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An experiment was conducted during the period November 1967 to November 1968 at Oregon State University (OSU) and the Umatilla Branch Experiment Station (BES) at Hermiston, two trials at each location, to answer several questions: (1) could comparable rations for swine be formulated by a computer on a least-cost basis; (2) would the rations produce equal results when fed; and (3) what effect would the switching of these rations during the feeding period have on the rate of gain, feed efficiency, and carcass characteristics of the pigs.

At OSU there were 45 pigs in each trial divided into 15 groups. Each of these groups received all rations in different sequences. At BES there were 168 pigs in each trial divided into 14 groups. Eight of the groups, in replicates of two groups per ration, were fed a given ration for the entire trial; the other six groups received all rations in different sequences.

A total of seven different rations were fed in the two trials. Six rations were formulated by the computer on a least-cost basis; the other was a standard experiment station ration. Three different rations were used in each trial and the standard ration was used in both trials.

Analysis of the data from the experiment showed that: (1) rations for swine can be formulated by computer on a least-cost basis if care is taken to insure that the input data given the computer to formulate the rations is correct; (2) these rations will produce nearly equal results when fed if both the economic and physical aspects are considered and not either alone; (3) switching the rations during the feeding period will produce little effect on the pigs for rate of gain, feed efficiency, or carcass characteristics. The significant differences between sequences, direct ration effects, residual ration effects, and constant ration vs. switched ration were not consistent and could not be interpreted to indicate that any of the above conclusions were invalid.

Response of Market Hogs to Periodic Changes Among Nutritionally Similar Rations

by

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RESPONSE OF MARKET HOGS TO PERIODIC CHANGES AMONG NUTRITIONALLY SIMILAR RATIONS

INTRODUCTION

With the increasing cost-price squeeze in agriculture today every possibility of reducing costs must be explored by the livestock producer. The largest cost of producing swine is feed cost so it is here that the largest savings might be made. Much work has been done in using computers to formulate least-cost linear programmed rations with swine and with other species. However, these least-cost rations are only least-cost until the prices of feedstuffs change the first time and after that it is probable that some other ration would be cheaper. Therefore, it is necessary for the feeder to keep his rations constantly updated and to be switching the rations during the feeding period. In addition, least-cost rations on the basis of price may not be most profitable rations due to animal response to the ration *per se* or to the change from one ration to another.

In the past it has been the practice to feed rations composed of the same feedstuffs during the entire growing-finishing period of swine except for some reduction in protein level as the pigs increase in weight. To effectively utilize least-cost rations it is desirable to determine the performance and carcass response of pigs fed a number of different rations during the growing-finishing period. It was to acquire this information that the experiments were carried out at Oregon State University and at the Umatilla Branch Experiment Station in Hermiston between November 1967 and November 1968.

REVIEW OF LITERATURE

Linear Programming

The computer and linear programming have become accepted and widely used tools in nutritional research and in the practical application of present knowledge. They are used extensively in industrial research and in commercial feed operations. Their potential was realized early and work was done in the early 1950's to use them in formulating rations, both least-cost and others.

Swanson (1955) used the computer to find several least-cost rations to meet varying requirements. The rations were formulated with 35% or 40% protein, with or without a 2000 pound total weight requirement. All had to meet the same nutrient specifications for energy, calcium, phosphorus, etc. The four rations obtained varied considerably in both composition and price. Price levels for the four rations were: 35% protein with 2000 pound total weight requirement--$99, 40% protein with 2000 pound total weight requirement--$107, 35% protein without 2000 pound total weight requirement--$96, and 35% protein with 2000 pound total weight requirement and with altered ingredient prices--$90.

Potter *et al.* (1962) formulated several least-cost broiler rations to the same nutritional specifications. Their rations showed a wide difference in the feedstuffs used and the levels of each in the ration. They found that the least-cost rations produced better feed efficiency.

Early weaned pigs were fed electronically computed least-cost rations by Lloyd et al. (1962). In their first trial one control ration and one computer formulated (CF) ration were formulated to the same specifications. The cost of the two rations was \$99 and \$73, respectively. The CF ration produced about the same gain but better feed efficiency. There was no difference in digestibility. In the second trial one control ration and three CF rations were produced (from the ration used in trial one) with costs of \$99 (control), \$73 with addition of iodinized casein, \$88 when more ingredients were available, and \$80 when certain vitamins were increased. The results showed that the control produced a significantly higher gain, significantly higher feed intake per day, and with the third CF ration allowed significantly better feed efficiency. They concluded that the difference between the computer formulated rations and the control in both trials could be attributed to the suboptimal feed intake for the CF rations. This illustrates the importance of "intangible" factors such as palatability.

Church et al. (1963) fed six linear programmed rations to feeder cattle. The rations were formulated to the same specifications except for energy which was at three different levels. The rations were composed of basically the same ingredients but the amounts varied considerably. Chemical analysis of the rations showed them to be in reasonably good agreement with the specifications. Performance on all rations was good.

Steer calves were used by Church et al. (1964) in a feeding trial using linear programmed rations. They fed three least-cost rations and a control with the protein level being the only variable. The least-cost rations were composed of the same ingredients at different levels but the control had different ingredients. The least-cost rations produced lower rates of gain and poorer feed efficiency than the control but cheaper gains. There were no measureable carcass differences.

Scott (1964) working with poultry found that least-cost rations did not necessarily give the cheapest production. The cost depends partly on the specification given the computer. (The tighter the specifications in the program the less freedom of choice enjoyed by the computer in the selection of feedstuffs and the lower the chance of economy in the ration produced). More of the cheap feed may be eaten than of the more expensive, thereby causing the cost per unit of production to increase. Lowering the cost of the rations may lower the quality. A higher quality, more expensive ration may give improved production, improved egg size, better feathering and maintenance of hens, lower moisture excretion, and lower total excrement.

Adair, Stout, and Oldfield (1961, 1962, 1963, 1964) have found that mink rations can be linearly programmed with a considerable economic advantage over the control rations fed. The computer formulation of the rations seemed to have no adverse effect on size, growth, quality of the pelt, or incidence of wet belly. The level of protein and fat and their ratio did affect these and points out the importance of the nutritional specifications given the computer.

Oliver et al. (1965) used linear programming to formulate least-cost beef cattle rations. The linear programmed rations and the control all met the recommendations of the National Research Council. The linear programmed ration was reformulated five times during the trial while the control was kept constant. There was no difference in gain, slaughter grade, or rib eye area. The controls had a slightly higher dressing percentage. Those fed the linear programmed rations had a lower feed cost and gain cost and returned more dollars above feed cost.

Church (1965) fed linear programmed rations to steers and lambs. A wide variety of rations were used but there were no poor results. With all rations rapid economical gains were achieved.

Pigs were used in a feeding trial by Dent et al. (1966). Four computer formulated rations were fed during the feeding period. All rations had the same ingredients but the amounts varied. The rations varied in their nutrient levels but each was optimum for the stage of growth. The gain and efficiency of feed usage were about as expected and there was no adverse effect on carcass quality.

Linear programmed rations were fed swine by Harrington _et al._ (1966). They fed 23 linear programmed diets that met the NRC recommendations and compared them to a corn-soybean meal diet. The controls gained significantly faster, more efficiently, and more economically.

Howard _et al._ (1968) compared two least-cost computer formulated rations with a conventionally formulated ration in a 20-week continuous trial with dairy cows. The first treatment was a least-cost ration formulated using the prices for the past year and was kept constant during the trial; the second treatment was a least-cost ration reformulated biweekly using current prices; and the third treatment was the conventionally formulated ration with no urea. Corn silage and grain were mixed and fed ad libitum. The rations were all nutritionally comparable and the computer formulated rations had less than one percent urea. The ingredients in the ration in the second treatment changed abruptly at the bi-weekly formulations. Dry matter consumption per unit of body weight, actual milk production, fat corrected milk production, milk fat and solids-not-fat percentages, and body weight gains were not significantly affected. The abrupt changes in ration in treatment two did not affect performance. The daily feed costs were significantly lower for the least-cost formulated rations in both treatments one and two.

Commercial feed companies, Nesheim (1968) and Kloster (1968), began using computer and linear programming in the early 1950's and today almost 100% of the commercial feed produced by large companies is formulated by computer. Their work has shown that there is no significant difference between conventionally formulated rations and computer formulated rations if the same nutrient requirements are used and met in both cases.

Ration Comparison

It is essential when using least-cost linear programmed rations in actual production programs that the rations produce equivalent results; they must, therefore, be of equal acceptability to the livestock for which they were formulated. If some rations are more or less acceptable to the livestock then it is important to know this for it would make little difference how much cheaper a ration was if the animals refused to eat it. Considerable work has been done in comparing the results of feeding various rations although not all rations have been compared.

Jacob and Duncan (1938) compared various concentrates alone and in combination when fed with corn silage for fattening swine. The amount fed and the feed value of each ration was about the same. The concentrates compared were: cottonseed meal, cottonseed meal and tankage, peanut oil meal, and soybean meal. Peanut oil meal produced a somewhat lower gain and poorer feed efficiency which was attributed to a palatability problem. Cottonseed meal and tankage caused a slight palatability problem at the beginning but was soon consumed as readily as the others. The cottonseed meal was the most economical. With the exception of the peanut oil meal there was no difference in carcass characteristics, gain, or feed efficiency.

Vegetable and animal protein supplements were compared by Krider et al. (1943). When fed to young pigs, birth to 75 pounds, they found that a ration containing only vegetable protein supplement was inadequate. The ration containing the animal protein supplement was adequate when additional vitamins were provided.

Dairy cows were used by Savage et al. (1943) in comparing various concentrate mixtures. The first trial showed a performance difference in the order the mixtures were fed. In the second trial there was no difference in production, health, weight change, or palatability. The third trial showed no difference in palatability.

Poucke et al. (1948) fed various protein supplements to weanling pigs. Two tests were conducted and all rations contained the same amount of protein. In test one, those pigs fed the basal ration did not gain as rapidly nor as economically as those fed the basal ration plus four percent dried whey with fermentation solubles. The basal ration plus four percent whey with fermentation solubles produced faster gains than a combination of fish solubles and meat scraps but the latter produced the more economical gains. In test two, the addition of dried whey with fermentation solubles and meat scraps increased gain by .25 pounds per pig per day and 18% less feed was needed per 100 pounds of gain. The addition of whey with fermentation solubles alone to the basal ration caused a slight increase in daily gain and improved the haircoat and skin condition of the pigs.

Dried molasses and potato or corn fermentation solubles were added to swine rations by Vander Noot and Skelley (1949). The rations contained 20% protein until the pigs reached 100 pounds and then dropped to 15%. There was no difference in gain between the groups and only a slight difference in feed efficiency between groups with the addition of corn distillers solubles being slightly better.

Thomas and Flower (1956) fed wheat mixed feed at two levels in swine rations. They found that it was better to feed a ration with wheat mixed feed at the 25% level during the entire feeding period rather than switching to a 50% level. The 50% level, however, was somewhat cheaper so that some lots of pigs made cheaper gains. Overall the 25% level was significantly better than the 50% level for gain.

Various protein supplements for swine were compared by Sewell et al. (1957). With all rations containing 16% protein there was no difference when up to 3/4 of the soybean meal was replaced by peanut oil meal, when up to 3/4 of the soybean meal was replaced by degossypolized cottonseed meal, when soybean meal, peanut oil meal and cottonseed meal were fed in equal parts, and when all were fed free choice or in combination.

Kercher and Mishimins (1961) fed three rations to steers: (1) a constant ingredient; (2) a variable corn silage; and (3) a variable grain. There was no significant difference in gain. The steers fed the variable grain ration required significantly more TDN per 100 pounds of gain than either of the others and the constant ingredient group required significantly more TDN to gain 100 pounds than the variable silage group. There was no significant difference in shrink but the constant ingredient group had significantly thicker rind over the 12th rib. The rations did not significantly affect the live selling price, live grade, in-transit shrink to slaughter, carcass grade, cooler shrink, carcass yield, length of body, length of loin, depth of round, depth of body, area of rib eye muscle, or area of fat covering the 12th rib.

Pigs were used by Williams and Diggs (1961) to evaluate creep rations at varying ages. The first ration contained oats, sugar, dry skim milk, corn, and soybean meal and the second contained corn and soybean meal. The pigs were weaned at six and eight weeks. They were started on creep at ten days and fed until ten weeks old. There were no significant differences attributed to the rations.

Thrasher et al. (1961) fed three supplements free choice or in mixed rations to swine. The supplements were soybean meal, soybean meal and meat meal, and soybean meal-meatmeal-fishmeal-cottonseed meal. All rations contained 16% protein but were reduced to 13% when average pig weight reached 100 pounds. There was no significant difference in gain between rations or methods. Also, there was no effect of treatment on backfat thickness, loin eye area, or yield of lean cuts.

Handlin et al. (1961) fed the following rations to swine: corn, barley, 1/2 corn 1/2 barley, milo, 1/2 corn 1/2 milo, 1/2 corn 1/2 oats, 3/4 corn 1/4 coats, and shelled corn and forage. All rations contained the same amount of protein but it varied with the weight of the pigs. A protein supplement of 50% fishmeal-25% alfalfa meal-25% soybean meal was fed with all rations. Corn produced a significantly higher gain than barley, milo, 1/2 corn 1/2 oats, and corn and forage. Barley produced significantly lower gain than corn, 1/2 corn 1/2 barley, 1/2 corn 1/2 milo, and 3/4 corn and 1/4 oats. Corn resulted in a significantly better feed efficiency than barley, 1/2 corn 1/2 milo, 1/2 corn 1/2 oats. Barley resulted in a significantly poorer feed efficiency than all except 1/2 corn 1/2 oats. Profit was the highest for milo or corn and the lowest for 1/2 corn 1/2 oats and barley. Barley produced leaner carcasses, lower dressing percentages, less back fat and higher percent of lean and primal cuts. Animals fed the milo and barley had the firmest fat.

Two starter rations, one containing corn, soybean meal, dried skim milk, sucrose, etc. and the other lacking dried skim milk and sucrose were compared by Thrasher and Rodriguez (1962). Each ration contained 18% protein and all pigs received the first ration until weaned at five weeks. The first ration resulted in significantly higher gain, feed intake, and better feed efficiency. About twice as much feed was wasted on the second ration but the cost per pound of gain was lower. The overall performance on the second ration was very satisfactory but those receiving sugar and milk in the diet gained faster and more economically.

A significant difference in digestibility before seven weeks of age, gain, and feed efficiency produced by rations containing different supplementary protein was found by Combs et al. (1963). There was no significant difference after seven weeks of age.

Reimer and Meade (1964) found that the replacement of part of the soybean meal in a pelleted barley-soybean meal ration by blood-meal, tankage, or fishmeal did not significantly affect the efficiency or rate of gain of growing pigs.

Meade et al. (1965) fed rations containing protein supplement from various sources to pigs weaned at three weeks of age and weighing 12.2 to 13.5 pounds. Inclusion of three percent tankage or fish-meal or ten percent dried skim milk in an 18% protein diet based on soybean as the major source of protein did not significantly affect the nine week weight or daily gain of the pigs. The inclusion of three percent tankage significantly depressed feed efficiency and diets containing three percent fishmeal or ten percent dried skim milk supported more efficient gain than did mixtures containing soybean meal alone or the combination of three percent each of tankage and fishmeal. The inclusion of three percent fishmeal and ten percent dried sweet whey, alone or in combination, in a basic 18% protein corn-soybean meal diet did not significantly affect the average eight week weights or daily gain of the pigs. The combination significantly reduced efficiency.

A number of nutritionally equivalent diets containing either barley, wheat, or 1/2 barley 1/2 wheat produced no difference in rate of gain, feed intake, or feed efficiency due to the source of grain in an experiment by Newman and Thomas (1967b).

In another experiment by Newman and Thomas (1967a) nutritionally equivalent rations of barley, 1/2 barley 1/2 wheat, wheat plus soybean meal and/or milk replacer, wheat plus dried bakery product were fed for three weeks to pigs weaned at three weeks of age. There was no difference due to the grains. The milk and soybean meal was better than the soybean meal alone for promoting gain. There was no effect from the bakery product.

There was a significant difference in gain and backfat but only a slight difference in feed efficiency when six nutritionally equivalent rations composed of a variety of feedstuffs were fed to pigs by Chamberlain and Clark (1967).

Clark and Hall (1967) fed a complex protein supplement in comparison with cottonseed meal to steers. The complex supplement contained cottonseed meal, dehydrated alfalfa meal, molasses, urea, dicalcium phosphate, trace mineral salt, and Vitamin A. There was no difference in performance due to differences in the rations.

Private research by commercial feed companies has shown that there is very little, if any, difference in animal performance between rations if they are all formulated to the same specifications and meet the minimum requirements for the animal being fed (Walker, 1968). The general policy seems to be for each plant or area to have its own formula but all formulas are nutritionally equivalent. These formulas are changed as often as weekly if the price change warrants. Some efforts are made to prevent drastic changes that might affect palatability but this does not seem to be a great concern (Johnson, 1968).

Palatability of Feedstuffs

Very little work has apparently been done on the palatability of feedstuffs or rations. There is evidence that when given a choice, animals will prefer one ration over another but no one seems to know whether one feedstuff tastes good and another bad or whether certain feedstuffs when combined in a ration acquire a bad taste not present when each is fed alone.

Waterhouse and Fritsch (1967) working with dogs, and Aldinger

(1968) working with swine, found that dogs and baby pigs have a preference for a ration they have not been receiving when they were offered both and the rations were equal in palatability.

A difference in palatability was found by Jacob and Duncan (1938) when they compared various protein supplements. Some of this was overcome, apparently, when the animals became accustomed to the new taste.

It is not unusual for one ration to be consumed at much higher levels than another when they are nutritionally equivalent. This was reported by Thrasher and Rodriguez (1962) and Lloyd *et al.* (1962). This preference for one ration over another can be considered a difference in palatability.

Palatability is apparently not considered much of a problem by the commercial feed companies. They change formulas using a wide variety of feedstuffs and report no problems from doing so (Childs, 1968 and Kloster, 1968).

Switching of Rations

If rations are to be formulated on a least-cost basis and the rations fed are to always be the current least-cost ration then the animals may have their ration changed often during the feeding period. With a variety of feedstuffs possibly being used in the formulation the effect of this switching could be critical.

Savage et al. (1943) conducted three trials to determine the effect of various concentrate mixtures on dairy cows. In the first trial they found a performance difference in the order fed. Overall, they found that there was no effect on the cows in any of the traits measured caused by switching, ". . . The results indicate that abrupt changes in concentrate mixtures that are equal in protein and total digestible nutrients can be made without harmful effect."

Rations for fattening steers were varied over a 170 day period and compared to a constant ration by Kercher and Mishimins (1961). One groups of steers had a variable corn silage ration, one group had a variable grain ration, and one group had a constant ingredient ration. There was no significant difference in gain between the switched and the constant. The variable grain group required significantly more TDN per 100 pounds of gain than the other groups and the constant group required significantly more TDN per 100 pounds of gain than the variable silage group. The controls had a significantly thicker rind over the 12th rib. There was no significant difference in any of the other characteristics measured.

Oliver et al. (1965) compared the performance of steers fed a constant ration with those fed a ration reformulated five times during the feeding period. There was no significant difference in gain, slaughter grade, or rib eye area. The constant ration produced a slightly higher dressing percentage. The switched rations produced a lower feed cost and lower cost per pound of gain and higher dollar return.

Four different rations, varying only in the amount of the feedstuffs in the rations and not in the feedstuffs themselves, were fed to hogs by Dent and English (1966). Their results showed gain and efficiency about as expected and no adverse effect on carcass characteristics.

Howard et al. (1968) compared a group of dairy cows fed rations reformulated bi-weekly for 20 weeks with two groups of cows fed a constant ration. The ration ingredients changed drastically with each reformulation. There was no significant effect on any of the traits or characteristics measured from switching the rations.

The research done by commercial feed companies (Kloster, 1968; Childs, 1968; and Walker, 1968), shows that there is no effect from switching the rations as often as weekly if the rations are nutritionally equivalent. It is the practice of these companies to reformulate their rations as often as weekly using a wide variety of feedstuffs so that probably every time a load of feed is delivered to a producer it is different from the one before. There does not seem to be any adverse effect from this.

EXPERIMENTAL PROCEDURE

Description of the Experiment

The actual design of the experiment was formulated by Dr. Kenneth Rowe of the Department of Statistics at Oregon State University. There were two designs, one used at OSU and the other at BES. They were the same for both trials.

A cross-over design was used because it permits each animal to be exposed to each ration; it also permits a greater number of degrees of freedom in the analysis of the data. The same number of animals were on each ration at all times during the feeding period. The designs are shown in Tables 1 and 1a.

At OSU there was no control group as such but the control was incorporated into the design of the experiment (Table 1). Each time the rations were changed three groups remained on the previous rations, one for each ration, which permitted a comparison between the effect of switching and the effect of the constant ration. At BES there were control groups for each of the three experimental rations and there were also two pens fed the standard Experiment Station ration so that all experimental rations could be compared to a standard ration as well as to each other (Table 1a). The standard ration was not included in the design dealing with effect of constant vs. switching rations. Since the facilities were available, however, the

Table 1. Ration sequences for three individually-fed pigs per group.

Group	Ration sequence at three week intervals at OSU			
1	1	1	2	3
2	1	2	3	1
3	1	2	1	3
4	1	3	2	2
5	1	3	3	2
6	2	1	1	3
7	2	1	3	3
8	2	2	3	1
9	2	3	1	2
10	2	3	2	1
11	3	1	2	3
12	3	1	3	2
13	3	2	1	1
14	3	2	2	1
15	3	3	1	2

Table 1a. Ration sequences for group-fed pigs.[1]

Group	Ration sequences at four week intervals at BES		
1	1	1	1
2	1	1	1
3	2	2	2
4	2	2	2
5	3	3	3
6	3	3	3
7	1	2	3
8	1	3	2
9	2	1	3
10	2	3	1
11	3	2	1
12	3	1	2
Standard experiment station ration			
13	4	4	4
14	4	4	4

1/ Twelve pigs per group.

standard ration was fed to two pens and the data used in comparing the computer-formulated ration with a standard, established ration. All rations were pelleted for both trials.

The data from the experiment were analysed to determine the effects of the following: (1) switching the ration as opposed to feeding a constant ration (constant vs. switched), (2) the differences between the rations themselves (constant ration), (3) switching the rations in various sequences (sequence of rations), (4) the ration within the feeding period (direct ration effects), and (5) the ration in the period following switching (residual ration effect).

Source of Animals and Allocation to the Experiment

Trial I was started at Oregon State University (OSU) in November 1967 and in December 1967 at the Umatilla Branch Experiment Station (BES).

At OSU 45 Yorkshire x Berkshire crossbred barrows were randomly allotted to the 45 pens that were randomly allotted to the different groups. All pigs were wormed before going on the experiment and again in January. Each pig had its own pen, approximately four feet by six feet, with a self feeder and waterer. The pigs were placed in the test pens at least one week prior to going on test and were placed on test as they reached 60 pounds. Thereafter they were weighed at the beginning of each experimental week. At the end of

12 weeks they were marketed.

Feeders were filled at the beginning of each experimental week and feed was added as needed to keep feed available at all times. At the beginning of each week all feed left in the feeder was weighed back and the new ration fed to those due to change. The feeders were checked daily and any unfit feed was cleaned out of the feeder cups..

The 168 pigs at BES were randomly allotted to the pens and the pens were randomly assigned to a group. Each pen was composed of 12 crossbred barrows provided by a local commercial producer. Pigs were assorted to pens at least a week before initiation of the experiment at about 52 pounds weight. All were wormed and each pen had a self feeder and waterer.

The pigs were weighed biweekly; they were fed at the beginning of each weigh period and as needed during the period to keep feed available at all times. At the end of each two week period the feed was weighed back and rations were changed every fourth week as prescribed by the experimental design. The pigs were marketed at approximately 200 pounds weight and carcass data were obtained.

Trial II was started at OSU in June 1968 and at BES in July 1968. The procedure for both was the same for the second trial as it was for the first except that at OSU the pigs were only wormed once, before they went on test, and at BES they were wormed a second time after four weeks.

Formulating the Ration

The program for ration formulation was written by a computer programmer in the Oregon State University computer center. The following specifications were used as a guide in preparing the program:

Protein	minimum 13.5%	maximum 14.5%
Digestible Energy	1500 Kcal per pound	
Fiber		maximum 6.5%
Calcium	minimum .5%	maximum .8%
Phosphorus	minimum .3%	
Niacin	minimum 5 milligrams per pound	
Pantothenic Acid	minimum 5 milligrams per pound	
Riboflavin	minimum 1 milligram per pound	
Vitamin B_{12}	minimum 5 micrograms per pound	

Total 99 oounds

Least Cost for each ration

Restraints as shown below were added to keep the rations within physiological bounds and to meet requirements of the feed mill in mixing and pelleting the ration:

Molasses	maximum 6.5%
Feathermeal	maximum 5.0%

In order to get three different rations all formulated on a least-cost basis it was necessary to place some further restrictions on the computer at the time of formulation. In the first trial it was specified that the first ration use barley and no other grain or grain by-product, in the second ration wheat and no other grain or grain by-product, and in the third ration no wheat or barley but any choice of all other grains and grain by-products. For the second trial, free choice of all possible ingredients was available for the first ration; for the second ration the major grain component in the first ration was removed[1] and free choice was available for all other ingredients; and for the third ration the major grain components in the first two rations were removed and free choice was available for all other ingredients. In addition, a standard premix was added to each ration to furnish constant amounts of minor ingredients. The rations used in the two trials are given in Tables 2 and 3 and the premix added to all rations is given in Table 4.

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[1] Discrepancy in Table 3 is result of minor corrections which had to be made in the ration after the trial started. The original formula had millrun as the major grain component.

Table 2. Formulas for rations used in Trial I.

Ingredient[1]	Ration 1	Ration 2	Ration 3	Ration 4
Barley	1615			1480
Wheat		1673		
Corn			647	
Millrun			1083	
Fishmeal			90	
Meatmeal				120
Bloodmeal	106	59		
Soybean Meal				180
Molasses	158	146	135	100
Tallow	101		25	
Alfalfa				100
Alfalfa Meal		102		
Premix	20	20	20	20

[1] Each shown in pounds per ton of complete ration.

Table 3. Formulas for rations used in Trial II.

Ingredient[1]	Ration 1	Ration 2	Ration 3	Ration 4
Barley				1480
Wheat			1638	
Corn	862	976		
Milo		599		
Millrun	811			
Meatmeal	118	112	14	120
Fishmeal	33	17	84	
Feathermeal		49		
Soybean Meal				180
Molasses	150	150	150	100
Tallow	6			
Alfalfa		77	72	100
Limestone			22	
Premix	20	20	20	20

[1]Each shown in pounds per ton of complete ration.

Table 4. Premix used in all rations.

Ingredient	Amount
Aureo-S-P-250	2.00 pounds
Salt	10.00 pounds
Zinc Sulphate	.80 pounds
Vitamin A	1,200,000 units
Vitamin D	120,000 units
Vitamin B_{12}	10,000 micrograms[1]
Pantothenic Acid	2,000 milligrams[1]
Millrun	enough to bring total weight to 20 pounds

[1]First trial only.

Table 5. Price list of possible ration ingredients.

Feedstuff	Price/cwt	
	Trial I	Trial II
Barley	$2.55	$2.50
Wheat	2.65	2.80
Corn	2.65	2.65
Milo	2.40	2.60
Oats	3.30	3.20
Peas	4.00	4.00
Rye	3.00	3.00
Millrun	2.00	2.05
Cottonseed Meal	4.50	4.25
Soybean Meal	4.80	4.95
Meatmeal	4.25	4.00
Feathermeal	5.20	5.20
Linseed Meal	5.10	5.05
Tankage	5.65	5.25
Fishmeal	7.00	7.40
Bloodmeal	5.00	5.00
Alfalfa	2.25	1.25
Alfalfa Meal	3.40	3.25
Limestone	0.60	0.62
Tallow	6.65	7.50
Molasses	1.49	1.35

RESULTS

Problems

Approximately four weeks after the experiment began at OSU it was noticed that some problems were developing with the pigs. The first indication was inadequate gains and feed efficiencies for certain pigs at the weekly weighings. As the experiment progressed these became more frequent and a general dislike for one of the rations developed. In the latter half of the experiment some pigs were lost, others had to be removed from the test, and deformities in the feet and legs were present in many of the animals that remained.

Initially each new batch of feed delivered had been analyzed only for protein and fiber content. When the rations were analyzed for calcium and phosphorus, the cause of the problem was found. The rations being fed at OSU had approximately .13 percent calcium instead of the .5 to .8 percent specified by the ration formula. The phosphorus level was approximately correct. Analysis of the rations at BES showed .16 to .28 percent instead of the specified .5 to .8 percent calcium; phosphorus content was approximately correct. The standard ration being fed as a control at BES was within the bounds intended for both calcium and phosphorus. Table 6 shows the analysis of the rations in trial I.

Since both BES and OSU used the same formulas for the rations the difference in calcium content was apparently the result of differences in calcium content of the grains used at the two locations. That BES did not encounter deficiency symptoms may indicate genetic differences in the pigs used at the two locations; the rations at BES were severely deficient according to accepted standards. The slightly higher amount of calcium may have been enough, however, to prevent the symptoms at BES that were observed at OSU.

Table 6. Analysis of rations used in Trial I.

Ration	Location	Analysis	%Protein	% Fiber	% Ca	% P
1	OSU	1	16.52	3.20	*	*
1	OSU	2	15.50	3.55	*	*
1	OSU	3	*	*	.13	.32
1	BES	1	15.17	4.29	.16	.33
2	OSU	1	13.86	3.92	*	*
2	OSU	2	13.40	3.06	*	*
2	OSU	3	*	*	.12	.30
2	BES	1	14.83	3.40	.22	.27
3	OSU	1	17.46	5.09	*	*
3	OSU	2	15.80	5.42	*	*
3	OSU	3	*	*	.16	.40
3	BES	1	15.97	4.63	.28	.62
4	BES	1	17.56	6.42	.72	.40

*Not analyzed.

Twenty-three pigs were lost to experiment at BES but this was due to ulcers and usually occurring disorders and no connection could be established between these losses and the calcium deficiency.

Cause of the calcium deficiency was eventually traced to a misplaced decimal point in the input data given the computer for the calcium content of molasses. The computer used large quantities of molasses in all rations (Table 1).

Results for Trial I

The data obtained from the first trial at OSU are not used in this report for evaluating the success or failure of the experiment. Because of the calcium deficiency in the rations and the problems this caused, it was concluded that the results do not give a true picture either in the comparison of one ration with another or for the effect of switching of the rations. The results of Trial I at OSU can be seen in Table 7.

Table 7. Results of Trial I at OSU.

	Ration 1	Ration 2	Ration 3	Average
Average daily gain (lbs.)	1.89	1.90	1.37	1.72
Feed/pound of gain (lbs.)	3.30	3.38	4.39	3.69
Feed cost/pound of gain ($)[1]	.0917	.0875	.1005	.0932

[1]The cost per pound of gain is determined using the prices as they came from the computer which does not include the premix or feed mill costs. Costs were determined this way so that they would be in the proper ratio since the actual delivered prices was not in the same ratio as the computer prices because of the manner in which the rations were obtained.

The difference in nutritive value of the rations is not as disparate as would appear for ration three. When the trial first started the animals ate all rations equally well and performance was similar (Figures 1 and 2). It was not until the pigs had been fed the calcium deficient diet for some time that a difference in ration palatability began to develop. As the trial progressed the animals grew more and more averse to eating ration three. There was also more waste with this ration. The aversion and the increased waste would account for most of the poor feed efficiency in comparison to the other rations, the poor gains while the animals were on it, and the residual effect in the period after the animals were switched to another ration.

Why the animals gradually refused to eat ration three was not determined. From the formula there is no indication that it should be any less palatable than the others. A tentative conclusion is that the calcium deficiency caused some palatability factor not normally of enough significance to become a problem. Part of the cause of low consumption of ration 3 may be because the pellets broke down more than did either of the other rations at OSU, but this was not a problem at BES. The cause for the pellet breakdown was not determined.

That pellet breakdown is a factor in consumption can be inferred from the work of several researchers. Dinussen et al. (1951), Thomas and Flower (1953), and Seerley et al. (1962) found that pelleted rations resulted in significantly higher gain and improved feed

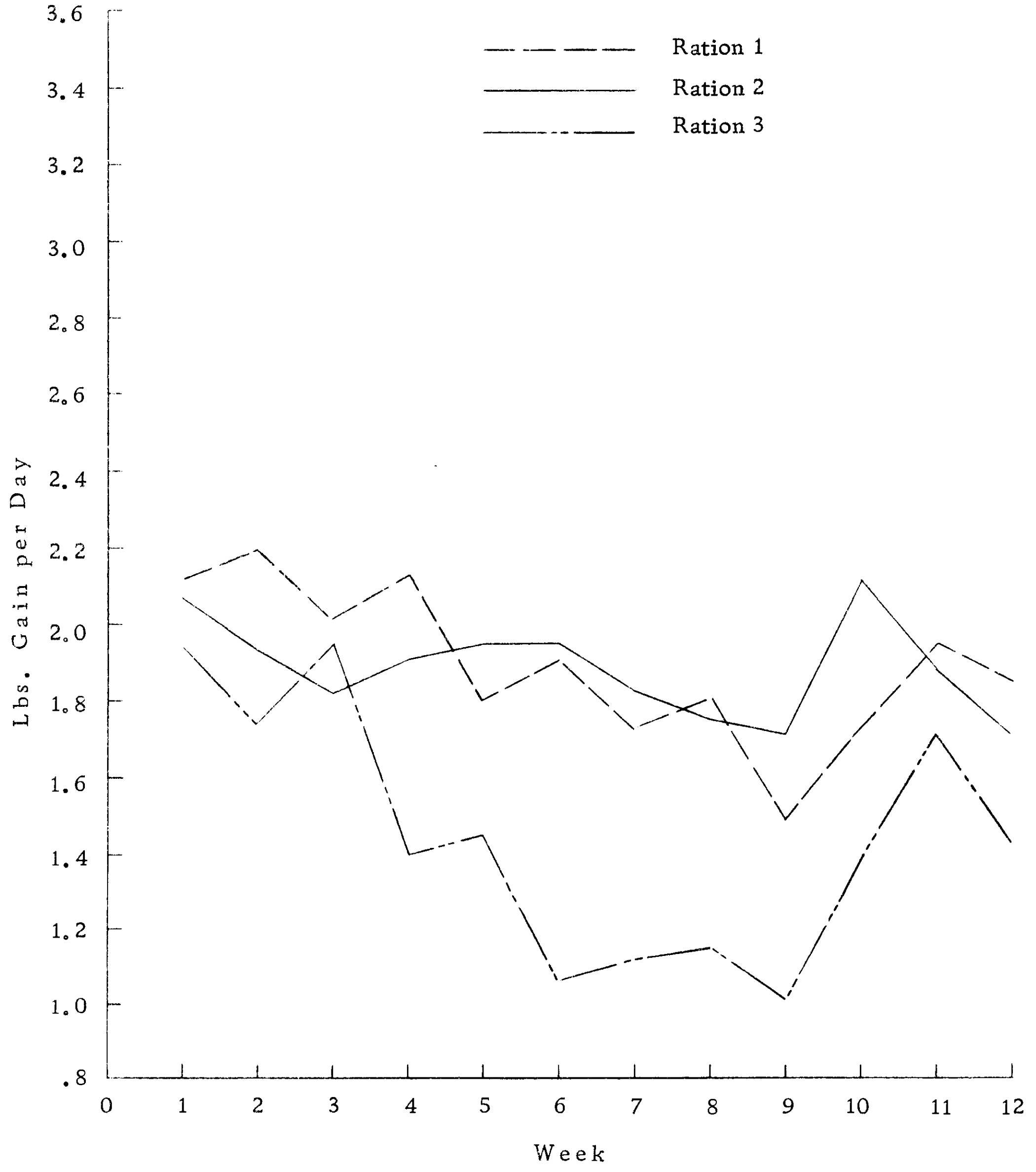

Figure 1. Growth Curves for Trial I at OSU

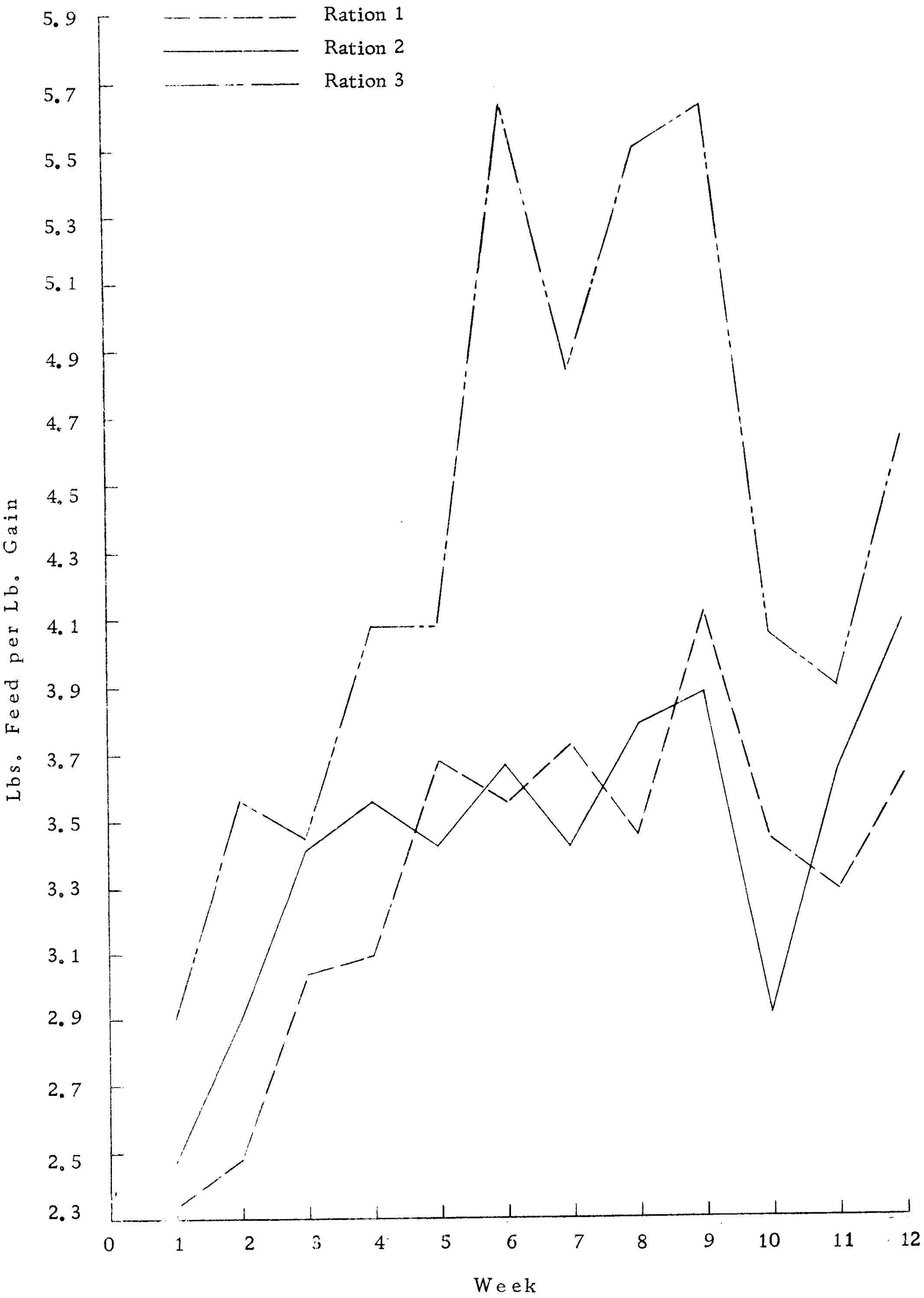

Figure 2. Feed Efficiency Curves for Trial I at OSU

efficiency as compared with meal rations. Unless the pellets hold shape the advantage from pelleting is not obtained was the conclusion of Dinussen and Bolin (1958). England, Oldfield, and Fancher (1965) and England et al. (1965) found that pelleting increased consumption and reduced wastage. That pigs fed pellets had significantly less wastage and that pigs fed meal spent more time eating but ate less was the finding of Gill (1966).

Compensatory growth can explain much of the different residual effect of ration 3. When the pigs were fed ration 3 they ate less and in some cases even lost weight; when they were switched to one of the other rations at the end of the ration 3 feeding period they regained their appetites and their gains were greater than would normally be expected. Working with cattle, Bohman (1955), Bohman and Torell (1956), Meger et al. (1965), and Bond and Lehmann (1967) found that after a period of restricted intake or low quality feed the animals had an increased rate of gain, increased feed efficiency, higher feed consumption, and no permanent effect from the low plane of nutrition. Similar work done with swine by Larson and Bell (1964), Robinson (1964), and Larson and Bell (1967) showed that following a nutritionally deficient diet the animals exhibited compensatory growth which made up almost entirely for any setback they had experienced.

The first trial at BES, although the rations were deficient in calcium according to NRC standards, did not have the problems that were experienced at OSU and the data from this part of trial I were used. The results are given in Tables 8 and 9 and the growth curve is given in Figure 3. No feed efficiency curve is given because of the pigs that died or had to be taken off the test.

Table 8. Results of Trial I at BES.

	Ration 1	Ration 2	Ration 3	Ration 4	Average
Average daily gain (lbs.)	1.63	1.69	1.45	1.64	1.58
Feed/pound of gain (lbs.)	3.11	3.05	3.44	3.17	3.19
Feed cost/pound of gain ($)[1]	.0865	.0790	.0839	.0875	.0842

[1]Cost determined as in Table 7.

Table 9. Comparison of constant and switched rations in Trial I at BES.

	Constant	Switched
Average daily gain (lbs.)	1.61	1.51
Feed/pound of gain (lbs.)	3.19	3.17
Carcass length (in.)	30.1	30.2
Backfat thickness (in.)	1.39	1.35
Loin eye area (sq. in.)	4.35	4.41

Analysis of the data for gain (Table 10) showed that there was a significant difference among rations either when fed as a constant or in a sequence. The analyses also indicate a significant difference between those pens fed a constant ration and those in which the rations were switched. There was a significant difference among the

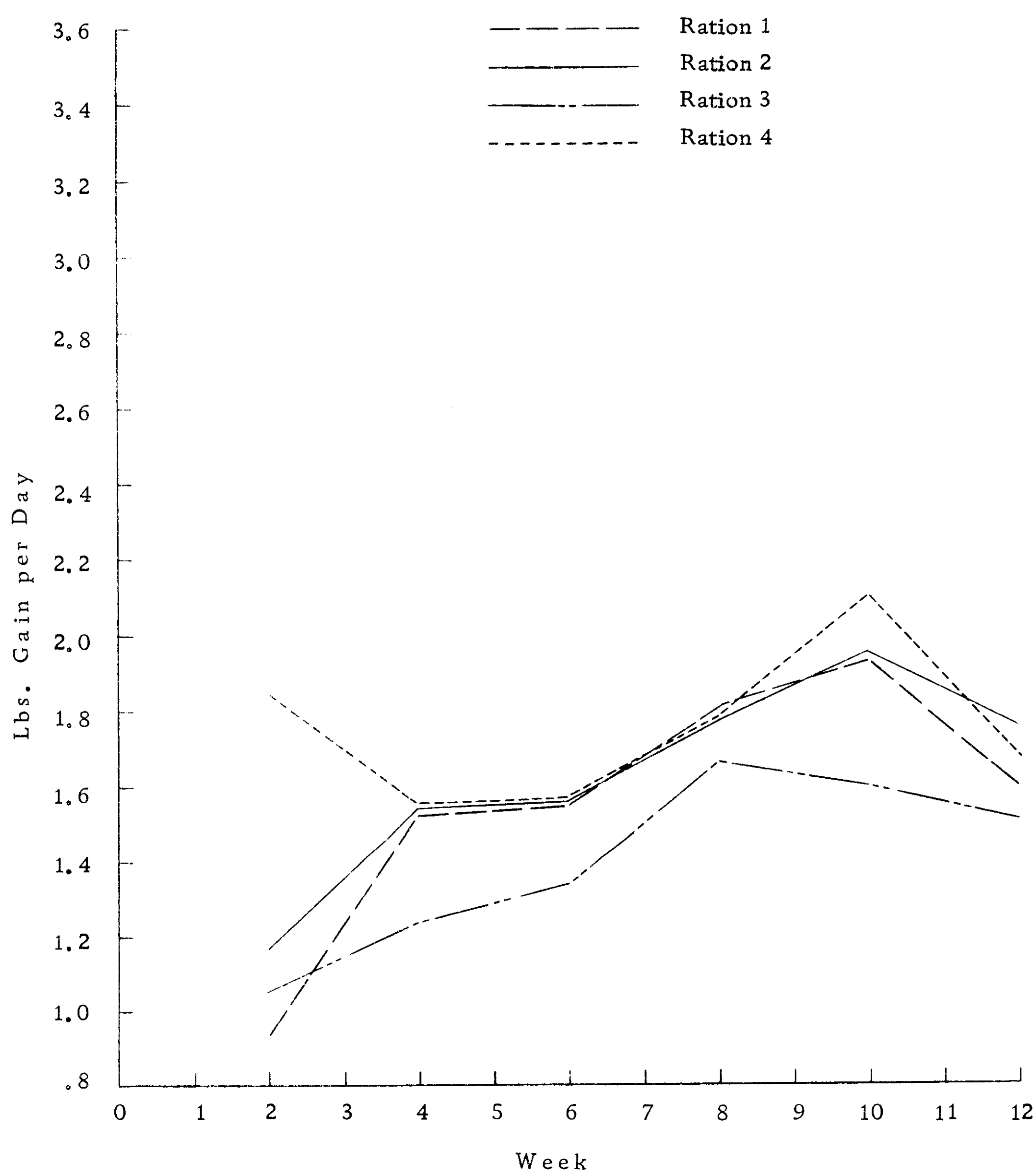

Figure 3. Growth Curves for Trial I at BES

various sequences when the rations were switched but no significant difference between the residual effects of any of the rations in the following feeding period.

Table 10. Statistical analysis of gain for trial I at BES.

Source of Variance	df	Sum of squares	Mean of squares	F Test
Constant vs. switched	1	14.2572	14.2572	6.165*
Constant rations	3	90.8004	30.2668	13.088***
Sequence of rations	5	28.8883	5.7777	2.498*
Direct ration effect	2	41.2141	20.6071	8.911***
Residual ration effect	2	1.7578	0.8789	0.380
Error	45	104.0658	2.3126	

*$P < .05$ ***$P < .001$

Analysis of the data for feed efficiency (Table 11) showed significant differences among the rations when each ration was fed as a constant and when they were fed in a sequence. There were no significant differences between the sequences. Analysis also showed no significant differences among the residual effects of the various rations in the period following switching and no significant difference between the pens fed a constant ration and those fed a sequence of rations.

Analysis of the carcass data indicated that there were no significant differences for any of the carcass traits studied: backfat thickness, loin eye area, or carcass length.

Table 11. Statistical analysis of feed efficiency for Trial I at BES.

Source of Variation	df	Sum of squares	Mean of squares	F Test
Constant vs. switched	1	0.0074	0.0074	0.134
Constant rations	3	1.9237	0.6413	11.666***
Sequence of rations	5	0.1060	0.0212	0.386
Direct ration effect	2	1.0400	0.5200	9.460***
Residual ration effect	2	0.0005	0.0003	0.005
Error	45	2.4736	0.0550	

***P < .001.

Results of Trial II

There were no problems with the rations in the second trial and no pigs were lost during the trial at either of the locations. The chemical analyses of the rations for the second trial are given in Table 12.

Table 12. Analysis of rations used in Trial II.

Ration	Location	Analysis	% Protein	% Fiber	% Ca	% P
1	OSU	1	14.39	2.98	.50	.51
1	BES	1	15.58	6.93	.66	.77
1	OSU	2	14.66	5.90	.48	.50
1	BES	2	16.33	9.05	1.08	*
2	OSU	1	17.39	2.59	.67	.84
2	BES	1	16.40	6.90	.60	.58
2	OSU	2	13.67	5.60	.55	.35
2	BES	2	14.65	5.40	.90	*
3	OSU	1	15.24	4.06	.59	.58
3	BES	1	14.92	4.40	.66	.43
3	OSU	2	13.67	3.66	.68	.41
3	BES	2	15.71	4.40	1.03	*
4	BES	1	17.23	10.19	.66	.57
4	BES	2	18.97	8.40	.86	*

*Not analyzed.

The pigs at OSU in the second trial gained well and the feed efficiency was quite acceptable. The results of the second trial at OSU are given in Table 13. Figures 4 and 5 show the growth and feed efficiency curves.

Table 13. Results of Trial II at OSU.

	Ration 1	Ration 2	Ration 3	Average
Average daily gain (lbs.)	1.98	2.02	2.03	2.01
Feed/pound of gain (lbs.)	3.21	3.34	3.10	3.22
Feed cost/pound of gain ($)[1]	.0787	.0881	.0865	.0844

[1]Cost determined as in Table 7.

Analysis of the data for gain (Table 14) showed that there was a significant difference among the sequences of rations and between the direct ration effect but no significant difference among the residual ration effects in the periods following a ration change or in the effect of switching compared to the constant ration. The gains shown in Table 13 do not indicate any difference among the rations so it is assumed that the difference is the result of the effect of the sequences since they showed a significant difference also.

Table 14. Statistical analysis of gain for Trial II at OSU

Source of Variance	df	Sum of squares	Mean of squares	F Test
Constant vs. switched	1	886,288.5800	886,288.5800	5757.686
Sequence of rations	14	5,931.6919	423.6923	2.752**
Direct ration effect	2	1,261.2264	630.6131	4.097*
Residual ration effect	4	401.6878	100.4219	0.652
Error	30	4,617.9414	153.9314	

*P < .05 **P < .01.

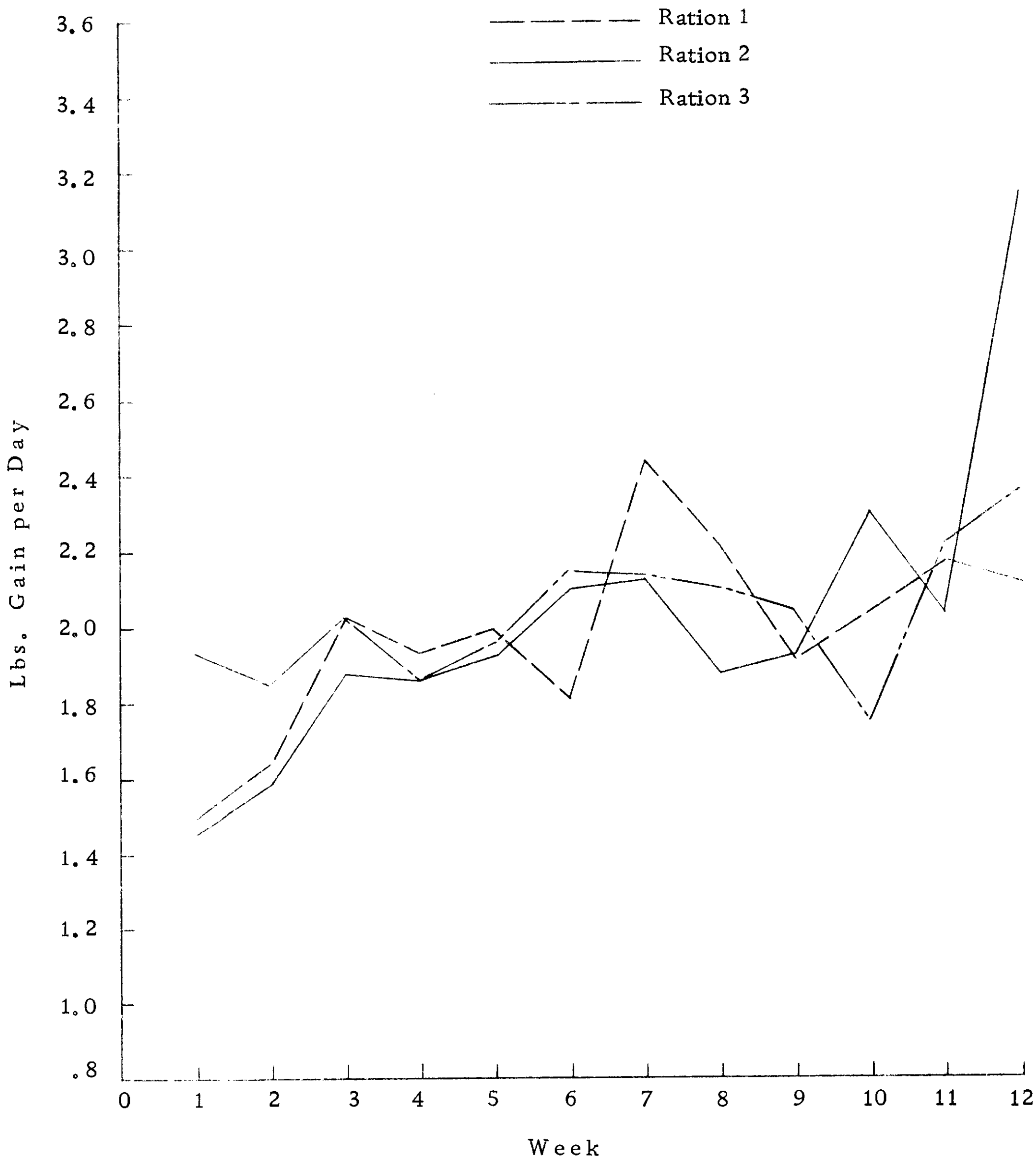

Figure 4. Growth Curves for Trial II at OSU

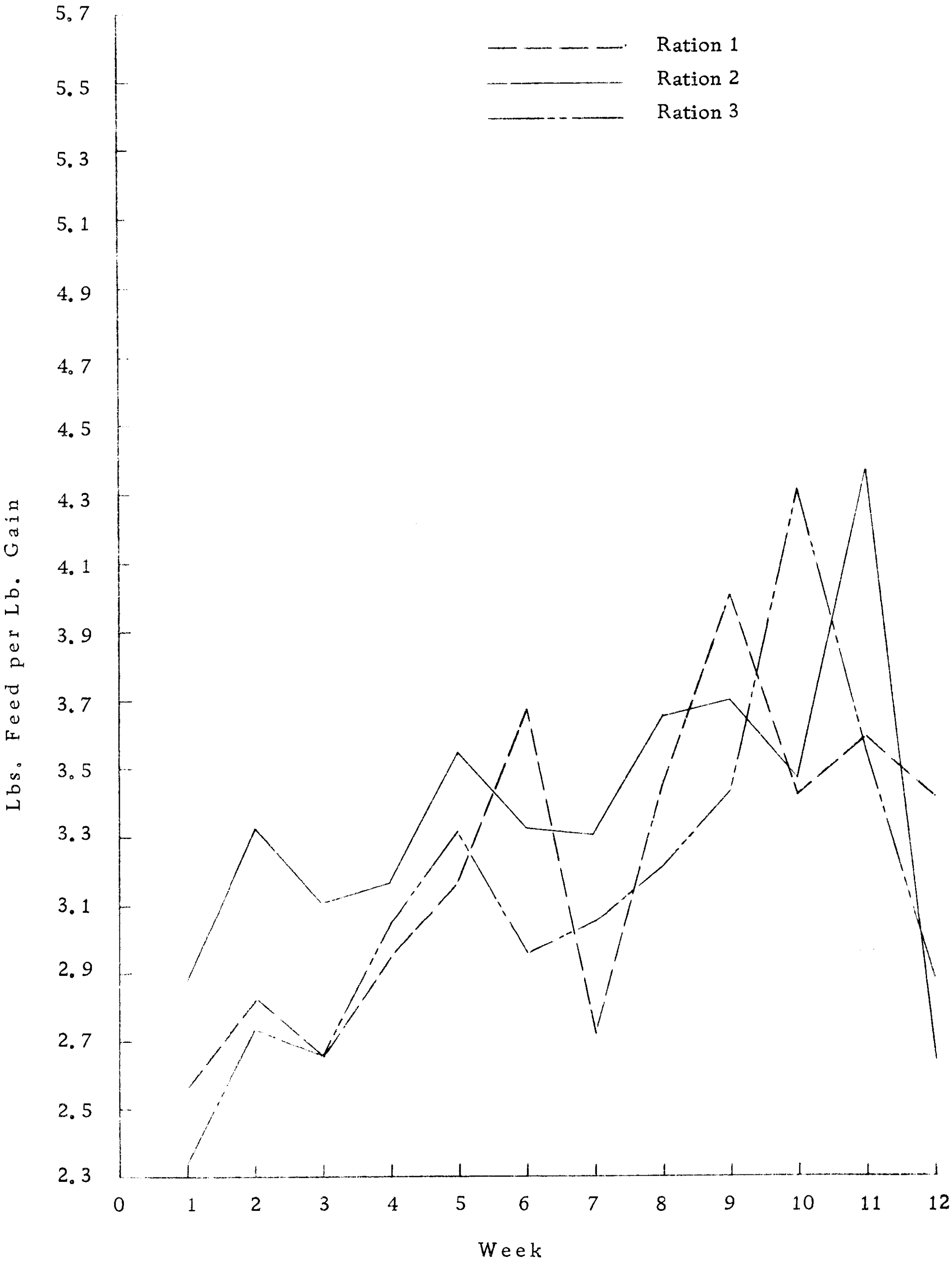

Figure 5. Feed Efficiency Curves for Trial II at OSU

The analysis of the data for feed efficiency (Table 15) showed no significant difference between the sequences of rations and the constant rations, among direct ration effects, nor among the residual ration effects in the following periods. There was a significant difference among the sequences of rations.

Table 15. Statistical analysis of feed efficiency for Trial II at OSU.

Source of Variance	df	Sum of squares	Mean of squares	F Test
Constant vs. switched	1	571.0829	571.0829	6682.842
Sequence of rations	14	2.6402	0.1886	2.207*
Direct ration effect	2	0.1637	0.0819	0.958
Residual ration effect	4	0.3156	0.0789	0.923
Error	30	2.5637	0.0855	

*$P < .05$.

No specific problems were recognized in the second trial at BES but the pigs did not perform as well as expected. No reason for this was determined but it was apparently not a ration problem since the animals fed the standard ration did not do significantly better than those fed the experimental rations. The results of Trial II at BES are given in Tables 16 and 17. The growth and efficiency curves are shown in Figures 6 and 7.

Table 16. Results of Trial II at BES.

	Ration 1	Ration 2	Ration 3	Ration 4	Average
Average daily gain (lbs.)	1.44	1.33	1.54	1.58	1.45
Feed/pound of gain (lbs.)	3.49	3.68	3.14	3.32	3.41
Feed cost/pound of gain ($)[1]	.0855	.0972	.0876	.0886	.0897

[1]Cost determined as in Table 7.

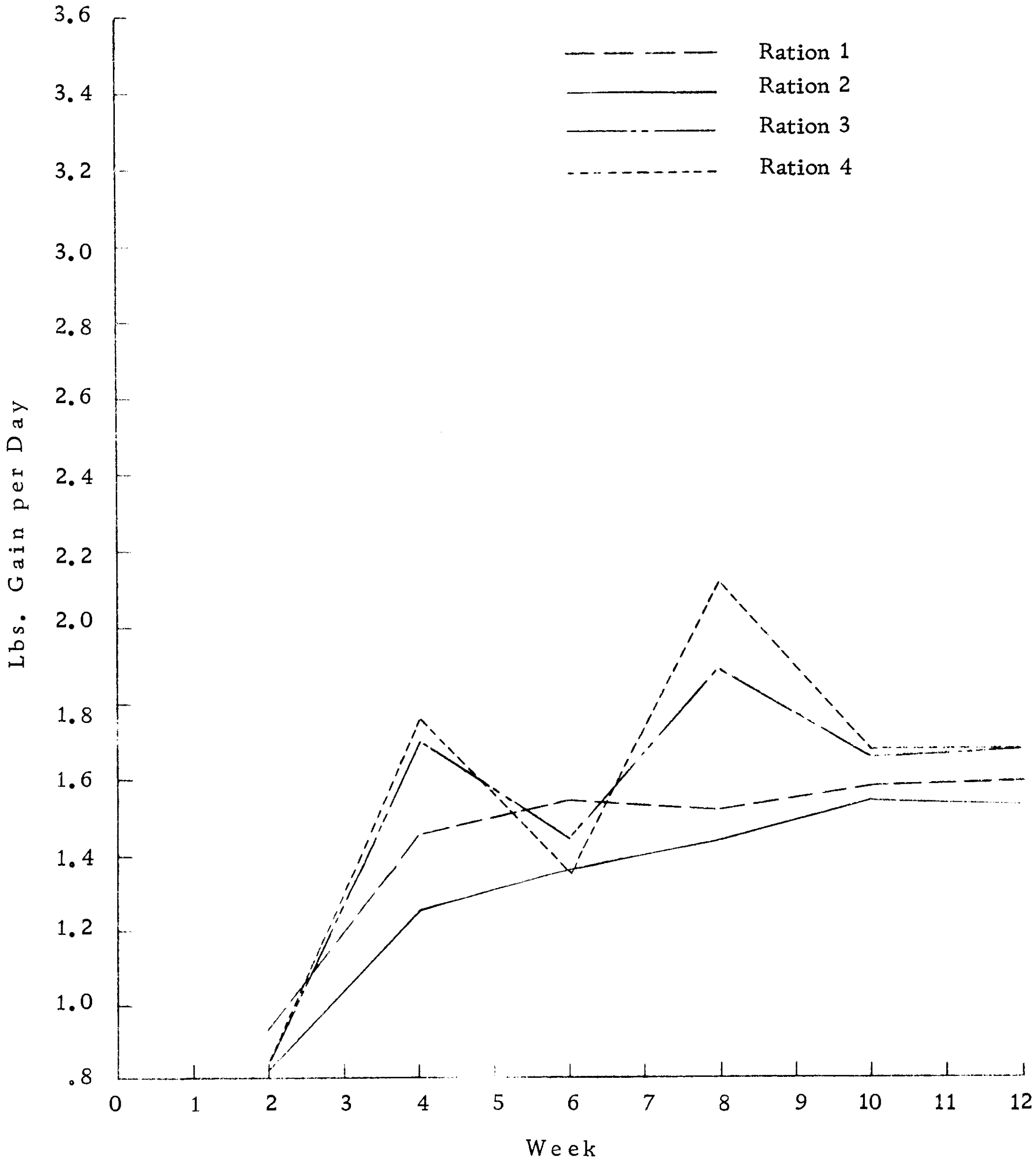

Figure 6. Growth Curves for Trial II at BES

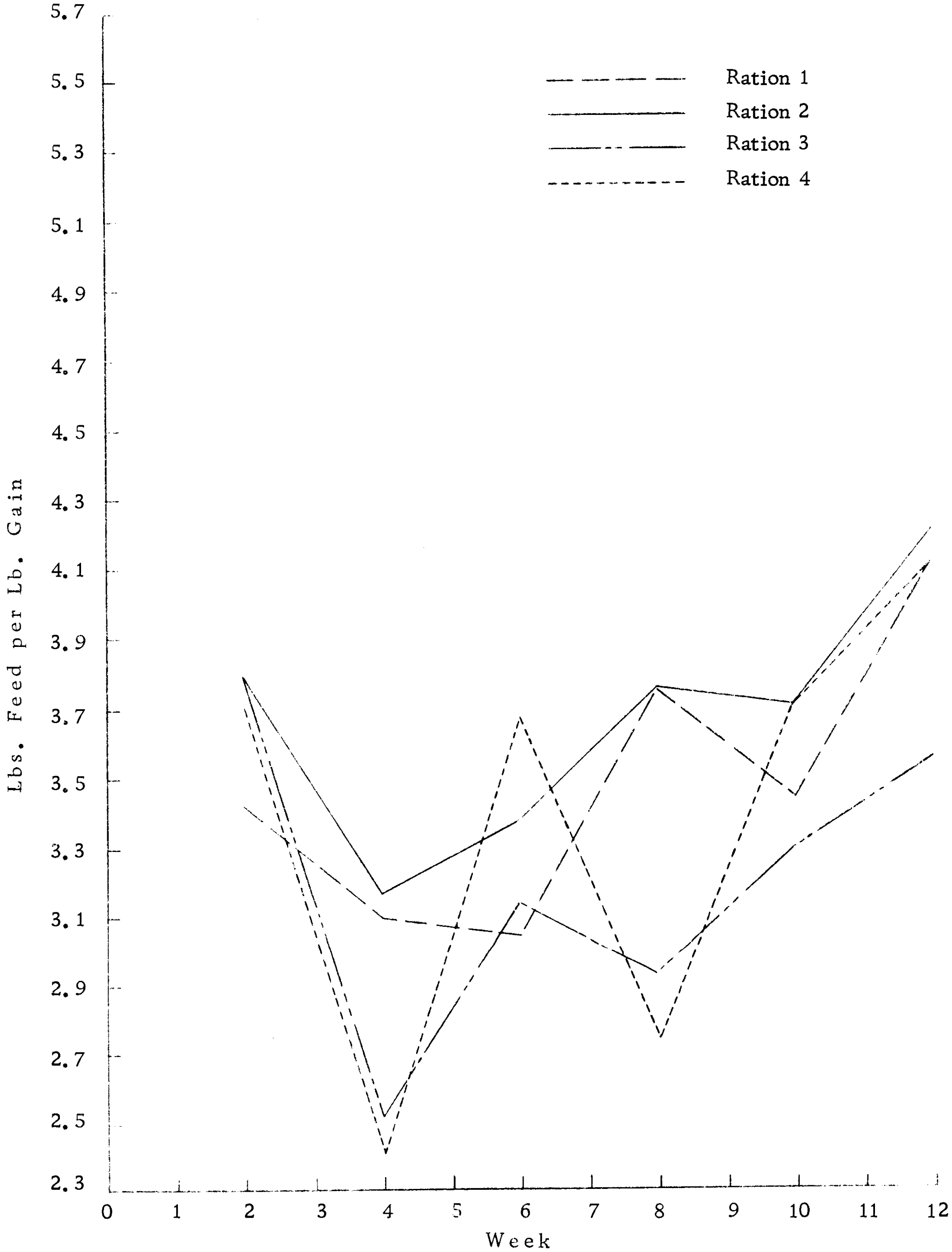

Figure 7. Feed Efficiency Curves for Trial II at BES

Table 17. Comparison of constant and switched rations in Trial II at BES.

	Constant	Switched
Average daily gain (lbs.)	1.50	1.39
Feed/pound of gain (lbs.)	3.42	3.39
Carcass length (in.)	30.6	30.8
Backfat thickness (in.)	1.37	1.35
Loin eye area (sq. in.)	3.72	3.79

The statistical analysis of the data for gain (Table 18) showed that there was a significant difference between the constant-fed rations and the switched rations and among the constant rations. It also showed that there were no significant differences among the sequences of rations, among the direct ration effects, nor among the residual ration effect.

Table 18. Statistical analysis of gain for Trial II at BES.

Source of Variance	df	Sum of squares	Mean of squares	F Test
Constant vs. switched	1	50.9045	50.9045	6.134*
Constant rations	3	91.1532	30.3844	3.661*
Sequence of rations	5	48.2250	9.6450	1.162
Direct ration effect	2	66.0996	33.0498	3.982
Residual ration effect	2	13.4260	6.7128	0.809
Error	45	373.4678	8.2993	

*P < .05.

The analysis of the feed efficiency data (Table 19) showed that the direct ration effect was significant. There was no significant difference between the constant-fed rations and the switched rations, between the constant rations, among the sequences of rations, or among the residual ration effect.

Table 19. Statistical analysis of feed efficiency for Trial II at BES.

Source of Variation	df	Sum of squares	Mean of squares	F Test
Constant vs. switched	1	0.0057	0.0057	0.028
Constant ration	3	1.3188	0.4396	2.116
Sequence of rations	5	0.6394	0.1279	0.616
Direct ration effect	2	1.7095	0.8548	4.115*
Residual ration effect	2	0.2879	0.1440	0.693
Error	45	9.3475	0.2077	

*$P < .05$.

The analysis of the data for the carcass traits showed no significant difference in backfat thickness or carcass length but there was a significant difference in loin eye area. This is shown in Table 20.

Table 20. Statistical analysis of carcass data for Trial II at BES.

Carcass characteristic	df	Sum of squares	Mean of squares	F Test
Loin eye area	9	0.7940	0.0882	8.778*
Backfat thickness	9	0.0735	0.0082	1.539
Carcass length	9	0.5036	0.0560	2.131

*$P < .05$.

DISCUSSION

Trial I at OSU gave results that were of such questionable value that they were not used but Trial I at BES gave usable results as did Trial II at both locations. The problems experienced with the first group of rations pointed out, in a way that no amount of reading or explanation could, how an extreme amount of care must be taken when preparing the input information for computer usage. The amount of time spent checking and rechecking the data, both before it is fed into the computer and again after it is in but before any runs are made, will be more than compensated for through avoidance of inadvertant errors. More care would have prevented the experience which occurred in the first trial.

The analyses of the rations in both trials showed that another problem exists which must be taken into account when formulating least-cost rations, namely, the variation in the nutrient levels in the resulting rations. This problem exists if the rations are formulated by hand but not to the extent that it does when using the computer. When formulating manually it is relatively easy to make small changes in the formula, but when using the computer these changes involve a change in the program. When using the computer it is advisable to allow a margin of error, or perhaps it should be called a margin of variability, in the specifications. For some of the nutrient specifications it is not as important as for others since a range is given to the computer to work within, but in these instances where certain maximum and/or minimums are set and must be met this margin should be considered. This does not mean, however, that it should be disregarded in the values. With a feed company that was large and modern enough to have its own laboratory so that all ingredients could be analyzed before they were used, exact specifications could be made with some degree of assurance that they would be met. It might be assumed, that since the recommendations of the NRC are of a general nature for each nutrient specification, that a margin of variability is already provided but this would probably be taking an unnecessary risk.

Palatability did not seem to be a problem with any of the rations except in the first trial at OSU under the unusual conditions of the severe calcium deficiency. Some of the rations were consumed more readily than others; this seemed to be directly affected by the amount to which the rations' pellets broke down in the feeders. The rations based on corn crumbled to a greater degree than either the wheat or the barley rations. There was less apparent problem at BES than at OSU so it may have been the preparation techniques at the latter location. This in turn would cause the feed efficiency data to reflect the pounds of feed fed per pound of gain and not the pounds of feed consumed per pound of gain. If the experiment were to be repeated, a slight change in technique could determine this. Since the experiment was conducted to provide information of benefit to the producer in the field, however, the rounds of feed fed is a more desirable gauge of feed efficiency; the producer is not interested in whether it was eaten or wasted but in the total amount of feed required to get his animals to market.

The figures for cost per pound of gain in both trials, but especially in the first (Table 8), point out that least-cost rations will not always give least-cost gain. In the first trial the cheapest ration in cost per ton of feed was ration three with rations one, two, and four more expensive in that order. The first trial at OSU must be discounted but at BES the cheapest gain was on ration two followed by rations three, one, and four. In the second trial the cheapest ration was ration one followed by rations two, three, and four. Here the cheapest ration produced the cheapest gain and was followed by ration three, four, and two. Thus, in not every case did the cheapest ration produce the cheapest gain but in every case but one the rations formulated by the computer on a least-cost basis made cheaper gains than did the standard hand formulated ration. It is therefore relatively safe to assume that on the average, rations formulated on a least-cost basis from appropriate feedstuffs will give the cheapest production. It should also be pointed out that the rations developed with the most degrees of freedom of choice will always be the cheapest.

As mentioned above, compensatory growth may be a factor in results achieved from the switching of rations and can have some effect on the efficiency of feed usage on certain feeds. This will at least partially compensate for any setback that the animals encounter while on a particular ration. Unless the animal is in the final feeding period or the degree of retardation is too severe, any setback should be no problem since performance on the following ration will compensate for it.

The switching of rations for the most part did not have an effect on feed efficiency in either direction, nor on any of the carcass characteristics. In both trials at BES there was a significant difference in gain in favor of the constant rations. The reduction in average daily gain with switched rations may be more than compensated for by the reduced cost of the least-cost rations.

There was a significant difference between the treatments in both trials at both locations. In the instance where this difference was among the constant rations, it was a reflection of the difference in rations. Where the difference was among the sequences of rations, it is not a total difference but only between certain combinations. At OSU in the second trial there were 25 significant differences out of 105 comparisons for gain and 21 out of 105 for feed efficiency. In the instance of gain at BES in Trial I, it was only one out of the six that was different. There was no significant difference of treatment on feed efficiency or carcass characteristics.

There was a significant difference among rations in both trials at both locations in either feed efficiency or gain. This difference was the greatest when the rations were fed for the entire trial. When the rations were switched, the effect of each ration was not as large and the differences were largely taken care of by compensatory growth, and the savings resulting from feeding the least-cost rations.

There were no significant differences among the residual effects of the rations in the following feeding period. Thus, carry-over effects were not encountered; a ration fed in one period did not determine animal response in the following period on a different ration.

There were no differences in any of the carcass characteristics because of the switching of rations, because of the treatment, or residual effect. The only significant difference was a reduction in loin eye area when ration two was fed for the entire Trial II at BES.

SUMMARY AND CONCLUSIONS

An experiment involving two trials at each of two locations was conducted to answer several questions: (1) can nutritionally comparable rations for swine be formulated by a computer using different feedstuffs on a least-cost basis; (2) will these rations produce similar results when fed; and (3) what effect will switching of these rations during the feeding period have on the rate of gain, feed efficiency, and carcass characteristics of swine.

These questions were all answered satisfactorily. Specific conclusions can be drawn as follows:

1. In the computer formulation of rations on a least-cost basis, care must be taken to insure that the input data provided the computer are correct.

2. For feasibility, it is desirable that a margin of variability be provided when the specifications for the various nutrient levels are established.

3. The least-cost rations will not always produce the least-cost gain but on the average will be more economical than hand formulated rations.

4. It is to be expected that there will be some variability in the results obtained from feeding the various rations. Variability will come from the amount of the ration wasted, the amount the

pelleted ration breaks down in the feeders, and from any differences in palatability. Such variability was encountered in varying degrees in this experiment.

5. Differences in response are more apparent and frequency of more significant differences is increased if the rations are fed constantly for the entire period; when rations are switched during the feeding period, differences are overcome to some extent by compensatory performance in the following period. Thus, switching of rations may provide a degree of insurance against suboptimum performance.

6. Switching the rations during the feeding period significantly decreased rate of gain below the mean of the constant-fed rations but had no significant effect on feed efficiency or carcass characteristics. The adverse economic effect of reduced rate of gain may be partially or wholly offset by the cost advantages to be gained from the feeding of least-cost rations.

The formulation of nutritionally equivalent rations for swine on a least-cost basis and the reformulation of these rations prior to each feed delivery would seem to be the direction toward which both producers and feed dealers should be working. This will provide the producer with the cheapest rations possible to meet his particular requirements and still give the feed dealer a satisfactory margin on the feed sold.

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APPENDIX

Table 21. Average 12 week weight by ration sequence for Trial I at OSU.

Ration sequence	Average weight
1 1 2 3	215
1 2 3 1	197
1 2 1 3	237
1 3 2 2	218
1 3 3 2	203
2 1 1 3	195
2 2 3 1	186
2 3 1 3	219
2 3 1 3	198
2 3 2 1	205
3 1 2 3	220
3 1 3 2	213
3 2 1 1	215
3 2 2 1	236
3 3 1 2	199

Table 22. Average 12 week weight by ration sequence for Trial I at BES.

Ration sequence	Average weight
1 1 1	197
2 2 2	199
3 3 3	180
4 4 4	201
1 2 3	179
1 3 2	188
2 1 3	189
2 3 1	198
3 2 1	191
3 1 2	192

Table 23. Average 12 week weight by ration sequence for Trial II at BES.

Ration sequence	Average weight
1 1 1	186
2 2 2	174
3 3 3	191
4 4 4	192
1 2 3	169
1 3 2	190
2 1 3	178
2 3 1	168
3 2 1	178
3 1 2	174

Table 24. Average 12 week weight by ration sequence for Trial II at OSU.

Ration sequence	Average weight
1 1 2 3	215
1 2 3 1	226
1 2 1 3	231
1 3 2 2	243
1 3 3 2	243
2 1 1 3	227
2 1 3 3	229
2 2 3 1	225
2 3 1 3	241
2 3 2 1	233
3 1 2 3	231
3 1 3 2	231
3 2 1 1	237
3 2 2 1	233
3 3 1 2	246

Table 25. Average daily gain, feed efficiency, and feed consumption by ration sequence for Trial II at BES.

Ration sequence	ADG[1]	FE[1]	FC[1]
1 1 1	1.52	3.28	420
2 2 2	1.36	3.63	412
3 3 3	1.56	3.10	408
4 4 4	1.58	3.32	440
1 2 3	1.32	3.64	402
1 3 2	1.56	3.28	431
2 1 3	1.40	3.26	382
2 3 1	1.33	3.44	382
3 2 1	1.41	3.28	385
3 1 2	1.37	3.58	402

[1]Expressed in pounds.

Table 26. Average daily gain, feed efficiency, and feed consumption by time period for Trial II at BES.

Time period	ADG[1]	FE[1]	FC[1]
1	0.66	3.65	44.2
2	1.51	2.80	59.5
3	1.44	3.24	65.4
4	1.68	3.32	78.2
5	1.64	2.51	59.2
6	1.61	3.67	82.9

[1]Expressed in pounds.

Table 27. Average daily gain, feed efficiency, and feed consumption by ration sequence for Trial II at OSU.

Ration sequence	ADG[1]	FE[1]	FC[1]
1 1 2 3	1.84	3.37	517
1 2 3 1	1.93	3.17	514
1 2 1 3	1.96	3.29	544
1 3 2 2	2.17	3.17	578
1 3 3 2	2.15	2.98	538
2 1 1 3	1.97	3.40	564
2 1 3 3	1.94	3.35	590
2 2 3 1	1.92	3.30	532
2 3 1 3	2.11	3.17	561
2 3 2 1	2.02	3.16	537
3 1 2 3	2.02	3.21	545
3 1 3 2	2.00	3.18	535
3 2 1 1	2.06	3.32	571
3 2 2 1	1.99	3.37	590
3 3 1 2	2.19	3.13	574

[1]Expressed in pounds.

Table 28. Average daily gain, feed efficiency, and feed consumption by time period for Trial II at OSU.

Time period	ADG[1]	FE[1]	FC[1]
1	1.78	2.80	105
2	1.96	3.24	133
3	2.09	3.38	148
4	2.23	3.47	163

[1]Expressed in pounds.