogen in urine, g/day	5.2	3.3	4.6

^a All values on dry weight basis.

^{b,c,d} Values on lines that vary significantly have different superscript letters ($P < .05$).

20% sludge dietary groups, respectively. While weight gain and feed efficiency were not significantly different, there was a trend to poorer utilization of the sludge-containing diets. Kienholz et al. (1976a) fed steers 5 or 15% dried sewage sludge in a finishing ration for 94 days and found that they gained respectively 32 and 63 lbs less than the control group. Edds et al. (1980) fed diets that contained 50% sewage sludge to swine and found gain significantly depressed as well as leukemia and lower PCV (packed cell volume) value in the animals. The toxicity, they observed was associated with increased levels of cadmium and lead and low concentration of copper and zinc as well as low protein content of the sludge ration (9.0% versus 17.2% in the control).

Mineral Concentration in Tissues

The data on mineral analyses of liver, kidney, spleen and muscle showed no increase in Pb, Cd, Cu, Cr, Zn, Mn, Al or Mg due to sludge in the diets. However, swine fed the 20% sludge-containing diet had a significant increase in the blood of Ni, Cu, Cr and Al. Iron was elevated in the liver with the 20% sludge level and Ni was higher in liver, kidney and muscle at the 10% level of dietary sludge. Only traces of Cr appeared in the tissues except in blood of swine fed the 20% sludge diet which indicated that Cr used as a feed and fecal marker was very unabsorbable in the alimentary tract. Kienholz et al. (1976a) found that a diet fed feedlot steers for 84 days and containing 15% sewage sludge resulted in liver and kidney concentrations of lead and mercury that were approximately ten-fold greater and cadmium and copper levels that were twice that of the controls. However, they observed no histological or

pathological lesions in the steer carcass or tissues that could be attributed to the sludge diet. During a ten day trial with rats receiving 0, 10 or 20% dietary sludge, Kindzell et al. (1976) observed that urinary excretion of iron and zinc significantly increased with addition of sewage solids. In the present study, urinary excretion of iron and zinc in swine also increased when sludge-containing diets were fed (table 5).

Reproductive Performance of Gilts Fed University of Florida Sewage Sludge

The reproductive performance of sows fed 10 and 20% sewage sludge diets was not adversely affected during their first and second pregnancies compared to controls. There were apparent linear decreasing weights of pigs from dams fed 10 and 20% sewage sludge diets (table 6). Gestation weight gain of sows decreased ($P < .05$) with the diets that contained 20% sewage sludge in both litters. These results are in agreement with those of Hammell and Edds (1977) when they fed equivalent amounts of Chicago sludge in diets to sows. There were no significant difference in number of pigs farrowed per sow, birth or weaning weight of pigs in either the first or second litters with the three dietary levels of sewage sludge. Approximately one to two more live pigs were farrowed on the average and slightly more (.45 Vs. .25) pigs were weaned per litter with diets that contained 20% sludge. However, the 21-day-old weaning weights were depressed by dietary sludge. Dams fed the 20% sludge diets had weaning weights of offspring that averaged .53 and 1.45 kg less (nonsignificant) than controls for the first and second litters, respectively. The slightly slower gaining pigs appeared to be normal in vigor and health.

TABLE 5. MINERALS IN TISSUES OF PIGS IN METABOLISM TRIAL

	Pb	Cd	Ni	Cu	Cr	Zn	Mn	Al	Fe	Mg
					Liver, mg/kg dry wt					
Control	<.01 ^a	1.5	<.01 ^b	19	<.01	287.2	9.5	1221.0	627.5 ^b	787.4
Sludge 10%	<.01	<.03	34.4 ^c	16.8	<.01	265.2	11.0	1252.8	685.3 ^b	734.7
Sludge, 20%	<.01	<.03	<.01 ^c	18.6	<.01	258.6	10.3	1012.3	325.5 ^c	846.8
					Kidney, mg/kg dry wt					
Control	<.01	7.4	9.4 ^b	33.3	<.01	217.9	8.0	1369.2	242.9	951.8
Sludge, 10%	<.01	6.6	29.3 ^c	29.7	<.01	201.4	7.9	1511.1	297.6	964.0
Sludge, 20%	<.01	6.9	10.3 ^b	40.3	<.01	200.5	8.5	1427.1	227.5	1171.3
					Spleen, mg/kg dry wt					
Control	<.01	<.03	18.7	8.5	<.01	200.3	<.05	1248.1	719.3	1172.5
Sludge, 10%	<.01	<.03	19.4	9.2	<.01	190.1	<.05	1274.2	690.2	1018.5
Sludge, 20%	<.01	<.03	9.9	10.5	<.01	201.5	<.05	1326.7	664.0	1298.2
					Muscle, mg/kg dry wt					
Control	<.01	<.03	8.8 ^b	8.4	<.01	144.1	<.05	1214.4	59.8	1115.8
Sludge, 10%	<.01	<.03	18.9 ^c	7.2	<.01	142.9	<.05	1186.7	68.2	1178.6
Sludge, 20%	<.01	<.03	8.1 ^b	9.6	<.01	175.8	1.3	1347.1	74.4	1185.6

Table 5.—continued

	Pb	Cd	Ni	Cu	Cr	Zn	Mn	Al	Fe	Mg
	Blood, mg/liter									
Control	<.01	<.03	3.7 ^b	7.7 ^b	<.01 ^b	29.3	<.05	418.4 ^b	2625.2	---
Sludge, 10%	<.01	<.03	6.1 ^b	9.1 ^b	<.01 ^b	20.6	<.05	480.1 ^b	2299.8	---
Sludge, 20%	<.01	<.03	22.2 ^c	14.6 ^c	22.4 ^c	31.8	1.9	608.8 ^c	2516.4	---
	Urine, mg/liter									
Control	.04 ^b	<.03	.39 ^b	.20 ^b	.11 ^b	12.04 ^b	.46	2.1	3.4	---
Sludge, 10%	.23 ^c	<.03	.54 ^c	.32 ^c	.20 ^c	22.7 ^c	.54	2.9	6.1	---
Sludge, 20%	.21 ^c	<.03	.52 ^c	.29 ^c	.22 ^c	16.5 ^b	.62	2.1	6.9	---

^a

The symbol < denotes limit of measurement by procedure.

^{bc}Means that have same superscript do not differ ($P < .05$).

TABLE 6. REPRODUCTIVE PERFORMANCE OF SOWS DURING FIRST AND SECOND LITTERS ON DIETS CONTAINING 0, 10 AND 20 PERCENT SEWAGE SLUDGE

Item	First litter			Second litter		
	0%	10%	20%	0%	10%	20%
No. mated	11	11	11	9	10	10
No. farrowed	10	10	10	7	9	8
Breeding weight, kg	152.2	148.2	154.4	164.5 ^a	167.8 ^a	155.1 ^b
Gestation period, days	113.4	115.2	114.4	114.6	114.6	114.5
Gestation weight gain, kg	42.9 ^a	40.3 ^a	30.1 ^b	47.4 ^a	41.8 ^a	31.9 ^b
Total pigs farrowed per litter	9.9	9.3	11.2	9.0	9.2	10.4
Live pigs farrowed per litter	7.4	7.6	9.5	3.3	8.7	9.4
Birth weight of live pigs, kg	1.19	1.24	1.09	1.44	1.24	1.39
Weaning weight/pig (21-day), kg	5.02	4.98	4.49	6.28	5.36	4.83
Pigs weaned/litter	6.55	6.80	7.00	8.00	7.11	8.25

a,b

Means having for given litters on lines same superscript letter do not differ significantly ($P < .05$).

Growing-Finishing Swine Performance

Performance data on first and second litter offspring fed growing-fattening diets that contained 0, 10 or 20% sewage sludge are presented in table 7. Pigs from the second litters fed the sludge-containing diets had lower ($P<.05$) daily weight gains and a greater ($P<.05$) feed to gain ratio than the controls. First litter swine fed diets with sludge increased their feed intake over controls and made similar weight-gains. They had greater ($P<.05$) feed to gain ratios. The failure of the second litter swine to consume more of the sludge-containing diets than the controls as was observed for the corresponding first litter groups may have been due to the stress of summer temperatures, as they were born in June and the first litters were born in January. Similar weight gain depression to that observed with the second litter groups was reported by Kienholz et al. (1976a) for feedlot steers fed 5 or 15% dried sewage sludge diets. Baxter et al. (1980) also observed that cattle ingesting sludge gained less weight than the control group. The feed to gain ratio of their sludge-fed steers averaged 2.2 and 2.0% for the 4 and 12% sludge diets, which was better than the 2.6% observed with the controls.

Mineral Accumulation in Milk and Tissues of Sows

Data obtained on mineral present in milk and tissues of sows slaughtered after weaning their second litters are presented in table 8. The sludge diets resulted in no increase in concentration of selected elements in milk or blood of the sows. However, sows fed the 10 or 20% sludge-containing diets had an increase in cadmium in the kidney and muscle

TABLE 7. PERFORMANCE OF FIRST AND SECOND LITTER OFFSPRING FED GROWING AND FINISHING DIETS THAT CONTAINED 0, 10 AND 20 PERCENT SEWAGE SLUDGE

Item	First litter			Second litter		
	0	10	20	0	10	20
Final weight, kg	94.50	92.90	91.40	95.41	86.91	81.63
Initial weight, kg	8.91	8.95	9.22	10.36	8.36	8.45
Weight gain, kg	85.59	83.95	82.10	85.05	78.55	73.10
Days on test	133	133	133	128	128	128
Avg. daily gain, kg	.64	.63	.62	.66 ^a	.60 ^b	.56 ^b
Avg. daily feed intake, kg	1.94 ^a	2.10 ^{ab}	2.30 ^b	2.03	1.99	1.86
Feed: gain ratio	3.06 ^a	3.34 ^b	3.69 ^b	3.05 ^a	3.36 ^b	3.39 ^b

a,b

Means in the same row that vary significantly have different superscript letters (p<.05).

TABLE 8. EFFECT OF SEWAGE SLUDGE IN DIETS FED SOWS ON CONCENTRATION OF MINERALS IN MILK AND SELECTED TISSUES WHEN THEY WERE SLAUGHTERED^{ab}

Diet	Pb	Cd	Ni	Cu	Cr	Zn	Mn	Al	Fe
Milk, mg/liter									
Control	1.0	.06	.1	1.0	<.01 ^c	9	.2	25	2
Sludge, 10%	1.3	.06	.1	1.1	<.01	9	.2	26	2
Sludge, 20%	1.0	.05	.1	1.2	<.01	10	.1	24	1
Liver, mg/kg dry wt									
Control	<.01	2	3 ^d	39 ^d	1 ^d	231	7 ^d	259 ^d	1217
Sludge, 10%	2	5	14 ^e	64 ^e	11 ^e	243	11 ^e	763 ^e	1133
Sludge, 20%	<.01	4	23 ^e	51 ^e	12 ^e	209	9 ^e	873 ^e	1126
Kidney, mg/kg dry wt									
Control	<.01	4 ^d	5 ^d	26	1 ^d	122 ^d	6	397 ^d	875
Sludge, 10%	<.01	17 ^e	10 ^d	54	8 ^e	123 ^d	5	1952 ^e	392
Sludge, 20%	<.01	24 ^f	20 ^e	44	15 ^f	147 ^e	6	1069 ^e	451
Spleen, mg/kg dry wt									
Control	<.01	.4	8 ^d	10	<.01 ^d	128	<.05	483 ^d	3030 ^d
Sludge, 10%	<.01	2	17 ^e	18	15 ^e	127	<.05	1123 ^e	4736 ^e
Sludge, 20%	<.01	<.03	19 ^e	17	16 ^e	123	<.05	1062 ^e	5104 ^f
Muscle, mg/kg dry wt									
Control	<.01	1 ^d	4 ^d	12	<.01 ^d	113	2	485 ^d	689
Sludge, 10%	<.01	2 ^e	11 ^e	15	12 ^e	111	.6	836 ^{de}	304
Sludge, 20%	<.01	<.03 ^d	21 ^e	10	14 ^e	90	<.05	1006 ^e	125
Blood, mg/liter									
Control	2	1	9	13 ^d	7 ^d	33	.5	384	2051
Sludge, 10%	<.01	2	8	12 ^d	<.01 ^e	28	<.05	139	2289
Sludge, 20%	<.01	1	9	7 ^e	.1	29	<.05	374	2181

a

Milk from three sows/treatment during seventh day of the first lactation period.

b

Tissues from six sows/treatment slaughtered after second pregnancy and lactation period.

c

The < symbol denotes limit of measurement by procedure.

d,e,f

Means in columns with unlike superscript letters differ significantly (P<.05).

(10% sludge only); nickel in the liver, kidney (20% sludge only), spleen and muscle; copper in the liver; chromium in the liver, kidney, spleen and muscle; zinc in the kidney (20% sludge only); manganese in the liver, and aluminum in the liver, kidney, spleen and muscle. Similar concentrations of several elements in swine liver to those found in the present study have been reported (Liebholz et al., 1962; Hedges and Kornegay, 1973; Gipp et al., 1974; Skutches et al., 1974).

Minerals in Weanling Pig Tissues

Concentrations of various elements in selected tissues of weanling offspring from the first and second litters of sows fed diets that contained 0, 10 or 20% sewage sludge are presented in table 9. The liver of pigs fed sludge-containing diets had more ($P < .05$) lead, cadmium, and iron in the first litter pigs, but not in those of the second litter. Aluminum was increased in pigs fed the 20% sludge level in the second litters but not in the first litter pigs. Nickel was increased with the 10% sludge diet but not at the 20% level with the first litter pigs. The sludge diets had no effect on chromium, zinc and manganese in the liver. Kidney concentrations of lead, cadmium, nickel, copper, chromium, zinc, aluminum and iron were increased in weanling pigs from the first litters of dams fed 20% sludge diets, and the same was true of cadmium, nickel and chromium with the corresponding second litter pigs. Manganese concentration in the kidney was not affected by dietary sludge. In the spleen, nickel, copper and manganese at higher concentration with weanling pigs of the first litters of dams fed diets that contained 20% sewage sludge. Manganese levels were also higher in the spleen of pigs from dams fed sewage sludge at the 10% and 20% level, in the first

TABLE 9. MINERALS IN WEANLING PIG TISSUES OF FIRST AND SECOND LITTERS

Sludge in diet %	Lead		Cadmium		Nickel		Copper		Chromium	
	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
	Liver, mg/kg, dry basis									
0	<.01 ^b	7.8	<.03 ^b	.9	<.01	.9 ^b	108 ^b	11	<.01	<.01
10	<.01 ^b	6.2	<.03 ^b	1.1	<.01	2.9 ^c	101 ^b	13	<.01	.62
20	6.51 ^c	5.1	1.06 ^c	1.5	<.01	1.7 ^b	85 ^c	12	.10	.86
	Kidney, mg/kg, dry basis									
0	<.01 ^b	8.0	<.03 ^b	3.5 ^b	<.1 ^b	.7 ^b	32 ^b	20	<.01 ^b	<.01 ^b
10	<.01 ^b	9.9	<.03 ^b	6.2 ^c	<.1 ^b	1.9 ^c	37 ^b	19	.16 ^c	.22 ^b
20	11	8.0	4.57 ^c	6.8 ^c	24 ^c	2.1 ^c	48 ^c	21	.71 ^d	2.02 ^c
	Spleen, mg/kg, dry basis									
0	<.01	13.6	.33	1.3	.1 ^b	2.2	18 ^b	8.2	.5	.4 ^b
10	<.01	11.4	.65	1.3	7.8 ^c	4.7	15 ^b	5.4	.8	<.01 ^b
20	<.01	7.9	.03	1.9	14.5 ^d	3.9	30 ^c	6.7	.1	2.1 ^c
	Muscle, mg/kg, dry basis									
0	<.01	6.0	.30 ^b	.8	<.1 ^b	.9	15	4.0	<.01 ^b	.21 ^b
10	<.01	5.4	.30 ^b	.6	<.1 ^b	1.9	9	2.5	<.01 ^b	.62 ^b
20	<.01	4.4	2.22 ^c	1.1	20.0 ^c	1.5	17	4.2	.62 ^c	<.01 ^c
	Blood, mg/liter									
0	7.2	10.8 ^b	1.12	.03	5.41 ^b	3.2	9.5	14.3	<.01 ^b	1.9 ^b
10	9.9	11.3 ^b	1.12	.03	4.43 ^b	2.5	9.4	11.1	<.01 ^b	1.1 ^b
20	7.6	5.1 ^c	.47	.94	<.01 ^c	2.6	10.0	8.1	1.03 ^c	<.01 ^c

Table 9.—continued.

Sludge in diet %	Zinc		Manganese		Aluminum		Iron	
	1st	2nd	1st	2nd	1st	2nd	1st	2nd
0	336	172	Liver, mg/kg, dry basis					
10	380	160	8.2	6.9	1239	441 ^b	274 ^b	476
20	408	139	10.2	7.5	1563	412 ^b	327 ^b	438
			10.6	7.8	1336	711 ^c	609 ^c	525
0	115 ^b	122	Kidney, mg/kg, dry basis					
10	103 ^b	100	2.7	6.6	1555 ^b	561	256 ^b	224
20	313 ^c	108	6.1	4.4	1691 ^b	351	263 ^b	205
			9.2	5.8	2207 ^c	530	475 ^c	257
0	114	132	Spleen, mg/kg, dry basis					
10	95	115	.05 ^b	2.0	1627	626	566	918
20	128	119	2.62 ^c	1.4	1842	458	616	1029
			2.69 ^c	1.8	1896	851	850	1003
0	59 ^b	111	Muscle, mg/kg, dry basis					
10	66 ^b	62	<.05 ^b	.35 ^b	1235	368	117	52
20	148 ^c	94	.63 ^c	<.05 ^c	1474	264	128	52
			4.28 ^c	.30 ^b	1529	232	345	53
0	25.7	21	Blood, mg/liter					
10	26.8	26	<.05 ^b	<.05	652	440	1901	2172
20	29.7	20	<.05 ^b	<.05	584	342	1881	2186
			<.05 ^c	<.05	607	344	1956	1800

a

1st and 2nd refers to first and second litters; each value is the mean of six pigs (3 male, 3 female) per diet; sex had no effect.

b,c,d

Means in columns for each tissue that have different superscript letters differ significantly with various treatments ($P < .05$).

litters. Chromium was higher in the spleen of corresponding pigs of the second litters of dams fed 20% sludge diets. Concentrations of lead, cadmium, zinc, aluminum and iron in the spleen were not affected by the sludge-containing diets. In skeletal muscle, cadmium, nickel, chromium, zinc and manganese were higher in the first litter pigs of dams fed 20% sludge diets, but, all except cadmium which was less, were not changed in the second litter pigs. Manganese was also less at the 10% sludge level in the second litter pigs. The sludge-containing diets had no effect on lead, copper, aluminum and iron in muscle.

Lead and chromium were less concentrated in the blood of offspring of second litters of dams fed 20% sludge diets. Nickel was less in the blood of the corresponding first litter offspring. Chromium was higher in first litter pigs of dams fed 20% sludge diets. Dietary treatments had no effect on copper, zinc, manganese, iron and aluminum concentrations in the blood.

Minerals in Growing-Finishing Swine

Concentration of selected elements in various tissues at time of slaughter of the growing-finishing offspring fed diets that contained 0, 10 or 20% sewage sludge are presented in table 10. The sludge-containing diets fed the first litter offspring had no effect on concentrations of any of the nine elements in the liver. However, in the second litter pigs cadmium of the 20% sludge group and zinc of both sludge groups were higher than controls. The kidney of the first litters was not affected by the sludge diets. But the kidneys of the second litter swine had more cadmium with both sludge levels. The sludge diets had no influence on mineral deposition in the spleen of pigs from either the first or the

TABLE 10. MINERALS IN TISSUES OF GROWING-FINISHING SWINE FROM FIRST AND SECOND LITTERS FED DIETS CONTAINING SEWAGE SLUDGE (SIX PER TREATMENT)

Sludge in diet %	Lead		Cadmium		Nickel		Copper		Chromium	
	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
	Liver, mg/kg, dry basis									
0	7.3	1.72	1.00	.33b	5.2	.1	44	14	.63	.01
10	8.6	<.01	1.19	.84b	3.2	.7	31	17	.85	2.77
20	7.2	<.01	.56	3.18c	3.4	6.6	19	17	.16	8.05
	Kidney, mg/kg, dry basis									
0	6.8	<.01	.76	1.40 ^b	4.2	<.1	19	22	<.01	<.01
10	11.4	<.01	2.50	8.60 ^c	7.7	.9	32	27	1.1	3.04
20	12.7	<.01	1.28	12.5 ^c	4.7	<.1	25	27	.22	2.18
	Spleen, mg/kg, dry basis									
0	12.1	1.84	1.03	.64	4.9	1.3	13	10	<.01	<.01
10	14.4	<.01	1.73	<.03	5.5	1.0	16	11	<.01	1.84
20	10.1	<.01	.67	<.03	4.6	4.7	15	6	<.22	7.06
	Muscle, mg/kg, dry basis									
0	3.8 ^b	2.14	.79	.75	2.3	<.1	9	9	.62	<.01
10	4.2 ^b	<.01	.72	<.01	2.5	1.2	6	7	.43	3.05
20	7.0 ^c	<.01	.64	<.01	3.2	3.1	10	8	1.15	2.18
	Blood, mg/liter									
0	5.3	11.2	.07	1.80	2.5	.7	11	9	1.01	<.01
10	7.1	9.7	.15	1.29	1.8	.5	11	11	.87	.01
20	4.6	10.6	.16	4.47	1.2	<.1	9	13	.30	.01

Table 10.—Continued.

Sludge in diet %	Zinc		Manganese		Aluminum		Iron	
	1st	2nd	1st	2nd	1st	2nd	1st	2nd
	Liver, mg/kg, dry basis							
0	172	109 ^b	6.2	9.3	441	687	519	615
10	143	136 ^c	5.9	6.8	472	587	614	507
20	168	176 ^d	5.1	8.3	401	853	558	546
	Kidney, mg/kg, dry basis							
0	130	95	4.3	15.7	563	668	296	269
10	177	96	7.0	4.4	781	582	585	242
20	197	139	5.8	5.8	552	612	663	285
	Spleen, mg/kg, dry basis							
0	157	104	3.3	1.6	1000	688	1081	758
10	145	118	3.7	.9	557	596	2507	764
20	131	106	3.7	.6	446	1073	1772	839
	Muscle, mg/kg, dry basis							
0	112	99 ^b	2.4	.51	330	486	227	112
10	85	76 ^c	2.1	<.05	393	545	239	88
20	137	69 ^c	3.7	<.05	517	665	392	87
	Blood, mg/liter							
0	17	24	.6	<.05	259	479	1884	221
10	17	26	<.1	<.05	216	348	1676	229
20	18	24	<.1	<.05	259	418	1491	223

^a First and second litters.

^{b,c,d}

Values in same column with different superscripts are different ($P < .05$).

second litters. Lead was greater in the muscle of the second litter pigs fed the 20% sludge-containing diet, while zinc was lower in muscle of second litter offspring that consumed 10 or 20% sludge diets. None of the minerals were increased in blood due to the dietary sludge. Statistical analyses of the data revealed more significant differences between the two litters studied than between the treatments used. A significant interaction between treatment and litter was observed only for cadmium in the liver.

Smith et al. (1977a) reported that heavy metals and potentially toxic trace elements tend to accumulate in the liver and kidney of rats fed sludge-containing diets. These tissues had higher levels than muscle tissue. They stated that levels of these elements in liver and kidney can be regarded as indicators of potential hazards in the human food chain. Baxter et al. (1980) fed cattle diets containing 0, 4, or 12% digested Denver or Fort Collins sludge for approximately three months and found increases of cadmium, copper and lead in the kidney and liver. The concentration of cadmium in kidneys increased with age of the animal while liver copper concentration appeared to be limited by the dietary intake. A four-month withdrawal period after feeding the sludge for three months did not change the cadmium tissue concentration but copper and lead declined. They concluded that sludge does not appear to have any positive or negative effects on animal health or performance other than to act as diet diluent. The accumulation in kidney of zinc and cadmium was postulated to be due to sequestering by the kidney of metallothionein, which tends to bind both metals in equimolar amounts.

Adverse Effect of Some Minerals in Tissues

Neathery and Miller (1975) reported that young calves are extremely susceptible to lead toxicity. Lead inhibits the utilization of iron and the biosynthesis of heme leading to anemia. It is believed to displace other elements from enzymes. It inhibits lipoamide dehydrogenase in the synthesis of acetyl Co-A and succinyl Co-A from pyruvate and α -ketoglutarate. In dairy cows, Neathery and Miller (1975) also reported that relatively little of the absorbed cadmium, inorganic mercury or lead are secreted in milk or deposited in muscle. In the present study with swine, dietary sludge did not affect cadmium concentration in milk or muscle, but pigs fed sewage sludge had increased ($P < .05$) cadmium in the kidney of sows, and level of the element in the sludge-containing diets had no effect on the amount excreted. Very little cadmium was secreted into milk. In rats, Neathery and Miller (1975) found that a cadmium binding protein limits cadmium transfer to milk. Cadmium, in general, was low in all the tissues analyzed in the present experiment. But according to Doyle (1977), when experimental animals are fed low levels of cadmium, a significant amount can accumulate in the liver, kidney, small intestines and spleen. Dry University of Florida sewage sludge fed to swine at 10 or 20% of the diets produced no obvious toxic effects. However, with high intake levels, Edds et al. (1980) reported that a toxicity may occur due to a deficiency of available protein and other nutrients, or from the accumulation of hazardous chemical residues, or was due to exposures to pathogenic micro-organisms or parasites. Edds et al. (1980) also fed swine Chicago sewage sludge (high in cadmium content) at 50% of dry weight of the diet for 42 days and observed a

cadmium toxicity. The metal blocked the microsomal enzyme system in liver. They also observed depressed growth and feed consumption in pigs fed 83 mg of cadmium per kilogram of feed. Kline et al. (1972) fed pigs 250 ppm dietary copper and observed improved gains and feed efficiency, but 500 ppm copper dietary levels depressed gains and showed no effect on feed efficiency. No mortality or morbidity was observed at the elevated copper levels. Popp et al. (1980) reported that swine receiving 10 or 20% University of Florida sludge in their ration had greater serum transaminase levels plus parenchymal liver disease and degeneration, cellular infiltration with multiple foci of lymphocytes and eosinophils as well as necrosis of the kidney. Kienholz et al. (1976b) reported some adverse effects of heavy metals frequently found in sludge. Cadmium was linked to hypertension, renal dysfunction and Itai-Itai disease. Sheep are especially sensitive to elevated levels of copper. High concentration of copper in the liver may cause liver damage. Copper deficiency as well as toxicity in animals is believed to be caused by a copper-molybdenum imbalance. Diets containing 900 ppm of zinc can cause deleterious effects in sheep and cattle. Lepple (1973) reported that grain treated with mercurials for seed purposes led to outbreak of human poisoning in Guatemala, Iran and Pakistan. In the review, it was pointed out that a New Mexico family became ill after they consumed pork from animals fed seed coated with an organic mercurial called panogen. The grain contained 32 ppm mercury compared to 28 ppm in the pork. Three children became delirious, blind and eventually comatose. On a New York farm, pigs fed wheat grain that had been coated with panogen exhibited symptoms of minamata disease for 3 to 5

days before dying in a coma. Toxicological tests confirmed that the problem was due to mercury poisoning.

SUMMARY AND CONCLUSIONS

The reproductive, growth and metabolism trials of the present study demonstrated the relative health safety and nutritive value of sewage sludge. Reasonable safety to health of swine was indicated by the observations that young sows could be fed 10 and 20% sewage sludge-containing diets and weaned two apparently healthy litters of pigs over approximately one year. There was no secretion in milk or accumulation of hazardous levels of metals in the tissues of the sows or their weanling offspring. The offspring, when grown to market weight on the sludge-containing diets grew normally and did not accumulate hazardous levels of potentially toxic minerals. Feed intake increased with sludge addition to the diets, probably due to a relative high ash (sand) level in the sludge. There was some depression in growth rate and feed efficiency with the sludge-containing diets, especially at the 20% sludge level. However, no mortality or morbidity was observed in any swine that consumed the diets. In the metabolism trial, ME, TDN and nitrogen retention were significantly depressed in the 20% sludge-containing diets. The 10% sludge levels also tended to decrease the availability of these nutrient factors. Feed efficiency was significantly depressed at both 10 and 20% levels of sludge in the growing-finishing diets. Overall, no significant nutritional benefit in reproduction and growth was observed when sludge was included in swine diets. However, the sludge in this study did not demonstrate the presence of any especially hazardous

pathogens, parasites, chemical contaminants or other material that affect the health of the animal consuming it. However, further research would be necessary before recommendations can be made.

BIBLIOGRAPHY

- Adrian, D. D. 1973. Dewatering sewage sludge on sand beds. Chemical Engineering Progress Symposium Series. pp. 188-191.
- American Society of Civil Engineers. 1959. Committee on sanitary landfill practice. Sanitary landfill. Manual of Engineering Practice No. 39. New York, N.Y. 62 p.
- AOAC. 1975. Official methods of analysis (12th Ed.). Association of Official Analytical Chemists. Washington, D.C.
- Ardern, D. A. 1976. The agricultural use of municipal sludge. In R. C. Loehr, ed. 1977. Land as a Waste Management Alternative. Ann Arbor Science. Ann Arbor, MI. p. 583.
- Barr, A. J., J. H. Goodnight, J. P. Sall and J. T. Hellwig. 1976. A user's guide to SAS 76. Sparks Press, Raleigh, N.C.
- Bastian, R. K. 1977. Guidance on land application of municipal sludge. EPA Construction Grants Program. In R. C. Loehr, ed. 1977. Food, Fertilizer and Agricultural Residues. Ann Arbor Science. Ann Arbor, MI. pp. 125-136.
- Bastian, R. K. and W. A. Whittington. 1977. EPA guidance on disposal of municipal sewage sludge onto land. In Proceedings of the 3rd National Conference on Sludge Management Disposal and Utilization. Information Transfer Inc. pp. 32-34.
- Bauer, D. H., D. E. Ross and E. T. Ross. 1977. Land cultivation of industrial wastewaters and sludges. In R. C. Loehr, ed. 1977. Food, Fertilizer and Agricultural Residues. Ann Arbor Science. Ann Arbor, MI. pp. 147-156.
- Baxter, J. C., D. E. Johnson and E. W. Kienholz. 1980. Uptake of trace metals and persistent organics into bovine tissues from sewage sludge - Denver Project. In Proceedings of the Conference on Evaluation of Health Risks Associated with Animal Feeding and/or Land Application of Municipal Sludge. G. Bitton, B. L. Damron, G. T. Edds and J. M. Davidson, eds. Ann Arbor Science. Ann Arbor, MI. pp. 285-310.
- Beaudouin, J., D. L. Hammell and R. L. Shirley. 1977. Sewage sludge diets fed swine Vs. reproduction, growth and tissue minerals. In Proceedings of the 69th Annual Meeting of the American Society of Animal Science. University of Wisconsin, Madison, WI. Abstract No. 199.

- Bertrand, J. E., M. C. Lutrick, H. L. Breland and R. L. West. 1980. Effects of dried digested sludge on performance, carcass quality and tissue residues in beef steers. *J. Anim. Sci.* 50(1):35-40.
- Black, S. A. 1974. Utilization of digested chemical sewage sludges on agricultural lands in Ontario. *In* Proceedings of the National Conference on Municipal Sludge Management. Pittsburg, PA. pp. 107-113.
- Blok, A. 1976. Pelletized sludge: resource recovery product. *In* procedure of the 3rd National Conference on Sludge Management, disposal and utilization. Miami Beach, FL. pp. 81-83.
- Cambel, P. 1971. Improved control of animal waste. *In* Animal Waste Management Proceeding of the National Symposium on Animal Waste. Airlie House, Warrenton, VA. p. 7.
- Cárdenas, R. R. and S. Varro. 1973. Disposal of urban wastes by composting. *In* G. E. Inlett ed. The Avi Publishing Co. Inc., Westport, CT. pp. 183-204.
- Chaney, R. L. 1973. Crop and food chain effects of toxic elements in sludges and effluents. *In* Proceedings of the Joint Conference on recycling municipal sludges and effluents on land. Champaign, IL pp. 129-143.
- Chaney, R. L. 1975. Plant uptake of heavy metals from sewage sludge applied to land. *In* Municipal Sludge Management and Disposal. Proceedings of the 1975 National Conference on Municipal Sludge. Management and Disposal. Anaheim, CA pp. 169-178.
- Chaney, R. L. 1980. Health risks associated with toxic metals in municipal sludge. *In* Proceedings of the Conference on Evaluation of Health Risks Associated with Animal Feeding and/or Land Application of Municipal Sludge. G. Bitton, B. L. Damron, G. T. Edds and J. M. Davidson, eds. Ann Arbor Science. Ann Arbor, MI pp. 59-83.
- Christian, K. R. and M. R. Coup. 1954. Measurement of feed intake by grazing cattle. *New Zealand J. of Sci. and Tech.* 36:328.
- Clayton, K. C. and J. M. Huie. 1973. Solid wastes management. Ballinger Publisher Co. Cambridge, MA 128 p.
- Damron, B. L., O. Osuna, R. L. Suber and G. T. Edds. 1980. Health effects of sewage sludge and grain from sludge treated soils in poultry. *In* Proceedings of the Conference on Evaluation of Health Risks Associated with Animal Feeding and/or Land Application of Municipal Sludge. G. Bitton, B. L. Damron, G. T. Edds and J. M. Davidson, eds. Ann Arbor Science. Ann Arbor, MI. pp. 330-331. (Abstr.).

- Dean, R. B. and J. E. Smith. 1973. The properties of sludges. Proceedings of the Joint Conference on Recycling Municipal Sludges and Effluents on land, US.EPA, Champaign, IL pp. 39-47
- Decker, A. M., R. L. Chaney, J. P. Davidson, T. S. Rumsey, S. B. Mohanty, R. C. Hammond, K. T. Doly and A. Machis. 1980. Forage production and animal performance as affected by liquid and composted sewage sludge. In Proceedings of the Conference on Evaluation of Health Risks Associated with Animal Feeding and/or Land Application of Municipal Sludge. G. Britton, B. L. Damron, G. T. Edds and J. M. Davidson eds. Ann Arbor Science. Ann Arbor, MI. p. 344. (Abstr.).
- Doyle, J. J. 1977. Effects of low levels of dietary cadmium in animal: A Review. J. Environ. Qual. 6(2):111.
- Edds, G. T., K. E. Ferslew and R. A. Bortell. 1978. Feeding of urban sewage sludge to swine. In Proceedings of the 82nd Annual Meeting of U.S. Animal Health Association, Buffalo, N.Y. pp. 207-220.
- Edds, G. T., O. Osuna and C. F. Simpson. 1980. Health effect of sewage sludge for plant production or direct feeding to cattle, swine, poultry or animal tissue to mice. In Proceedings of the Conference on Evaluation of Health Risks Associated with Animal Feeding and/or Land Application of Municipal Sludge. G. Bitton, B. L. Damron, G. T. Edds and J. M. Davidson, eds. Ann Arbor Science. Ann Arbor, MI. pp. 311-325.
- Engelbrecht, R. S. and T. Amirhor. 1976. Disposal of municipal solid wastes by sanitary landfill. In L. B. Baldwin, J. M. Davison and J. F. Gerber, Eds. 1976, Virus Aspects of Applying Municipal Waste to Land. University of Florida Symposium Proceedings. pp. 59-67.
- Epstein, E. and G. B. Willson. 1974. Composting sewage sludge. In Proceedings of the National Conference on Municipal Sludge Management. Pittsburg, PA. U.S. EPA. pp. 123-128.
- Epstein, E., J. M. Taylor and R. L. Chaney. 1976. Effects of sewage sludge compost applied to soil on some physical and chemical properties. J. Environ. Qual. 5(4):422.
- Farrel, J. B. 1974. Overview of sludge handling and disposal. In Proceedings of the National Conference on Municipal Sludge Management. Pittsburg, PA. U.S. EPA. pp. 5-9.
- Farrell, J. B. 1976. EPA's research, development and demonstration program for sludge processing and disposal. In Proceedings of the 3rd National Conference on Sludge Management, Disposal and Utilization. Miami Beach, FL pp. 208-210.
- Firth, J. A. and B. C. Johnson. 1955. Sewage sludge as a feed ingredient for swine and poultry. J. Agr. Food Chem. 3(9):795-796.

- Gabler, R. C. and D. L. Neylan. 1977. Incinerated municipal sewage sludge as secondary resource for metals and phosphorus. In Proceedings of the 3rd National Conference on Sludge Management Disposal and Utilization. Miami Beach, FL. pp. 197-200.
- Garrett, M. T. 1974. Drying of sludge for marketing as fertilizer. In Proceedings of the National Conference on Municipal Sludge Management. Pittsburg, PA. U.S. EPA. pp. 93-95.
- Gipp, W. F., W. G. Pond, F. A. Kallfelz, J. B. Tasker, D. R. van Campen, L. Krook and W. J. Visek. 1974. Effect of dietary copper, iron and ascorbic acid levels on hematology, blood and tissue copper, iron and zinc concentration and ^{64}Cu and ^{59}Fe metabolism in young pigs. J. Nutrition 104:532.
- Goldstein, J. 1977. Sensible sludge: A new look at a wasted natural resource. Rodale Press. Emmaus, PA. 184 p.
- Hackler, L. R., A. L. Neumann and B. C. Johnson. 1957. Feed from sewage. III Dried activated sewage sludge as a nitrogen source for sheep. J. Anim. Sci. 16:125.
- Hammell, D. L. and G. T. Edds. 1978. Effect of feeding sewage sludge on reproduction, growth and tissue mineral accumulation. In Proceedings of the 70th Annual Meeting of the American Society of Animal Science. Michigan State University. East Lansing, MI Abstract No. 627.
- Hansen, L. G., J. L. Dorner, C. S. Byerly, R. P. Tarara and T. D. Hinesly. 1976. Effect of sewage sludge-fertilized corn fed to growing swine. Am. J. Vet. Res. 37:711-720
- Hedges, J. D. and E. T. Kornegay. 1973. Interrelationships of dietary copper and iron as measured by blood parameters, tissue stores and feedlots and feedlot performance of swine. J. Anim. Sci. 37:1147.
- Hill, R. D. and A. Montaque. 1975. The potential for using sewage sludge compost in mine reclamation. In Proceeding of the 1975 National Conference on Municipal Sludge Management and Disposal. Anaheim, CA. pp. 39-45.
- Hoffmann, E. M. and J. Bertrand. 1980. Feed-lot cattle: Bacterial analysis of feed, sludge, feces and animal tissues. In Proceedings of the Conference on Evaluation of Health Risks Associated with Animal Feeding and/or Land Application of Municipal Sludge. G. Gitton, B. L. Damron, G. T. Edds and J. M. Davidson, eds. Ann Arbor Science. Ann Arbor, MI. pp. 332-333.
- Jelinek, C. F. and G. L. Braude. 1976. Management of sludge use on land. FDA Considerations. In Proceedings of the 3rd National Conference on Sludge Management, Disposal and Utilization. Miami Beach, FL. pp. 35-38.

- Kelley, K. c., O. Osuna and R. L. Shirley. 1980. Performance and tissue mineral analyses data on mice. In Proceedings of the Conference on Evaluation of Health Risks Associated with Animal Feeding and/or Land application of Municipal Sludge. G. Bitton, B. L. Damron, G. T. Edds and J. M. Davidson eds. Ann Arbor Science. Ann Arbor, MI. pp. 349-350. (Abstr.).
- Kienholz, E. W., G. M. Ward and D. E. Johnson. 1976a. Sewage sludge metals in cattle tissues. J. Anim. Sci. 43:230. (Abstr.).
- Kienholz, E. W., G. M. Ward, D. E. Johnson and J. C. Baxter. 1976b. Health considerations relating to ingestion of sludge by farm animals. In Proceeding of the 3rd National Conference on Sludge Management, Disposal and Utilization. Miami Beach, Fl. pp. 128-134.
- Kindzell, J. H., P. R. Cheeke and R. W. Chen. 1976. Nutritive value of activated sewage sludge for rats: growth, tissue heavy metals and reproduction performance. Proceeding Western Section. American Society of Animal Science 27:142.
- Kline, R. D., V. W. Hays and G. L. Cronwell. 1972. Related effects of Cu, Zn and Fe on performance, hematology and Cu stores of pigs. J. Anim. Sci. 34:393.
- Lepple, F. K. 1973. Mercury in the environment. A global review including studies in the Delaware Bay Region. College of Marine Studies. University of Delaware. Newark, DE. pp. 8-18.
- Liebholz, J. M., V. C. Speer and V. W. Hays. 1962. Effect of dietary manganese on baby pigs performance and tissue manganese levels. J. Anim. Sci. 21:772.
- Loehr, R. C., W. J. Jewell, J. D. Novax, W. W. Clarkson and G. S. Friedman, Editors. 1979. Land Application of Wastes. Van Nostrand Reinhold Company, New York, NY. 431 p.
- Lutrick, M. C. and Cornell, J. A. 1980. The uptake of certain metals by corn grown on soil treated with Chicago or Pensacola sewage sludge. In Proceedings of the Conference on Evaluation of Health Risks Associated with Animal Feeding and/or Land Application. G. T. Bitton, B. L. Damron, G. T. Edds and J. M. Davison eds. Ann Arbor Science. Ann Arbor, MI. pp. 352-353. (Abstr.).
- McCaslin, B. D. and P. S. Titman. 1977. Fertilizer value of undigested and digested thermoradiation treated sewage sludge on calcareous soil. In R. C. Loehr ed. 1977. Food, Fertilizer and Agricultural Residues. Ann Arbor Science, Ann Arbor, MI. pp. 217-228.

- Manning, W. J. and R. A. Spitko. 1980. Land application of irradiated digested sewage sludge: Effects on heavy metals uptake by field-grown vegetables. *In* Proceedings of the Conference on Evaluation of Health Risks Associated with Animal Feeding and/or Land Application. G. T. Bitton, B. L. Damron, G. T. Edds and J. M. Davidson eds. Ann Arbor Science. Ann Arbor, MI. pp. 353-354. (Abstr.).
- Martin, W. J. and J. C. Baxter. 1976. Institutional arrangements and marketing options of Metro Denver's sludge reuse plan. *In* Proceedings of the 3rd National Conference on Sludge Management, Disposal and Utilization. Miami Beach, FL. pp. 3-6.
- Miller, R. 1973. Soil microbiological aspect of recycling sewage sludge and waste effluents on land. *In* Proceedings of the joint Conference on Recycling Municipal Sludge and Effluents on land. E.P.A., Champaign, IL. p. 83.
- Miner, J. R. and T. E. Hazen. 1971. Transportation and application of organic wastes to land. *In* Soils for Management of Organic Wastes and Wastewaters. Soil Science Society of America. Madison, WI.
- Montague, A. 1975. Urban sludge disposal or utilization alternatives: Socio-economic factors. *In* Proceedings of the 1975 National Conference on Municipal Sludge Management and Disposal. Anaheim, CA. p. 60.
- Natarajan, M. and T. J. Varghese. 1978. Digested sewage sludge cakes as manure for fish culture. *Nutr. Abstr. and Rev.* 49:366.
- Naylor, L. M., R. C. Loehr, L. D. Tyler, M. B. McBride, D. Iisk and B. McDuffie. 1980. Uptake of cadmium and zinc by corn grown on acid soils fertilized with a high cadmium sludge. *Proceedings of the Conference on Evaluation of Health risks Associated with Animal Feeding and/or Land Application of Municipal Sludge.* G. Bitton, B. L. Damron, G. T. Edds and J. M. Davidson, eds. Ann Arbor Science. Ann Arbor, MI. pp. 354-355. (Abstr.).
- Neathery, M. W. and W. J. Miller. 1975. Metabolism and toxicity of cadmium, mercury and lead in animals: a review. *J. Dairy Sci.* 58:1767.
- Otte, A. D. and K. V. Laconde. 1977. Environmental assessment of municipal sludge utilization at 9 locations in the U.S. *In* R. C. Loehr ed. 1977. Food, Fertilizer and Agricultural Residues. Ann Arbor Science. Ann Arbor, MI. pp. 135-146.
- Pal, D. 1980. Chemical characterization of sewage sludges for prediction of potential risks in land treatment systems. *In* Proceedings of the Conference on Evaluation of Health Risks Associated with Animal Feeding and/or Land Application of Municipal Sludge. G. Bitton, B. L. Damron, G. T. Edds and J. M. Davidson, eds. Ann Arbor Science. Ann Arbor, MI. p. 355-356.. (Abstr.).

- Parr Instrument Company. 1960. Oxygen bomb calorimetry and combustion methods. Technical Manual No. 130. Parr Instrument Co., Moline, IL.
- Perkin Elmer Corporation. 1973. Analytical methods of atomic absorption spectrophotometry. Perkin-Elmer Corp., Norwalk, CT.
- Peterson, J. R., C. Lue-Ling and D. R. Zeng. 1973. Chemical and biological quality of municipal sludge. In Recycling Treated Municipal Wastewater and Sludge through Forest and Cropland. W. E. Sopper and L. T. Kardos, eds. Penn State University Press. pp. 23-36.
- Popp, J. A., O. Osuna, G. T. Edds. 1980. Pathologic lesions in cattle, swine and poultry receiving DCS, DFS or corn from DCS amended soils. In Proceedings of the conference on evaluation of health risks associated with animal feeding and/or land application. G. T. Bitton, B. L. Damron, G. T. Edds and J. M. Davidson, eds. Ann Arbor Science. Ann Arbor, MI. pp. 336-337. (Abstr.).
- Reisner, G. C. and R. L. Christensen. 1977. Impact on farm costs and returns from sludge application in forage production. In R. C. Loehr, ed. 1977. Food, Fertilizer and Agricultural Residues. Ann Arbor Science. Ann Arbor, MI. pp. 157-167.
- Robens, J. F. 1980. Regulatory aspects of sludge application to land. In Proceedings of the conference on evaluation of Health Risks Associated with Animal Feeding and/or Land Application of Municipal Sludge. G. Bitton, B. L. Damron, G. T. Edds and J. M. Davidson, eds. Ann Arbor Science. Ann Arbor, MI. pp. 5-12.
- Roesler, J. F. 1977. The state of the art for automation of sludge handling processes. In Proceeding of the 3rd National Conference on Sludge Management Disposal and Utilization. Miami Beach, FL. pp. 173-178.
- Ryan, J. A. 1978. Cadmium: utilization and environmental implications. In Proceedings of the 1st Annual Conference of Applied Research and Practice on Municipal and Industrial Waste. Madison, WI. p. 269.
- Satriana, M. J. 1974. Large scale composting. Noyes Data Corporation. Park Ridge, N.J. 269 p.
- Schauer, P. S., W. R. Wright and J. Pelchat. 1978. Sludge borne heavy metal availability and uptake by vegetation crops under field condition. J. Environ. Qual. 9(1):69.
- Sidle, R. C. 1977. The potential use of forest land as a sludge disposal site. In R. C. Loehr ed. 1977. Food, Fertilizer and Agricultural Residues. Ann Arbor Science. Ann Arbor, MI. pp. 199-217.
- Sing, S. M. and P. N. Ferns. 1978. Accumulation of heavy metals in rainbow trout (*Salmo Gairdneri*. R) maintained on a diet containing activated sludge. J. of Fish Biology. 13(2):277-286.

- Sittig, M. 1979. Incineration of industrial hazardous wastes. Pollution Technology. Review No. 63. Noyes Data Corporation. Park Ridge, N.J.
- Skutches, C. L., D. L. Herman and F. H. Smith. 1974. Effect of dietary free gossypol on blood components and tissue iron in swine and rats. J. Nutr. 104:415.
- Smith, G. S., J. M. Caddle, P. M. Walters and H. E. Kiesling. 1976a. Sewage solids as feeds for ruminants. J. Anim. Sci. 43:334. (Abstr.).
- Smith, G. S., B. D. McCaslin and H. E. Kiesling. 1976b. Recycling sewage solids as feeds and fertilizer. J. Nutr. 106:XXXi (abstr.).
- Smith, G. S. and C. R. Staples. 1976. Heavy metals in rats fed sewage solids. J. Ani. Sci. 43:233. (Abstr.).
- Smith, G. S., H. E. Kiesling, J. M. Caddle, C. Staples, L. B. Bruce and H. D. Sivinski. 1977a. Recycling sewage solids as feedstuffs for livestock. In Proceeding of the 3rd National Conference on Sludge management, Disposal and Utilization. Miami Beach, FL pp. 119-127.
- Smith, G. S., H. E. Kiesling and H. D. Sivinski. 1977b. Nutrient usage and heavy metal uptake by sheep fed thermoradiated, undigested sewage solids. In R. C. Loehr, ed. 1977. Food, Fertilizer and Agricultural Residues. Ann Arbor Science. Ann Arbor, MI. pp. 239-256.
- Smith, G. S., H. W. Kiesling and E. E. Ray. 1979. Perspective usage of sewage solids as feed for cattle. In Proceedings of the 8th National Conference on Municipal Sludge Management. Impact of Industrial Toxic Materials on POTW Sludge. Miami Beach, FL. pp. 190-200.
- Smith, G. S., H. E. Kiesling, C. H. Herbel, E. E. Ray, P. Trujillo, R. Oscaberro and J. S. Sivinski. 1980. Sewage solids as supplemental feed for ruminants grazing rangeland forage. Publication S. P. 132. New Mexico State University Agr. Exp. Sta. Las Cruces, N.M. 5 p.
- Steel, R. G. D. and J. H. Torrie. 1960. Principles and Procedures of Statistics. McGraw Hill Book Company, New York.
- Stevens, R. W. 1976. Perspectives on fertilizer use, residue utilization and food production. In R. C. Loehr, ed. 1977. Food, Fertilizer and Agricultural Residues. Ann Arbor Science, Ann Arbor, MI. pp. 5-26.
- Stoewsand, G. S., J. T. Reid, W. M. Hasehek, J. N. Telford and D. J. Lisk. 1980. Hepatic changes in lambs fed corn silage grown on municipal sludge amended soil. In Proceedings of the Conference on Evaluation of Health Risks Associated with Animal Feeding and/or Land Application of Municipal Sludge. G. Bitton, B. L. Damron, G. T. Edds and J. M. Davidson, Eds. Ann Arbor Science. Ann Arbor, MI. pp. 359. (Abstr.).

- Styers, F. C. 1973. Sludge recycling. The Winston-Salem experience. Proceedings of the 1978 National Symposium on ultimate disposal of wastewaters and their residuals. Durham, N.C.
- Toth, S. J. 1973. Composting agricultural and industrial organic wastes. In G. E. Inlett ed. Symposium: Processing Agricultural and Municipal Wastes. The AVI Publishing Co., Inc., Westport, CT. p. 172.
- Vesilind, P. A. 1979. Treatment and disposal of wastewater sludges. Ann Arbor Science. Ann Arbor, MI. 323 p.
- Waller, R. 1976. Impact of sewage treatment and operations on sludge handling and disposal. In Proceedings of the 3rd National Conference on Sludge Management, Disposal and Utilization. Miami Beach, FL. pp. 3-6.
- White, E. C., D. L. Hammell, O. Osuna. 1980. Effect of feeding digested sewage sludge on long-term sow reproductive performance. In Proceedings of the Conference on Evaluation of Health Risks Associated with Animal Feeding and/or Land Application of Municipal sludge. G. Bitton, B. L. Damron, G. T. Edds and J. M. Davidson, Eds. Ann Arbor Science. Ann Arbor, MI. pp. 339-340.
- Willson, G. B., E. Epstein and J. R. Parr. 1976. Recent advances in compost technology. In Proceedings of the 3rd National Conference on Municipal Sludge Management, Disposal and Utilization. Miami Beach, FL. pp. 167-172.

BIOGRAPHICAL SKETCH

Joseph Jean Beaudouin was born March 16, 1938, in Les Cayes, Haiti. In July 1963, he graduated from the State University of Haiti with a B.S. degree in Agronomy. From August 1963 to September 1966, he worked for the Haitian Department of Agriculture as an extension agent. In April 1968, he obtained his Master of Science in Agriculture from the Interamerican Institute of Agricultural Sciences of the Organization of American States (OAS) in Turrialba, Costa Rica. At present, he is a candidate for the Ph.D. degree in Animal Science at the University of Florida. He is married to the former Winie Bernard, who is also from Haiti.

He is a member of the Latinamerican Association of Animal Production and the American Society of Animal Science.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Dr. R. L. Shirley, Chairman
Professor of Animal Science

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Dr. A. Z. Palmer
Professor of Animal Science

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Dr. G. T. Edds
Professor of Veterinary Science

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Dr. D. S. Anthony
Professor of Botany

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Dr. P. H. Smith
Professor of Microbiology and Cell
Science

This dissertation was submitted to the Graduate Faculty of the College of Agriculture and to the Graduate Council, and was accepted as partial fulfillment of the requirements for the degree of Doctor of Philosophy.

March 1981

Dean, College of Agriculture

Dean, Graduate School

UNIVERSITY OF FLORIDA

3 1262 08553 9582