

AN ABSTRACT OF THE THESIS OF

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(Name of student) (Degree)

in ANIMAL SCIENCE presented on July 24, 1967
(Major) (Date)

Title: ENERGY-PROTEIN RELATIONSHIPS IN HIGH-FAT
RATIONS FOR GROWING-FINISHING SWINE

Abstract approved: [REDACTED]

An experiment was conducted with 48 Yorkshire x Berkshire crossbred barrows to evaluate the influence of varying Calorie:protein ratios in high-fat rations on performance and carcass quality of growing-finishing swine. Pigs were individually fed rations containing three levels of fat (lard): 0, 15 and 30 percent. Each fat level was incorporated into rations differing by Calorie:protein ratio (Kcal. digestible energy per gram of crude protein). Two ratios were employed, based on (1) a ration containing 1500 Kcal. of digestible energy and 14 percent crude protein, approximately that commonly used in swine grower diets, and (2) a ration containing a similar energy level as (1), with the crude protein level raised to 20 percent. Responses were obtained over two growth periods (60-130 and 130-200 pounds live weight). Animals were slaughtered after exceeding a weight of 200 pounds and carcass data

were collected.

Pigs consuming the higher protein diets exhibited a significantly poorer average daily gain ($P < .01$) and were less efficient in dry matter utilization ($P < .05$). Further evidences of the lower nutritive value of the higher protein diets were: an apparent reduction in daily intakes of digestible energy and dry matter, and a significantly ($P < .01$) larger quantity of calculated digestible energy consumed per pound of gain. The poorer performance noted with the higher protein diets tended to become more pronounced with increasing levels of fat.

Inclusion of increasing quantities of fat significantly ($P < .01$) improved both average daily gain and dry matter utilization. Considering the mean results from the two ratios used, average daily gain was increased by 7.5 and 18.4 percent and dry matter conversion by 21.3 and 45.0 percent with the addition of 15 and 30 percent fat, respectively. Further, additional fat resulted in significantly ($P < .01$) greater daily intakes of calculated digestible energy and crude protein. Calculated digestible energy consumption per pound of gain as an indication of energy utilization was not altered by varying fat levels.

The effects of energy:protein ratio and fat supplementation on pig performance were comparable over the two growth periods studied. Statistically, the addition of fat to rations of older pigs

was found to be more beneficial ($P < .01$) in relation to dry matter conversion than with younger animals. However, there was no indication that this interaction between growth stage and fat level existed with regard to calculated digestible energy consumed per pound of gain. This finding, along with the main effects of added fat on dry matter and calculated digestible energy consumption per pound of gain, showed that efficiency of gain would be more representative if reported in terms of energy utilization in studies concerned with varying caloric density.

Additional fat brought about a definite trend toward increased carcass fatness. With increasing fat levels there was a significant, ($P < .01$) linear increase in backfat thickness and an apparent reduction in loin eye area. Increasing the quantity of dietary protein in relation to the energy content of the diet was ineffective in improving carcass desirability. Pigs fed the low-fat, high-protein ration had 0.28 inches more backfat ($P < .05$) and 0.49 square inches less loin eye area than comparable animals on the low-fat, low-protein ration. However, at the higher fat levels there was no indication of poorer carcass quality being associated with higher protein intake.

ENERGY-PROTEIN RELATIONSHIPS IN HIGH-FAT
RATIONS FOR GROWING-FINISHING SWINE

by

FINDLAY MOYE PATE

A THESIS

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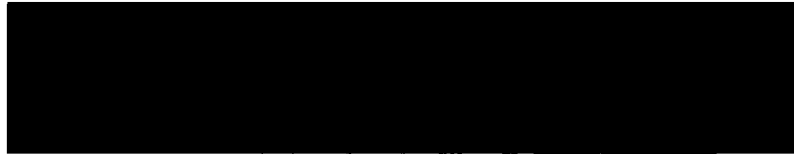
OREGON STATE UNIVERSITY

in partial fulfillment of
the requirements for the
degree of

MASTER OF SCIENCE

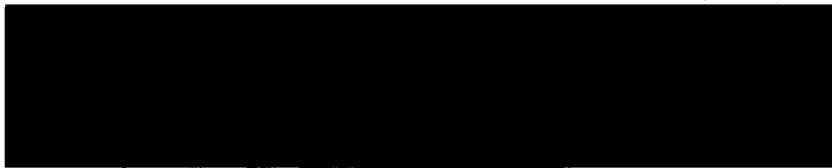
June 1968

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Date thesis is presented July 24, 1967

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ACKNOWLEDGMENTS

To Dr. James E. Oldfield, the author owes a debt of gratitude for his generous assistance, guidance and advice throughout the course of this study.

Sincere appreciation is extended to Roy Fancher for his assistance with the experimental animals, and to Dr. David C. England for his most helpful suggestions in carrying out this study.

The author wishes to express his appreciation to the Department of Animal Science for the financial aid supplied during the course of his study at Oregon State University.

Appreciation is extended to Dr. Kenneth E. Rowe, Experiment Station Statistician, for his advise and assistance in analyzing experimental data.

I especially want to thank my wife, Vicky, for her active help and encouragement throughout the course of this study.

TABLE OF CONTENTS

INTRODUCTION	1
REVIEW OF LITERATURE	4
Influence of Energy Source in Energy-Protein Studies; Fat vs. Carbohydrate	5
Energy and Protein as Factors Affecting Food Intake	8
Expressing Energy-Protein Relationship	10
Importance of Protein Quality	12
Energy-Protein Relationship as Affected by Growth Stage	14
Influence of Energy-Protein Relationships on Animal Response and Nutrient Utilization	15
Influence of Energy-Protein Relationships on Carcass Composition	19
General Conclusions	21
EXPERIMENTAL PROCEDURE	24
Methods and Materials	24
RESULTS AND DISCUSSION	31
Effect of Calorie:Protein Ratio	33
Effect of Fat Level	38
Effect of Growth Stage	42
Effect of Calorie:Protein Ratio and Fat Level on Carcass Quality	44
SUMMARY	47
BIBLIOGRAPHY	50
APPENDIX	56

LIST OF TABLES

<u>Table</u>		<u>Page</u>
1.	Ingredient formulas of experimental rations.	27
2.	Nutrient composition of experimental rations (moisture free basis).	32
3.	Influence of Calorie-protein ratio, fat level and growth stage on rate and efficiency of gain of growing-finishing swine.	34
4.	Influence of Calorie:protein ratio and fat level on growth rate, efficiency of gain and carcass characteristics of growing-finishing swine.	35
5.	Main effect of fat level and Calorie:protein ratio on pig response and carcass characteristics.	36
<u>Appendix Table</u>		
I.	Statistical analysis (mean squares).	56

ENERGY-PROTEIN RELATIONSHIPS IN HIGH-FAT RATIONS FOR GROWING-FINISHING SWINE

INTRODUCTION

Over the past few decades economic changes have developed in the inedible tallow and grease trade which are of major concern to the livestock industry. Beginning with the termination of World War II there has been a consistent decline in the price of inedible fats. Statistics (U. S. Economic Research Service, 1966) show that the price of prime tallow for the ten years between 1956 and 1965 has averaged about 2 cents per pound below that for the preceding ten years (7.05 vs. 9.02 cents). Since inedible fat is an important byproduct of the livestock industry, this reduction in value will in turn affect the value of the animal produced.

This economic situation is attributed to the steady increase in the production of inedible fats without a simultaneous increased demand by the U. S. market. In 1965 there were 4,731 million pounds produced compared to 1,862 million pounds in 1946. Of that produced in 1965, 2,124 million pounds were exported, which indicates the enormous surplus beyond U. S. consumption. This rising surplus is primarily due to the drastic decline in the use of inedible fat in the soap industry, which at one time was one of its major outlets. In 1946, 1,210 million pounds of fat were employed in the

manufacture of soap vs. 688 million pounds in 1964. More recently, possibly one of the most striking effects on the fat situation in general, has resulted from the changing food habits of the American public due to the publicity given to polyunsaturated fatty acids in relation to heart disease. This has led to a sizable increase in the use of liquid fats as a replacement of edible fats from animal sources (Smith, 1966), a trend which will have an even more important influence on the animal industry in the future.

The only market which looks promising is the channeling of inedible fats back into the livestock industry as a supplemental energy source in animal feeds. In 1953 only 71 million pounds were used in livestock rations compared to 714 million pounds in 1964, over a 1,000 percent increase. Although it is impractical to produce animal fat specifically for feed use, at the present fat is a predestined byproduct of the livestock industry, and if it is necessary that it be utilized in animal rations in order to maintain maximum profit, its use must be developed to the fullest potential.

During the early 1950's considerable interest was directed toward the use of fat in swine rations. Although practically devoid of other nutrients, fats have proven to be a very potent source of energy for swine, containing approximately 2.5 times the digestible energy of an equivalent amount of corn. Further, fat supplementation has been shown to promote a faster rate of growth and improved

feed efficiency. However, to partially offset these advantages, increasing quantities of dietary fat have the tendency to impair carcass quality.

It has been recognized that both pig performance and carcass desirability associated with the use of fat is dependent upon the balance between the dietary energy and protein fraction of the ration. Since the pig consumes quantities of feed to satisfy its energy needs, two conditions control the quantities of protein taken in by the animal: (1) the energy level of the diet and (2) the concentration of protein in the diet. Therefore, if the caloric density is increased, there should be a subsequent increase in the protein content of the ration, proportional to the increased energy level, to maintain adequate protein intake. However, there is evidence (Lewis, 1965; Clawson, 1956) that the quantity of protein in relation to the energy level generally adequate for conventional (low-fat) rations is insufficient with the addition of fat, particularly in relation to carcass quality.

Considering the above evidence, the present study was initiated to investigate the potential of rather high levels of fat and to determine the advantages of increasing the protein concentration in relation to the energy level beyond that commonly employed in conventional rations for swine.

REVIEW OF LITERATURE

The most recent report by the National Research Council (1964) on the nutrient requirements of swine states that for the greatest accuracy, nutrient needs should be calculated on the basis of each nutrient per kilocalorie of diet. This close association among essential dietary nutrients and energy supply has been recognized for quite some time. Mitchell (1934) states "---the utilization of any food nutrient for any purpose in the animal body requires the simultaneous presence of all other nutrients for that purpose." This relationship not only refers to nutrient deficiencies as commonly believed, it is of equal importance that dietary excesses be minimized to insure proper nutritive balance (Mitchell, 1934; Crampton, 1964).

The energy supplying fraction of the ration is used as a reference for the supply of other nutrients for two reasons. First, energy carriers make up the major proportion of most feed ingredients and all rations; and second, the quantity of feed consumed daily by growing-finishing swine fed ad libitum is controlled by the energy concentration of the ration (Crampton and Lloyd, 1959).

In all probability the most noteworthy interrelation among nutrients in swine rations is that which exists between the energy and protein moieties. Its importance was realized by Henry (1908) in

the early 1900's when he initiated a means of evaluating feedstuffs and complete rations employing this concept, which he termed "nutritive ratio". This ratio was derived from the relationship between the quantity of digestible crude protein in a given feedstuff or ration and the amount of digestible carbohydrate and ether extract. However, most of the research carried out in the study of energy-protein relationships in animal rations has been relatively recent. Review of the literature indicates that interest in this specific area did not fully develop until the early-to-mid 1950's. This was possibly due to the fact that up until this period all rations were relatively uniform in energy content since the use of fats in livestock and poultry rations was practically negligible previously.

Combs, working with poultry at the University of Maryland, is considered to be the first to investigate the relationship between the dietary energy:protein ratio and animal response under practical conditions, and by far the majority of work in this area has dealt with poultry. Although a sizable quantity of research has been published on swine, these data obtained through experimentation with poultry are generally applicable to swine studies, since the two species are comparatively similar in their nutritive needs.

Influence of Energy Source in Energy-Protein Studies; Fat vs. Carbohydrate

During the latter half of the nineteenth century a great deal of

concern developed in the evaluation of feedstuffs in terms of animal usage. Rubner became interested in the replacement value of the principal nutrients (fats, carbohydrates, and proteins) as energy sources, and formulated the now classical "isodynamic law" (Lusk, 1928). This law evolved into what is now termed "physiological fuel values" of these nutrients which state that the value of fat as an energy source is approximately 2.25 times that of carbohydrate.

Quite often it is popularly accepted that the only difference between fat and carbohydrate as dietary energy sources is in their caloric density. In some cases, depending on the response being measured, this may be true. Munro (1951) in a comprehensive review on carbohydrate and fat as factors in protein utilization and metabolism reported that these two nutrient classes appear to exhibit little difference in protein sparing ability when both are present in the diet. Carroll and Bright (1965) found that rats fed isocaloric diets varying in carbohydrate-to-fat ratio showed little or no difference in response measured as weight gain, feed intake, or feed efficiency.

In some instances, particularly with regard to carcass composition, there is a definite difference in response. Carroll and Bright also found that total liver lipids were significantly affected by carbohydrate-to-fat ratio. Their data show that the livers of rats consuming high-fat diets contained larger quantities of fat. Forbes

et al. (1946a, 1946b) noted that rats fed diets of identical energy: protein ratios and equivalent energy intake showed increased gain in body fat as the caloric density of the ration was increased by the addition of corn oil. They also demonstrated, along with French, Black and Swift (1948), that with increases in the fat level of the diet, heat production was significantly decreased. This measurement coincided with higher utilization of energy, which indicates that energy was being stored as fat in the body.

Ahrens and co-workers (U.S. Agricultural Research Service, 1967) have studied varying proportions of fat and carbohydrate in the diets of rats in relation to their weight reducing potential. Comparing diets differing in levels of beef tallow (7 and 30 percent) and cornstarch (57 and 16 percent), they found that a given number of calories did not alter final weight whether obtained from a high-fat or low-fat diet; but with the high-fat diets, the proportion of body fat was generally higher.

The work of Sibbald et al. (1957) showed that varying the energy content of rat diets through the addition of cellulose such that the energy source was derived solely from carbohydrates had no effect on carcass composition. Although this experiment was rather short in duration (two weeks), it might indicate that the results of Forbes and Ahrens could not be attributed solely to differences in caloric density of rations used.

Lewis (1965) states that overfat swine will be produced if increased dietary fat is used not to replace part of the energy supply but to add to it. Further, his experimental data showed that by adjusting feed intake to maintain a constant digestible energy intake over varying fat levels (0 to 10 percent), increasing levels of dietary fat tended to produce a leaner carcass, measured as percent total lean, backfat thickness, and loin eye area.

There is a definite need for additional and more critical studies pertaining to differences between dietary fat and carbohydrate in relation to carcass composition, particularly with swine.

Energy and Protein as Factors Affecting Food Intake

Cowgill (1928), using dogs as experimental subjects, was perhaps the first to show conclusively that the predominant factor controlling food intake of monogastrics is the caloric density of the ration. That is, these animals tend to consume quantities of food necessary to satisfy their needs for energy.

Mitchell (1962) states that one provision to the above convention is that the ration be balanced with all essential nutrients, since most dietary deficiencies of an essential nutrient will lead to impaired appetite, or even complete refusal of food. Bosshardt and Barnes (1946) have shown this effect in relation to protein balance. They found that rats exhibited maximal caloric intake per unit of

body size, and the highest intake was obtained at that level of protein which maintained maximal protein utilization.

Combs et al. (1964) reported that voluntary energy consumption of chicks increased in relation to energy needs as protein level was reduced. Greeley, Meade and Hanson (1964), working with swine, also found that over varying levels of dietary fat, increasing the protein content of the ration produced a significant linear decrease in feed consumption. From these reports it may be derived that to a certain extent animals might tend to satisfy their protein needs without regard to energy intake.

Protein balance may exert a limited effect on food intake; however, most reports reviewed indicate that ration consumption is largely controlled by caloric density even though protein level may vary considerably. Experimental evidence of this has been presented by Hegsted and Haffenreffer (1949). Working with rats fed diets varying both in quantity and quality of protein, they found that caloric intake varied with the mean body weight raised to a constant power even though weight gain could not be directly related to caloric intake. They suggested that if the food eaten does not contain enough protein to allow growth or only limited growth the remaining calories must be consumed, probably in increased activity. Although possible changes in body composition were not determined, Hegsted felt that Calories unaccounted for by increased gain were not consumed

in fattening.

A second factor which affects food intake is palatability.

There have been few reports of problems of this nature attributed to the incorporation of fats in swine rations. Those noted have dealt with a specific type of fat, such as corn oil (Greeley, Meade and Hanson, 1964). In general, most fats appear to be readily consumed by swine. Pond, Kwong and Loosli (1960) noted that pigs consumed significantly greater quantities of TDN with the addition of 10 percent beef tallow, which agrees with the statement by Morrison (1959), that fats may improve the palatability of the ration, possibly through the reduction of dustiness. However, Donaldson, Combs and Romoser (1956) noting that chicks consumed larger amounts of energy with increasing levels of dietary fat, reasoned that the increased intake from fat vs. carbohydrates might be related to differences these two nutrients have on appetite control mechanisms.

Expressing Energy-Protein Relationship

One of the major criticisms in the planning and reporting of energy-protein studies has been the irregularities encountered in methods of expressing energy-protein relationships. This variability in procedure makes the comparison of individual studies quite complicated. Poultry nutritionists have been relatively consistent in that most of their reports show this relationship computed

either as Kcal. of metabolizable, or productive energy per pound of diet per percentage of crude protein.

Researchers working with swine have been less consistent in their computations. Many workers simply give the level of energy and crude protein of individual experimental treatments. Others have used computed ratios varying from gross Calories per gram of protein (Clawson et al., 1960), to Kcal. digestible energy per pound per percentage of crude protein (Lowrey, Pond and Maner, 1958).

A possible reason for this variation might be the lack of standardized tables for the energy value of feedstuffs for swine similar to those presented on productive energy (Fraps, 1946) and metabolizable energy (Titus, 1961) for poultry. Wagner et al. (1963), Boenker, Tribble and Pfander (1960), Noland and Scott (1960), and Sewell, Thomas and Price (1961) have employed values determined for poultry in their calculations; however, Mulholland, Erwin and Gordon (1960) indicate that productive energy values of feedstuffs determined for poultry are not the same for swine.

Diggs et al. (1965) have determined the metabolizable energy value of a selected few feed ingredients, but other than these, values of this nature are non-existent. A complete list of values for digestible and gross energy of feedstuffs commonly used in swine rations is presented in the National Research Council (1964) swine

publication. However, these are somewhat crude, especially those for gross energy, compared to metabolizable or productive energy data for evaluating feeds. This is possibly the reasoning behind their being avoided by some workers.

Almquist (1958) feels that all of the current methods used in expressing energy-protein balance are somewhat ambiguous, in that they imply that all dietary protein is simultaneously consumed to produce Calories and also for growth purposes. He proposes that the most accurate procedure would be to designate the energy fraction as non-protein energy and relate this value to the protein content of the ration. In applying the above procedure to some previous studies carried out with chicks and rats, he found a tremendous increase in the correlation between energy:protein ratio and growth.

Importance of Protein Quality

In any nutritional study concerning protein, one factor which invariably demands special consideration is protein quality. The importance of essential amino acid balance in energy-protein studies has been adequately demonstrated by several workers. Lowrey et al. (1963) noted that the addition of corn oil to baby pig diets resulted in an increase in gain when casein (5 percent) was used as the source of protein, but with gluten supplying an equal quantity of protein, added energy depressed growth.

Mitchell et al. (1965), working with pigs on 16 percent crude protein rations, found a significant lysine x energy interaction in response. They reported that feed efficiency on low energy diets remained constant over varying additions of lysine, while with high energy rations there was an improvement in feed utilization with increasing levels of lysine. Similar results have been reported by Baldini and Rosenberg (1955) experimenting with chicks; their data show that the methionine requirement of the chick expressed in percent of total diet increased as the productive energy level increased.

These reports bring out two important aspects which apply directly to energy-protein studies. First, they establish the role of essential amino acids as the necessary nutrients required by the animal in relation to the dietary energy level rather than protein which merely acts as a carrier. Second, they give ample evidence for the need of a consistent balance in amino acid make-up when carrying out energy-protein experiments.

This second point is of particular importance; not only does it complicate the comparison of results from separate studies, but it tends to distort the interpretation of data within individual studies if the ratio between amino acids is altered. Since, of necessity, energy and protein levels are varied, this irregularity can be eliminated by supplying protein-containing ingredients at a constant ratio in all treatments.

Energy-Protein Relationship as Affected by Growth Stage

It is generally accepted that the need of most essential nutrients required by swine progressively decreases in relation to the total ration as body weight increases. The National Research Council (1964) recommends a 16 percent crude protein level for 50-75 pound pigs, decreasing this quantity by intervals of 2 percent for each 50 pound increase in weight gain, such that 175-225 pound pigs require a level of only 12 percent. Yet the digestible energy requirements remain constant, 1500 Kcal. per pound of ration, over the same growth period. This suggests that the most adequate balance between energy and protein is dependent on the growth stage of the animal.

Several workers have shown experimentally that this is the case. Noland and Scott (1960) reported that during the earlier growth periods (40-125 pounds), Calorie:protein ratios (Kcal. productive energy per percent crude protein) from 45 to 75 produced the fastest gains, while ratios around 100 resulted in the most rapid gains during the finishing period. Sibbald, Slinger and Ashton (1962), working with poultry, state that it is generally accepted that for each type of bird, in each stage of production, there is an optimum Calorie:protein ratio. These workers also noted that weight gain curves for older birds tended to be horizontal at low energy:

protein ratios compared to more clearly defined peaks for younger fowl. This indicates that energy-protein relationship is much more critical for younger animals.

Recently, Lewis (1965) reviewing studies carried out at the University of Nottingham, has questioned the merit of the convention of decreasing the dietary protein level for the larger pigs in relation to carcass quality. To confirm his belief, Lewis showed that no improvements in growth rate and feed conversion were obtained at protein levels greater than 18 percent crude protein by pigs consuming 10 percent fat rations, yet carcass quality was improved up to 22 percent crude protein. However, Sewell and Carmon (1959) using all possible combinations of two energy levels over two growth periods (weaning-110 pounds, 110 pounds-market) found no differences among treatments with regard to backfat thickness, percent loin, percent ham, percent shoulder or percent total lean cuts.

Influence of Energy-Protein Relationships on Animal Response and Nutrient Utilization

Animal response, measured as average daily gain and feed efficiency, is commonly used to assay the relationship between energy and protein levels in rations. However, in order to better understand the basic mechanisms of energy-protein balance it would be more desirable to examine its influence on energy and protein

utilization in conjunction with these data. Since these two nutrients represent the major portion of the ration, and are largely responsible for increases in body weight, growth and feed efficiency data should be highly correlated with their utilization by the animal.

Data on energy utilization are of particular importance in studies concerned with varying dietary energy levels. When the caloric density of the ration is altered, results presented as efficiency of feed utilization may be quite deceiving. The National Research Council (1964) reported that the addition of 20 percent fat to swine rations improved feed efficiency up to 43 percent; however, if this is expressed on an energy basis there would be little improvement in feed efficiency.

Undesirable animal response with regard to inadequate energy-protein balance has been shown to be more pronounced when an insufficient supply of protein is consumed in relation to energy intake. O'Neil et al. (1962) reported that broilers fed an excess of productive energy in relation to protein intake exhibited a depressed rate of growth and reduced feed efficiency. Lowrey et al. (1958) noted practically the same response with swine; they observed a sizable reduction in average daily gain with the addition of 10 percent fat to a 13 percent crude protein ration (1.07 vs. 0.83 pounds per day), whereas average daily gain was greatly improved (1.02 vs. 1.20) with the same fat addition to a 19 percent crude protein ration. Donaldson, Combs and Romoser (1958) found that this deficiency

in protein supply greatly influenced energy utilization. They reported that Calories required by chicks per unit of gain increased as the energy:protein ratio widened.

Several workers have also reported that an overabundance of protein may produce adverse effects. Wagner et al. (1963), and Mulholland et al. (1960) studying energy-protein relationships in swine rations, observed that increases in the crude protein level resulted in slower rates of gain. Patterson et al. (1955) noted that upon increasing the crude protein level in low-fat diets of chicks, both growth and feed efficiency were reduced. Patterson reported these effects were overcome and further improved by fat supplementation, which would be expected since added fat would increase caloric density, thereby, reduce protein intake.

Combs et al. (1964) suggests that the level of certain amino acids or their metabolites which accumulate in the blood when high levels of protein or unbalanced protein mixtures are fed may reduce the voluntary consumption of metabolizable energy by the chick. This could possibly account for the adverse effects of high quantities of protein noted with swine as well. Further evidence that adequate amino acid balance is critical at high protein levels as well as low levels has been reported by Hill and Dansky (1950). Studying protein requirements of chicks in relation to the energy level, Hill et al. fed diets containing 20, 25, and 30 percent protein in all possible

combinations with graded levels of fish meal (0-4 percent). They found that with adequate quantities of fish meal, all protein levels promoted equal growth; with inadequate fish meal, high protein levels depressed growth rate.

Some reports show that once the quantity of protein reaches an adequate level in relation to the energy content, further increases have little or no effect on animal response, with excess protein being utilized for energy. Donaldson et al. (1956) have shown that once the energy:protein ratio narrows beyond a value of 44 Kcal. productive energy per pound per percent of protein, energy utilization remained constant. Sibbald et al. (1962) also noted a similar response by chicks, but found the ratio at which energy utilization became relatively uniform was dependent on the grain used as the major ration component (wheat, corn or barley) and the growth stage of the bird.

An excess of protein in relation to energy content, while not adversely affecting either growth or feed efficiency, does indicate a wastage of protein when used as a source of energy.

Donaldson et al. (1956) noted that chicks fed rations containing added fat could tolerate wider energy:protein ratios. This response is possible due to the influence of added energy on protein utilization. Munro (1951), in his review, states that most studies show that nitrogen retention is increased with the addition of energy

when both carbohydrates and fat were used as the energy source. Several workers, (Lowrey et al., 1958; Likuski, Bowland and Berg, 1961; Bowland and Kuryvial, 1961) have observed an improvement in protein digestibility associated with added energy which might partially account for this elevated utilization.

Influence of Energy-Protein Relationships on Carcass Composition

Results have been somewhat variable concerning the influence by energy-protein relationships on carcass quality of swine. Clawson, Barrick and Blumer (1956) reported that increases in the energy:protein ratio resulted in increased deposition of body fat. Their data also showed this response to be independent of fat level. However, Wagner et al. (1963) and Mulholland et al. (1960) found that no interaction existed between the energy and crude protein fractions. Their results showed that these two nutrients acted independently in relation to carcass desirability.

Greeley et al. (1964) reported that the level of crude protein, varying from 13 to 19 percent, had no effect on carcass measurements and differences in backfat thickness was attributed solely to the addition of fat. Kennington, Perry and Beeson (1958) found that both crude protein level and energy:protein ratio had little or no effect on backfat thickness. Abernathy, Sewell and Tarpley (1958)

using rations containing 14 and 18 percent crude protein with 0, 5, and 10 percent additions of fat, and Baird, McCampbell, and Neville (1958) employing similar additions of fat with crude protein levels of 15 and 21 percent, reduced by 2 percent intervals at weights of 80 and 125 pounds, reported no differences in depth of backfat among any treatments.

Lack of concrete evidence on the influence of energy-protein balance on carcass quality may be attributed to the crude methods used in assaying carcass composition of swine. The most accurate procedure would be to determine actual composition through chemical means, but because of cost involved, this has been generally infeasible.

Donaldson et al. (1956; 1958) carrying out carcass composition studies with chicks found a highly significant positive correlation between energy:protein ratio and fat content of the carcass and a highly negative one for protein and water content. The analysis of Summers, Slinger and Ashton (1965) indicates that the action of protein and energy levels are independent. They found that carcass protein increased and carcass fat decreased in a linear manner with increasing levels of protein; conversely, increasing levels of fat resulted in decreased carcass protein and increased fat. In a second experiment Summers et al. noted that while dietary fat levels significantly increased carcass fat, there was insufficient

evidence to conclude it affected the protein content of the carcass. Spring and Wilkinson (1957) found that variations in either dietary energy or protein levels in chick rations had little influence on carcass protein content, but were reflected in the percentage of fat and water of the carcass. With increasing protein levels or decreasing fat levels, carcass water increased and fat decreased.

General Conclusions

In general, studies with poultry show dietary energy-protein relationships to be more influential on animal response than with swine. Sibbald et al. (1962) found that a knowledge of dietary energy:protein ratio in poultry rations could be used to predict weight gains, gain:feed ratios, gain:energy ratios, and gain:protein ratios. If the ages of these two species are compared on a physiological basis, using a standard based on weight-growth equivalence (Brody, 1945), poultry appear to be younger physiologically during the period of study. Since studies indicate that younger animals are more sensitive to energy:protein ratio, this might account for this difference between poultry and swine. It was also noticed that procedures employed by poultry nutritionists are more refined and complex. They attempt to eliminate factors distorting the influence of energy-protein balance, and are able to use a large number of treatments and observations, which researchers working with swine

are unable to apply because of the economics involved.

From the literature cited it appears that no concise deductions can be formulated on the relationship between the dietary protein and energy levels of swine rations. Accordingly, the above review was presented in such a manner as to note only general findings reported in the literature, and to eliminate material concerned with methodology and specific results which would be of little direct interest.

There are, however, a number of general conclusions which can be derived from previous research in this area:

1. Dietary energy use is dependent upon the protein level of the ration, in that protein requirements for maximum growth must be met in order to maintain maximum energy utilization.
2. Dietary protein use is dependent upon an adequate energy supply from non-protein nutrients, so that protein will not be used as an energy source.
3. There is evidence which indicates that protein itself may produce adverse effects when its supply is overabundant in relation to the energy content.
4. The caloric density of the ration controls feed consumption. Since energy intake is relatively constant, dietary protein should be formulated in relation to the caloric density.

5. The addition of fat is apparently influential in increasing daily energy intake and possibly energy utilization, thus improving growth rate and protein utilization. Added fat also tends to impair carcass quality either related to increased energy intake or possibly as a nutrient in specific. Fats, in general, do not produce adverse effects on ration palatability, and may enhance this property of feeds.

6. There are several factors encountered in energy-protein studies which should be taken into consideration; otherwise, interpretation of results may be distorted. These include protein quality, energy level, growth stage of experimental animals, and computation of energy-protein relationship.

EXPERIMENTAL PROCEDURE

Studies cited in preparation for the following experiment indicate that there are three principal factors to be contemplated in energy-protein investigations. These include: (1) the energy: protein ratio, (2) the energy level of the ration, and (3) the growth stage of the animal under study. Therefore, with these items in consideration the experimental work reported herein was designed in the following manner.

Methods and Materials

The study was set up as a completely randomized, $2 \times 3 \times 2$ factorial, split-plot experimental design, with six treatments and eight replications over two growth periods. Forty-eight Yorkshire x Berkshire crossbred barrows selected from the Oregon State University swine herd were used as experimental animals. Because of the lack of numbers of pigs of uniform size at the beginning of the study, three groups consisting of 18, 12 and 18 pigs, averaging 58.9, 58.5 and 55.0 pounds, were started on test on October 29, November 5, and November 11, respectively. From each group, an equal number of pigs was randomly allotted to the six treatments so that a total of eight animals occurred in each treatment.

The six experimental treatments differed either by Calorie:

protein ratio or fat level as indicated in the following outline:

1. Wide Calorie:protein ratio; low-fat level.
2. Narrow Calorie:protein ratio; low-fat level.
3. Wide Calorie:protein ratio; medium-fat level.
4. Narrow Calorie:protein ratio; medium-fat level.
5. Wide Calorie:protein ratio; high-fat level.
6. Narrow Calorie:protein ratio; high-fat level.

Calorie:protein ratio was calculated as; Kcal. of digestible energy (DE) per gram of crude protein. Crude protein content was determined chemically, while caloric value of various feed ingredients used was taken from a feed composition table presented in the National Research Council publication on the Nutrient Requirements for Swine (1964). The wider Calorie:protein ratio was derived from National Research Council energy and crude protein levels (1500 Kcal. of DE and 14 percent crude protein) recommended for 75-125 pound growing-finishing pigs, and the narrower ratio from the same DE level and an arbitrarily-assigned crude protein content of 20 percent. The medium and high-fat levels were obtained by the addition of approximately 15 and 30 percent levels of lard.

Rations were prepared according to University specifications at a feed mill in Salem, Oregon¹ in two separate mixes approximately six weeks apart. The principal ingredients employed were

¹ Gro-Mor Inc. , 280 Church Street, S. E. , Salem, Oregon

barley, soybean oil meal, fish meal and stabilized lard; with soybean oil meal and fish meal included at a consistent 2:1 ratio in an effort to maintain the balance among dietary essential amino acids over all treatments as uniform as possible (Table 1).

Calculated mineral, vitamin and essential amino acid make-up of each ration was computed from the Joint U. S. and Canadian Feed Composition Tables (N. R. C. , 1959) to see if these nutrients met recommended levels. From these calculations it was apparent that the essential amino acid composition of all rations met or surpassed National Research Council (1964) recommendations, even when the recommended requirements were raised to compensate for increased energy levels. However, vitamin A, vitamin D (pigs did not have access to sunlight), panthothenic acid, niacin, manganese, copper and zinc appeared to be limiting in certain rations; therefore, these nutrients were supplemented in all rations, proportional to the energy level, to meet or exceed National Research Council recommendations (Table 1).

Pigs were housed in individual four foot x six foot pens located in an enclosed, but adequately ventilated, nutrition barn at the Oregon State University Swine Center. Pens were divided into approximately equal sections of slotted and solid type flooring, each equipped with an automatic waterer and self-feeder. Feed was offered on an ad libitum basis. The high energy (30 percent fat)

Table 1. Ingredient formulas of experimental rations

Feedstuff	Ration					
	1	2	3	4	5	6
	Wide-Ratio	Narrow-Ratio	Wide-Ratio	Narrow-Ratio	Wide-Ratio	Narrow-Ratio
	Low-Fat	Low-Fat	Medium-Fat	Medium-Fat	High-Fat	High-Fat
	(lbs.)	(lbs.)	(lbs.)	(lbs.)	(lbs.)	(lbs.)
Barley, ground	88.86	77.27	63.47	49.15	38.85	20.95
Soybean oil meal (50 percent crude protein)	6.44	14.18	13.32	22.90	19.90	31.77
Herring meal	3.24	7.09	6.74	11.48	9.88	15.91
Lard	0	0	14.77	14.77	29.43	29.43
Limestone flour	0.80	0.80	1.00	1.00	1.20	1.20
Salt (iodized)	0.50	0.50	0.50	0.50	0.50	0.50
Premix*	0.16	0.16	0.20	0.20	0.24	0.24
Total	100.00	100.00	100.00	100.00	100.00	100.00

*Premix was formulated to supply the following quantities of nutrients per pound of complete ration.

Nutrient	Ration					
	1 and 2		3 and 4		5 and 6	
Vitamin A	600	I. U.	750	I. U.	900	I. U.
Vitamin D	60	I. U.	75	I. U.	90	I. U.
Pantothenic acid (Ca-d-Pantothenate)	4.50	mg.	5.62	mg.	6.75	mg.
Riboflavin	2.45	mg.	3.06	mg.	3.68	mg.
Niacin	11.03	mg.	13.79	mg.	16.55	mg.
Choline (Choline Chloride)	10.61	mg.	13.26	mg.	15.91	mg.
Copper ($\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$)	2.00	mg.	2.40	mg.	3.00	mg.
Manganese ($\text{MnSO}_4 \cdot \text{H}_2\text{O}$)	16.00	mg.	20.00	mg.	24.00	mg.
Zinc ($\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$)	10.00	mg.	12.50	mg.	15.00	mg.

rations could not be fed as received from the feed mill, due to the fact that fat had to be heated during the mixing process in order to secure a uniform mix, which upon standing and cooling formed a rather solid mass. Therefore, these rations had to be broken up into a loose form before feeding. This process was carried out manually, in a plywood box made specifically for this purpose.

Pigs were weighed weekly throughout the entire study. The total trial was divided into two growth periods of approximately equal weight gains. The final period was terminated when each individual animal reached or exceeded a weight of 200 pounds on a routine weighing date.

All animals were slaughtered four days after removal from test at a local slaughter plant. One day following slaughter, loin eye tracings and backfat measurements were obtained from the chilled carcasses. Backfat thickness was calculated from an average of three measurements; opposite the first rib, last rib and last lumbar vertebra, and was adjusted to 200 pounds live weight.

Two pigs were replaced during the early phases of the study because of extremely poor growth; both from the group on the narrow-ratio, high-fat ration. One of these pigs died, while the other, when placed on a standard grower ration reestablished satisfactory growth. Although this ration may have attributed to the stress, it was felt that other factors were the principal cause of

poor performance. A third pig on the wide-ratio, high-fat diet developed a hematoma, and severe bleeding was observed from the penil orifice. This latter abnormality occurred near the end of the experiment (160 pounds) and the animal was immediately slaughtered and carcass data collected. Again it was felt that this condition was not due to treatment, since satisfactory growth was exhibited until illness became evident.

As rations were fed, representative samples were taken and placed in airtight polyethylene bags. Samples were later analyzed in the Oregon State University Animal Nutrition Laboratory for moisture, crude protein and ether extractable materials by methods recommended by the Association of Official Agricultural Chemists (1965). Gross (combustible) energy determinations were made with an Oxygen Bomb Calorimeter, Series 1300, Parr Instrument Company.

Data calculated from chemical analyses, and growth and feed consumption data included:

1. Average daily gain.
2. Daily dry matter consumption.
3. Dry matter required per pound of gain.
4. Daily crude protein consumption.
5. Protein consumption per pound of gain.
6. Daily calculated DE consumption.

7. Calculated DE consumption per pound of gain.

Data were analyzed statistically using the analysis of variance of a completely randomized, split-plot design (Appendix, Table I).

Carcass data were analyzed using the analysis of variance of a completely randomized design (Steel and Torrie, 1960). Linear trends of response curves due to varying energy levels were also determined, employing a method using coefficients for orthogonal comparisons in regression (Steel and Torrie, 1960).

RESULTS AND DISCUSSION

Data concerning the chemical composition of respective experimental rations are presented in Table 2. There are a few deviations from values expected when the study was set up which demand special explanation. The computed Calorie:protein ratios of the two high-fat treatments were slightly wider than anticipated, not conforming with calculated ratios for treatments one through four. This inexactness is attributed to the fact that chemically determined protein levels of rations representing these treatments were lower than anticipated. Since digestible energy levels used were computed from tabular values and remained constant, there appears to be slightly more digestible energy per unit of protein in comparison with the lower energy treatments.

A second discrepancy concerns the fat content of the high-fat diets. Ether extract determinations indicate that existing fat levels were lower than intended. This, along with the overestimated protein levels of the same two treatments may tend to compensate for the divergent Calorie:protein ratios noted.

Other than these differences, ration composition appeared to adhere reasonably closely to predetermined intentions. Gross energy determinations were performed as a check on the caloric density of experimental rations. No important errors in the

Table 2. Nutrient composition of experimental rations (moisture free basis).

Treatment	Ration					
	1	2	3	4	5	6
	Wide-Ratio Low-Fat	Narrow-Ratio Low-Fat	Wide-Ratio Medium-Fat	Narrow-Ratio Medium-Fat	Wide-Ratio High-Fat	Narrow-Ratio High-Fat
Calculated Calorie:protein ratio (Kcal. digestible energy per gram of protein)	23.44	16.92	23.54	17.10	25.42	18.04
Protein level (%)	14.55	20.14	18.11	24.92	19.97	28.10
Calculated digestible energy level (Kcal. per kg.)	3433	3444	4224	4239	5022	5029
Ether extract (%)	1.66	2.22	16.78	17.42	29.02	28.46
Gross energy content (Kcal. per kg.)	4391	4471	5187	5293	5866	5789
Moisture (%)	14.52	14.70	10.49	10.32	8.42	8.78

proposed energy levels were detected by this measure.

The results of response measures used in assaying the effectiveness of various factors and treatments are presented in Tables 3, 4 and 5. Table 3 gives response data broken down by growth period, while Table 4 represents results over the entire study, along with carcass data. Table 5 depicts the main effects of fat level and Calorie:protein ratio on pig response and carcass measurements, again taken over the entire feeding period. Statistical treatment of data is summarized in Appendix, Table I.

Effect of Calorie:Protein Ratio

Results show that average daily gain (ADG) and dry matter (DM) required per unit of gain were significantly ($P < .01$ and $P < .05$, respectively) influenced by Calorie:protein ratio. Both measures were found to be adversely affected by those diets containing the larger quantity of protein in relation to the energy level. Since the wider ratio employed was based on energy and protein requirements set up by the National Research Council for growing-finishing swine, one might anticipate that a narrower ratio would not greatly improve either growth rate or feed efficiency. However, the poorer response obtained was unexpected, since it is generally accepted that excessive levels of protein are disadvantageous only from a standpoint of economics (Morrison, 1959). A limited number of studies

Table 3. Influence of Calorie-protein ratio, fat level and growth stage on rate and efficiency of gain of growing-finishing swine.

Treatment	Early Growth Stage						Late Growth Stage					
	1	2	3	4	5	6	1	2	3	4	5	6
	Wide- Ratio Low- Fat	Narrow- Ratio Low- Fat	Wide- Ratio Medi- um-Fat	Narrow- Ratio Medi- um-Fat	Wide- Ratio High- Fat	Narrow- Ratio High- Fat	Wide- Ratio Low- Fat	Narrow- Ratio Low- Fat	Wide- Ratio Medi- um-Fat	Narrow- Ratio Medi- um-Fat	Wide- Ratio High- Fat	Narrow- Ratio High- Fat
Average initial weight (lb.)	61.1	57.9	57.0	56.4	56.3	58.6	131.4	128.9	130.8	129.6	133.0	128.0
Average daily gain (lb.)	1.59	1.53	1.82	1.62	2.06	1.71	1.97	1.94	2.18	1.92	2.42	2.10
Average daily dry matter intake (lb.)	4.12	4.11	4.07	3.59	3.78	3.41	6.06	6.21	5.35	5.00	4.90	4.58
Dry matter/lb. of gain (lb.)	2.59	2.69	2.24	2.22	1.83	1.99	3.08	3.20	2.45	2.60	2.02	2.18
Average daily protein intake (lb.)	0.60	0.82	0.74	0.89	0.75	0.96	0.88	1.25	0.97	1.25	0.98	1.29
Protein consumed/lb. of gain (lb.)	0.38	0.54	0.41	0.55	0.36	0.56	0.45	0.64	0.44	0.65	0.40	0.61
Average daily calculated digestible energy intake (Kcal.)	6415	6420	7798	6904	8610	7778	9435	9700	10251	9615	11162	10447
Calculated digestible energy consumed/lb. of gain (Kcal.)	4035	4196	4285	4262	4180	4548	4789	5000	4702	5008	4612	4974

Table 4. Influence of Calorie:protein ratio and fat level on growth rate, efficiency of gain and carcass characteristics of growing-finishing swine.

Treatment	1	2	3	4	5	6
	Wide-Ratio Low-Fat	Narrow-Ratio Low-Fat	Wide-Ratio Medium-Fat	Narrow-Ratio Medium-Fat	Wide-Ratio High-Fat	Narrow-Ratio High-Fat
Number of pigs	8	8	8	8	8	8
Average daily gain (lb.)	1.76	1.71	1.98	1.76	2.22	1.89
Average daily dry matter intake (lb.)	5.00	5.05	4.62	4.31	4.28	3.91
Dry matter/lb. of gain (lb.)	2.84	2.95	2.33	2.45	1.93	2.07
Average daily protein intake (lb.)	0.73	1.02	0.84	1.07	0.85	1.10
Protein consumed/lb. of gain (lb.)	0.41	0.59	0.42	0.61	0.39	0.58
Average daily digestible energy intake (Kcal.)	7785	7888	8852	8288	9750	8919
Calculated digestible energy consumed/lb. of gain (Kcal.)	4423	4613	4470	4709	4392	4719
Loin eye area (sq. in.)	4.53	4.04	4.00	4.19	3.85	3.89
Backfat thickness (in.)	1.33	1.51	1.49	1.49	1.61	1.58

Table 5. Main effect of fat level and Calorie:protein ratio on pig response and carcass characteristics.

Treatment	Fat Level			Calorie:Protein Ratio	
	Low Fat	Medium Fat	High Fat	Wide-Ratio	Narrow-Ratio
Number of pigs	16	16	16	24	24
Average daily gain (lb.)	1.74	1.87	2.06	1.99	1.79
Average daily dry matter/intake (lb.)	5.03	4.47	4.10	4.63	4.42
Dry matter/lb. of gain (lb.)	2.90	2.39	2.00	2.37	2.49
Average daily protein intake (lb.)	0.88	0.96	0.98	0.81	1.06
Protein consumed/lb. of gain (lb.)	0.50	0.52	0.48	0.41	0.59
Average daily digestible energy intake (Kcal.)	7837	8570	9335	8796	8365
Calculated digestible energy consumed/lb. of gain (Kcal.)	4528	4590	4556	4428	4680
Loin eye area (sq. in.)	4.29	4.10	3.87	4.13	4.01
Backfat thickness (in.)	1.42	1.49	1.60	1.48	1.53

(Mulholland et al. , 1960; Wagner et al. , 1963) were found, however, which have more critically assayed the effect of seemingly high protein levels in swine rations. These workers noted a similar response to that observed in the present study.

Data collected by Combs et al. (1964) suggest that the level of certain excess amino acids, or their metabolites which accumulate in the blood when high levels of protein or unbalanced protein mixtures are fed, may reduce the voluntary consumption of metabolizable energy by the chick. This seems to be the most logical explanation for the inferior ADG and DM utilization exhibited by animals on the narrower Calorie:protein ratio rations in this study. Results show an apparent, though not statistically significant, reduction in daily intakes of calculated digestible energy (DE) and DM by pigs consuming the higher quantities of protein. There was also a significant ($P < .01$) increase in the quantity of DE consumed per pound of gain which is not fully explained by the reduced DE intake.

The most striking evidence supporting the findings of Combs and others and pertinent to this study is that the reduced daily calculated DE intake and increased calculated DE consumption per pound of gain, as well as the poorer ADG and DM utilization associated with the narrower ratio, tended to become more pronounced with increasing fat levels. The linear component of this interaction between ratio and fat level was found to be significant ($P < .05$) with

respect to ADG. Since fat was supplemented in the place of barley there was a change in the ratio of protein-containing constituents, with less protein being supplied by barley and more from soybean oil meal and fish meal. This would then alter the amino acid balance, and such alteration might increase the adverse effects noted.

It was also found that daily protein consumption was significantly ($P < .01$) increased with increasing fat levels. Since the protein fraction appears to contain the factor depressing growth and DM utilization, it is reasonable to assume that increasing amounts of the same protein would be even more harmful.

Along with the higher intake of protein there was a significantly higher quantity of protein consumed per pound of gain by pigs on the narrower Calorie:protein ratio rations. This difference in response was expected, since it is generally accepted that with increasing protein intake, protein utilization is diminished.

Effect of Fat Level

Results show that both ADG and DM required per pound of gain were significantly ($P < .01$) improved with increasing fat levels. ADG was increased by 7.5 and 18.4 percent and DM utilization by 21.3 and 45.0 percent with additions of 15 and 30 percent fat, respectively. These data are in general agreement with the comments

cited by the National Research Council (1964) on fat supplementation in swine rations. They state that the addition of fat at levels of 10, 15 and 20 percent increased rates of gain 7 to 10 percent and improved feed efficiency up to 43 percent when 20 percent fat was added.

The quantity of calculated DE consumed per pound of gain was approximately equal over all fat levels. This agrees with the findings reported by Greeley et al. (1964) on apparent DE utilization. In contrast, Pond et al. (1960) noted that TDN per unit of gain tended to decrease with increasing fat levels. It appears that differences in energy utilization with increasing fat levels are not very pronounced if dietary protein needs are met. With respect to the extensive improvement in DM utilization observed in the present study, the data on DE per pound of gain indicate that it would be more meaningful to relate the efficiency of gain on an energy utilization basis in studies concerning varying energy levels.

With additional amounts of fat, it was noted that daily calculated DE intake was significantly ($P < .01$) increased. Although this is in conflict with the general assumption that energy intake remains relatively constant, it agrees with the findings reported by Greeley et al. (1964) for swine. These data might indicate that the appetite control mechanisms of swine react differently to fat as compared to carbohydrates. Similar reactions have been proposed by Donaldson

et al. (1956) for poultry. Sibbald, Slinger and Ashton (1960) have shown a direct relationship between caloric density and energy intake by chicks. They found that by diluting the diet with cellulose or kaolin, birds attempted to maintain a constant energy intake by increasing feed intake, but were unsuccessful when the diet contained as much as 12 percent cellulose or 18 percent kaolin. These results by Sibbald et al. indicate that the capacity of the digestive tract may be influential in controlling energy intake. Since fat supplemented rations have increased caloric density it is logical to assume that the pig will be able to consume larger quantities of energy because of the limited effect of these rations on gut capacity.

The increased daily intake of calculated DE is probably responsible for the improved ADG observed with increasing energy levels. Lewis (1965) found that when a constant intake of DE was maintained over varying levels of dietary fat, pigs showed little or no improvement in growth rate.

Results show that the quantity of protein consumed per pound of gain was significantly ($P < .05$) reduced with increasing fat levels. This difference in response is probably associated with the increased caloric density rather than with fat specifically. Munro (1951), in his review on the influence of carbohydrate and fat on protein utilization, reported that most studies show that nitrogen retention is improved with increased energy intake, rather than fat being superior

to carbohydrate as a protein-sparing energy source.

The hypothesis that protein utilization was improved with increasing caloric density, in this study, may be criticized on the basis of existing evidence to the contrary. Statistical analysis shows the trend observed to be quadratic ($P < .05$) in response, with an actual increase in the amount of protein consumed per unit of gain with the addition of 15 percent fat. Secondly, with the method used (pounds of protein consumed per pound of gain) it appears that protein is responsible for all increased gain. Therefore, as an indication of true protein utilization this method is inadequate for comparing separate rations if the quantity of protein tissue produced is variable in relation to weight gain. It was noted from carcass data collected that backfat thickness was significantly ($P < .05$) increased and loin eye area tended to decrease with increasing fat levels.

As a note of special interest, it was found that the high-fat rations (30 percent) were very troublesome to feed. As obtained from the mill, these rations were of a rather solid consistency and had to be broken into a loose form before being fed. Also, because of their doughlike nature in this loose condition they would not flow freely through the conventional type self-feeders employed and had to be administered by hand. Without the development of special equipment or possible modifications of the ration itself, feeds of this nature would be quite difficult to handle in practical swine

operations.

Effect of Growth Stage

All response measures employed were significantly ($P < .01$) affected by growth stage. Since it is generally accepted that older animals will grow faster in terms of absolute weight gains, consume larger quantities of feed and will be less efficient in feed and nutrient utilization, these differences were anticipated and are of little concern. Interests were directed mainly toward interactions associated with stage of growth which may or may not have occurred.

Results show that the effects of Calorie:protein ratio on all response measures were uniformly distributed over the entire growth period studied. In view of findings reported by other workers, it was felt that growth stage might possibly influence animal response to varying ratio. Noland and Scott (1960) noted that Calorie:protein ratios from 16 to 24 (Kcal. DE per gram of protein), which covered the range used in the present study, produced the fastest gains from 40 to 125 pounds, while ratios of around 32 resulted in the most rapid gains from 125 to 200 pounds. Sibbald, Slinger and Ashton (1962), working with chicks, reported that younger birds were considerably more sensitive to changing ratio than older fowl. They further noted that the adverse effects of higher protein levels on energy utilization were quite pronounced in younger

birds, but had little or no influence upon older chicks.

It was interesting to note that a significant ($P < .01$) interaction existed between growth stage and fat level with respect to DM conversion. Data show that the improvement in DM utilization noted with increasing fat levels was greater during the latter growth period than in the earlier period. This indicates that fat supplementation is of greater benefit to feed conversion efficiency during the later stages of growth. However, it is felt this is an inborn difference linked with body size, and is of little significance in this case. If energy consumption per pound of gain is noted as an indication of the usefulness of added fat, one finds this interaction between growth stage and fat level to be nonexistent. This again illustrates that feed conversion data may be quite misleading when varying energy levels are used.

One would anticipate an increase in the amount of DE consumed per pound of gain with increasing fat levels during the later growth stage in view of the poor carcass quality noted. Lewis (1965) states that fat deposition increased the energy requirement per unit of gain and this is particularly noticeable in the latter stages of fattening.

The improved ADG related to increasing fat levels appeared to be evenly distributed between growth stages. This measure, along with energy utilization data, shows that fat is apparently well utilized over the entire growth period studied.

Effect of Calorie:Protein Ratio and Fat Level
on Carcass Quality

One of the principal factors determining the commercial usefulness of added fat to swine rations is the influence it may have on carcass quality. Clawson et al. (1956) reported that while there were no noticeable advantages in narrowing the Calorie:protein ratio in the diet of growing-finishing swine in terms of ADG or feed efficiency, there was adequate evidence to conclude that with use of a narrow ratio, added fat had little effect on fat composition. Later work by Wagner et al. (1963) showed that increasing the protein level in fat-containing rations resulted in a linear decrease in backfat thickness, increase in percent lean cuts, decrease in intramuscular fat and increased tissue nitrogen.

Considering these findings in the light of carcass composition, it was felt that by employing relatively high levels of protein it might be possible to utilize large quantities of fat without reducing carcass quality. However, results show there were no apparent advantages to carcass composition in narrowing the Calorie:protein ratio and that carcass desirability was almost entirely dependent upon the fat level of the diet. Analysis of data shows that significant ($P < .05$) differences resulted between dietary fat levels in relation to the thickness of backfat produced. There was a highly significant ($P < .01$) linear trend toward increased backfat thickness with

increasing caloric density. Loin eye area (LEA) followed an opposite trend; with increasing additions of fat there was a very noticeable reduction in this measurement, but nonsignificant due to the enormous variation within treatments.

Results reported by Sewell and Carmon (1959) and Kropf et al. (1954) indicate that added fat has no clear-cut effect on carcass desirability; however, a number of studies show that fat is quite influential on carcass quality. Kennington et al. (1958) and more recently, Greeley et al. (1964) demonstrated that fat level was the predominant factor influencing carcass quality with varying protein levels having little or no effect, which agrees with the findings of this study.

The results of this study tend to agree with the proposal of Lewis (1965) that the tendency towards fat deposition is enhanced by increasing the supply of energy. Since there was a sizable increase in daily calculated DE intake with increasing fat levels it would be impossible to conclude that fat was specifically responsible for the apparent increase in fat composition of the carcass, as has been indicated by several workers with laboratory animals (U.S. Agricultural Research Service, 1967; Carroll et al., 1965).

There are indications that the adverse effects of higher protein levels on ADG and DM utilization may have also been reflected in carcass desirability. With respect to the low-fat diets, it was

noted that carcasses of pigs on the higher protein treatment had a somewhat smaller loin eye area and a significantly ($P < .01$) greater depth of backfat. However, these differences appear to be rather erratic in view of the fact that growth and DM utilization was least affected by the narrower ratio at this level of fat, and differences between protein levels were nonexistent at higher fat levels. Furthermore, Wagner et al. (1963) and Mulholland et al. (1960) found that leaner carcasses resulted from higher protein levels even though growth rate was limited.

SUMMARY

The recognized nutritional potential of fat as a supplemental energy source, along with the trend toward the economic feasibility of its utilization has precipitated interest in the use of fat in swine rations. To some extent however, the advantages of feeding fat to swine are offset by its tendency to impair carcass quality. It has been recognized that both performance and carcass desirability associated with additional energy from fat are interrelated with protein intake. In view of the need for more information on this relationship, particularly at high levels of fat feeding, a study was initiated to determine if pig performance and/or carcass quality could be improved by using relatively high levels of dietary protein in relation to the digestible energy (DE) content.

The study compared three supplemental levels of fat (stabilized lard), 0, 15 and 30 percent, and two Calorie:protein ratios. One ratio was based on the quantity of DE and crude protein used in conventional non-fat supplemented swine rations (1500 Kcal. of DE and 14 percent crude protein), while the second ratio was implemented by a ration containing a similar energy concentration with a crude protein level of 20 percent. Animal performance was measured over two growth periods.

The most notable observations are summarized as follows:

1. By using a narrower Calorie:protein ratio, ADG and DM utilization were significantly ($P < .01$ and $P < .05$, respectively) reduced, and these reductions tended to become more pronounced with increased dietary fat levels. The linear component of this interaction between ratio and fat level was found to be significant ($P < .05$) with respect to ADG. Further, there was a very noticeable reduction in daily intakes of DE and DM by pigs on the narrower ratio diets, along with a significant ($P < .01$) increase in the quantity of calculated DE consumed per pound of gain, which possibly explains the poorer gains and DM utilization observed. These results indicate that in certain instances, high protein intake may also be disadvantageous from a standpoint of poorer performance in addition to its economic limitations.

2. With increasing levels of fat there was a significant ($P < .05$) improvement in both ADG and DM utilization. Over the combined Calorie:protein ratios, ADG was increased by 7.5 and 18.4 percent and DM utilization by 21.3 and 45.0 percent with the addition of 15 and 30 percent fat, respectively. The addition of fat also significantly ($P < .01$) increased daily intakes of DE and protein. It was noted, however, that additional fat was not instrumental in reducing the calculated energy consumption per pound of gain.

3. The influence of Calorie:protein ratio and fat level appeared to be uniformly distributed over the two growth periods studied.

Analysis showed that there was a significantly ($P < .01$) greater improvement in DM utilization with increasing fat levels by older pigs than by younger ones. However, this interaction did not prove to be significant with regards to DE consumption per pound of gain produced, which indicates, along with those data on the main effects of fat supplementation on calculated DE per pound of gain, that feed efficiency data may be misleading in studies employing varied energy levels.

4. Carcass desirability was found to be influenced principally by the level of dietary fat. With increasing caloric density there was a significant ($P < .01$) linear increase in backfat thickness and a very noticeable trend toward reduced loin eye area. Carcass data also suggested that the higher protein intake may have adversely affected carcass quality. Pigs on the low-fat, narrow-ratio ration had 0.28 inches more backfat ($P < .05$) and 0.49 square inches less loin eye area. However, at the higher fat levels, carcass differences between ratios were small.

5. The high-fat (30 percent) rations were found to be quite troublesome to feed. This difficulty was due to the solid consistency these rations acquired upon cooling after being heated during the mixing process. Subsequent to being broken up into a loose form these rations also proved to be rather adhesive and would not flow through the self-feeders used.

BIBLIOGRAPHY

- Abernathy, R. P. , R.F. Sewell and R. L. Tarpley. 1958. Interrelationships of protein, lysine and energy in diets for growing swine. *Journal of Animal Science* 17:635-639.
- Almquist, H. J. 1958. Calorie and protein intake as related to growth. *Proceedings of the Society for Experimental Biology and Medicine* 97:353-355.
- Association of Official Agricultural Chemists. 1965. Official methods of analysis. 10th ed. Washington, D. C. 957 p.
- Baird, D. M. , H. C. McCampbell and W. E. Neville, Jr. 1958. The performance and carcass characteristics of growing-fattening swine as affected by ration levels of protein and inedible fats. (Abstract) *Journal of Animal Science* 17:1165-1166.
- Baldini, J. T. and H. R. Rosenberg. 1955. The effect of productive energy level of the diet on the methionine requirement of the chick. *Poultry Science* 34:1301-1307.
- Boenker, D. E. , L. F. Tribble and W. H. Pfander. 1960. An evaluation of calorie-protein ratios for growing-finishing swine. (Abstract) *Journal of Animal Science* 19:1248-1249.
- Bosshardt, D. K. and R. H. Barnes. 1946. Caloric intake and the utilization of dietary protein for growth. (Abstract) *Federation Proceedings* 5:228.
- Bowland, J. P. and M. S. Kuryvial. 1961. Fat and protein relationships in rations of growing-finishing bacon pigs. (Abstract) *Journal of Animal Science* 20:681.
- Brody, S. 1945. *Bioenergetics and growth*. New York, Hafner. 1023 p.
- Carroll, C. and E. Bright. 1965. Influence of carbohydrate-to-fat ratio on metabolic changes induced in rats by feeding different carbohydrate-fat combinations. *Journal of Nutrition* 87:202-210.

- Clawson, A. J. , E. R. Barrick and T. N. Blumer. 1956. The relation of energy-protein ratio to performance and carcass composition of swine. (Abstract) *Journal of Animal Science* 15: 1255-1256.
- Clawson, A. J. et al. 1960. Influence of energy-protein ratio on performance and carcass characteristics of swine. *Journal of Animal Science* 21:62-68.
- Combs, G. F. et al. 1964. Effect of protein level and amino acid balance on voluntary energy consumption and carcass composition. (Abstract) *Poultry Science* 43:1309.
- Cowgill, G. R. 1928. The energy factor in relation to food intake: Experiments on the dog. *American Journal of Physiology* 85:45-64.
- Crampton, E. W. 1964. Nutrient-to-calorie ratios in applied nutrition. *Journal of Nutrition* 82:353-365.
- Crampton, E. W. and L. E. Lloyd. 1959. *Fundamentals of nutrition*. San Francisco, Freeman. 494 p.
- Donaldson, W. E. , G. F. Combs and G. L. Romoser. 1956. Studies on energy levels in poultry rations. 1. The effect of calorie-protein ratio of the ration on growth, nutrient utilization and body composition of chicks. *Poultry Science* 35:1100-1105.
- Donaldson, W. E. , G. F. Combs and G. L. Romoser. 1958. Studies on energy levels in poultry rations. 3. Effect of calorie-protein ratio of the ration on growth, nutrient utilization and body composition of poults. *Poultry Science* 37:614-619.
- Diggs, B. G. et al. 1965. Energy value of various feeds for the young pig. *Journal of Animal Science* 24:555-558.
- Forbes, E. B. et al. 1946a. Relation of fat to economy of food utilization. I. By the growing albino rat. *Journal of Nutrition* 31:203-212.
- Forbes, E. B. et al. 1946b. Further experiments on the relation of fat to economy of food utilization. I. By the growing albino rat. *Journal of Nutrition* 32:387-396.

- Fraps, G.S. 1946. Composition and productive energy of poultry feeds and rations. College Station, 37 p. (Texas Agricultural and Mechanical College. Bulletin 678)
- French, C.E., A. Black and R.W. Swift. 1948. Further experiments on the relation of fat to economy of feed utilization. III. Low protein intake. Journal of Nutrition 35:83-88.
- Greeley, M.G., R.J. Meade and L.E. Hanson. 1964. Energy and protein intakes by growing swine. I. Effects on rate and efficiency of gain and on nutrient digestibility. Journal of Animal Science 23:808-815.
- Greeley, M.G. et al. 1964. Energy and protein intakes by growing swine. II. Effects on rate and efficiency of gain and on carcass characteristics. Journal of Animal Science 23:816-822.
- Hegsted, D.M. and V.K. Haffenreffer. 1949. Caloric intakes in relation to the quantity and quality of protein in the diet. American Journal of Physiology 157:141-148.
- Henry, W.A. 1908. Feeds and feeding. 8th ed. Madison, Published by the Author. 657 p.
- Hill, F.W. and L.M. Dansky. 1950. Studies on the protein requirements of chicks and its relation to dietary energy level. (Abstract) Poultry Science 29:763.
- Kennington, M.H., T.W. Perry and W.M. Beeson. 1958. Effect of adding animal fat to swine rations. (Abstract) Journal of Animal Science 17:1166.
- Kropf, D.H., A.M. Pearson and H.D. Wallace. 1954. Observations on the use of waste beef fat in swine rations. Journal of Animal Science 13:630-637.
- Lewis, D. 1965. High nutrient density diets for bacon pigs. Feed-stuffs, May 22, p. 18-19.
- Likuski, H.J.P., J.P. Bowland and R.T. Berg. 1961. Energy digestibility and nitrogen retention by pigs and rats fed diets containing non-nutritive dilutes and varying in protein level. Canadian Journal of Animal Science 41:89-101.

- Lowrey, R.S. , W.G. Pond and J.H. Maner. 1958. The effect of the calorie-protein ratio on digestibility, feed efficiency and weight gain in growing swine. (Abstract) Journal of Animal Science 17:1165.
- Lowrey, R.S. et al. 1963. Effect of dietary protein and fat on growth, protein utilization and carcass composition of pigs fed purified diets. Journal of Animal Science 22:109-114.
- Lusk, G. 1928. The elements of the science of nutrition. 4th ed. Philadelphia, Saunders. 844 p.
- Mitchell, H.H. 1934. Balanced diets, net energy values and specific dynamic action. Science 80:558-561.
- Mitchell, H.H. 1962. Comparative nutrition of man and domestic animals. Vol. 1. New York, Academic Press. 701 p.
- Mitchell, J.R. , Jr. et al. 1965. Caloric density of the diet and the lysine need of growing swine. Journal of Animal Science 24: 977-980.
- Morrison, F.B. 1959. Feeds and feeding. 22d ed. Ithaca, Morrison. 1165 p.
- Mulholland, R. , E.S. Erwin and R.S. Gordon. 1960. Protein-energy ratios for barrows and gilts marketed at 145 and 195 pounds. (Abstract) Journal of Animal Science 19:1278.
- Munro, H.N. 1951. Carbohydrate and fat as factors in protein utilization and metabolism. Physiological Reviews 31:449-488.
- National Research Council. Agricultural Board. Committee on Animal Nutrition. 1959. Joint United States-Canadian tables of feed composition. Washington, D.C. 80 p. (Publication 659)
- National Research Council. Agricultural Board. Committee on Animal Nutrition. 1964. Nutrient requirements of swine. Washington, D.C. 40 p. (Publication 1192)
- Noland, P.R. and K.W. Scott. 1960. Effect of varying protein and energy intakes on growth and carcass quality of swine. Journal of Animal Science 19:67-74.

- O'Neil, J.B. et al. 1962. Protein energy relationships in the diet of the chick. Poultry Science 41:739-745.
- Patterson, E.B. et al. 1955. Effect of protein level and tallow on the growth response of poult to sources of unidentified factors. (Abstract) Poultry Science 34:1215-1216.
- Pond, W.G. , E. Kwong and J.K. Loosli. 1960. Effect of level of dietary fat, pantothenic acid and protein on performance of growing-fattening swine. Journal of Animal Science 19:1115-1122.
- Sewell, R. F. and J. L. Carmon. 1959. Effect of variations in dietary energy density on carcass value in swine. (Abstract) Journal of Animal Science 18:1483-1484.
- Sewell, R. F. , M.C. Thomas and D. Price. 1961. Protein-energy relationships in the rations of early weaned pigs. Journal of Animal Science 20:820-823.
- Sibbald, I. R. , S. J. Slinger and G. C. Ashton. 1960. The weight gain and feed intake of chicks fed a ration diluted with cellulose or kaolin. Journal of Nutrition 72:441-446.
- Sibbald, I. R. , S. J. Slinger and G. C. Ashton. 1962. Further studies on the influence of dietary calorie:protein ratios on the weight gains and feed efficiency of growing chicks. Poultry Science 41:626-640.
- Sibbald, I. R. et al. 1957. Apparent digestible energy and nitrogen in the food of the weanling rat. Influence on feed consumption, nitrogen retention and carcass composition. Journal of Nutrition 61:71-85.
- Smith, T.B. 1966. Marketing oilseeds and oilseed products. p. 170-193. (Economic Research Service. U.S. Department of Agriculture. ERS-319. Reprint from Agricultural market in change, Agricultural Economic Report 95)
- Spring, J. L. and W.S. Wilkinson. 1957. The influence of dietary protein and energy level on body composition of broilers. (Abstract) Poultry Science 36:1159.
- Steel, R. G. D. and J. H. Torrie. 1960. Principles and procedures of statistics. New York, McGraw-Hill. 484 p.

- Summers, J. D. , S. J. Slinger and G. C. Ashton. 1965. The effect of dietary energy and protein on carcass composition with a note on a method for estimating carcass composition. Poultry Science 44:501-509.
- Titus, H. W. 1961. The scientific feeding of chickens. 4th ed. Danville, Interstate. 297 p.
- U.S. Agricultural Research Service. 1967. Rats don't benefit from high fat diets. Agricultural Research 15(9):7-8.
- U.S. Economic Research Service. 1966. U.S. fats and oils statistics, 1909-65. Washington, D.C. 222 p. (Statistical Bulletin 376)
- Wagner, G.R. et al. 1963. Effect of protein energy relationships on the performance and carcass quality of growing swine. Journal of Animal Science 22:202-208.
- Waldern, D. E. 1964. Influence of energy and protein level in rations for finishing pigs on performance and carcass characteristics. Canadian Journal of Animal Science 44:168-173.

APPENDIX

Appendix, Table I. Statistical analysis (mean squares).

Source of Variation	d.f.	Average Daily Gain	Dry Matter/ Pound Gain	Dry Matter Intake	Protein Intake	Protein Consump- tion/Pound Gain	Calculated Energy Intake	Calculated Energy Con- sumption/ Pound Gain	Loin Eye Area	Backfat Thick- ness
Calorie-protein ratio	1	0.9720**	0.2915*	0.7562	1.7739**	0.9228**	3,228,133	2,190,708**	0.0910	0.0326
Fat level	2	0.7920**	6.3510**	7.3694**	0.1058**	0.0124	18,211,485**	138,570	0.7010	0.1263*
Linear component	1	1.5656**	12.6114**	14.6402**	0.1764**	0.0048	36,386,532**	55,460	1.3986	0.2487**
Quadratic component	1	0.9165	0.0906	0.0986	0.0354	0.0199*	36,438	221,680	0.0033	0.0030
Ratio x fat	2	0.1799	0.0145	0.3828	0.0044	0.0020	1,701,258	131,708	0.5099	0.0506
Ratio x linear	1	0.3525*	0.0070	0.6828	0.0072	0.0025	3,214,743	219,492	0.5592	0.0880
Ratio x quadratic	1	0.0071	0.0219	0.0826	0.0015	0.0015	127,771	43,923	0.4607	0.0140
Error within treatments	42	0.0733	0.0519	0.3353	0.0138	0.0037	1,181,625	216,905	0.4752	0.0304
Stage of growth	1	3.2561**	2.5971**	50.6342**	2.1010**	0.0838**	172,736,907**	6,552,150**		
Stage x ratio	1	0.0002	0.0244	0.0013	0.0305	0.0039	3,361	15,708		
Stage x fat	2	0.0177	0.1936**	1.9498**	0.0202	0.0035	1,534,745	300,706		
Stage x linear	1	0.0017	0.3829**	3.0844**	0.0238	0.0038	1,193,826	347,805		
Stage x quadratic	1	0.0160	0.0043	0.8151	0.0167	0.0032	1,875,659	253,607		
Stage x ratio x fat	2	0.0100	0.0216	0.0552	0.0037	0.0017	175,555	1,425		
Error within periods and treatments	42	0.0213	0.0374	0.1996	0.0091	0.0010	678,806	127,804		

*Significant at $P < 0.05$ **Significant at $P < 0.01$