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A COMPARISON OF TWO STRAINS OF RATS AND THE CROSSES BETWEEN THEM UNDER TWO ENVIRONMENTAL CONDITIONS

Thesis for the Degree of Ph. D.
MICHIGAN STATE UNIVERSITY

Kay Reed Bendixsen

1965

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Ph.D. degree in Animal Husbandry

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ABSTRACT

A COMPARISON OF TWO STRAINS OF RATS AND THE CROSSES BETWEEN THEM UNDER TWO ENVIRONMENTAL CONDITIONS

By Kay Reed Bendixsen

Pure-strain and cross-strain offspring from two strains of rats were tested. The strains had been selected for heavy weaning weight (WW) and rapid rate of growth (RG) from 21 to 49 days. Genetic differences were evaluated on full feeding for weaning weight and on both full and limited feeding for growth after weaning. Growth rate and feed efficiency were evaluated on full and limited feeding between 21 and 49 days on the feed test. Relationship between growth rate and mature weight was tested.

Offspring were produced in two seasons in each of two generations. There were 189 male and 280 female rats in the pure-strain and cross-strain comparisons.

The RG strain averaged significantly heavier weaning weights than the WW strain (13.7 grams for males and 13.8 grams for females). The reciprocal cross-strain groups showed a highly significant 12.7 gram difference for males and 10.7 gram difference for females in weaning weight

favoring the WW X RG cross. The male parent strain caused no difference between the strains in weaning weight, but there was a large difference when the strains were used as female parents.

Gain after weaning difference was highly significant favoring the RG strain. Male offspring were 60 grams heavier and females were 52 grams heavier in the pure-strain comparisons. Differences between strains used as male parents indicated a genetic superiority for growth present in the RG strain.

There was no hybrid vigor in any of the trials.

Replication differences were highly significant for weaning weight, rate of gain and 49-day weight.

The two pure-strains were tested under two environments, full or limited-fed in four replications. There were 104 female rats tested for growth rate and feed conversion. The difference between levels of feeding for average daily gain was 1.48 grams in the RG strain and 0.92 grams for the WW strain. The RG strain out-gained the WW strain 1.77 grams for the full-fed and 1.21 grams for the limited-fed groups. Differences between strains and between treatments and the interaction between strains and treatments were highly significant.

Differences in efficiency of gain between strains and between treatments were highly significant. Feed



efficiency difference between the RG F (full-fed) and RG L (limited-fed) rats was 0.25 grams more feed required by the limited-fed group. The WW L group required 0.10 grams more feed to gain a gram of weight than the WW F group. Interaction between strains and treatments was highly significant.

Within group correlations between daily gain and feed efficiency were tested. There was a high correlation between feed efficiency and rate of gain in the RG L, WW F and WW L groups but a low correlation in the RG F group.

As the rats grew older the differences in weight increased.

In all cases the limited-fed rats were less efficient than the full-fed rats. As the size of the rats increased the feed efficiency decreased.

Limited feeding during the 21 to 49-day growth period caused no significant difference in mature weights of the rats.

There was a significant difference in the average mature weight of the two strains. The WW strain females averaged 259 grams compared with 354 grams for the RG females. The RG and WW strain males averaged 646 grams and 428 grams, respectively.

A COMPARISON OF TWO STRAINS OF RATS AND THE CROSSES BETWEEN THEM UNDER TWO ENVIRONMENTAL CONDITIONS

By

Kay Reed Bendixsen

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I. INTRODUCTION

Limited information is available on the results of crossing of strains that have been selected for different characteristics. There are a few reports of research work done on genetic environmental interaction, but much additional work is needed. Only limited information is available on the relationship between growth rate to an early age and mature size.

Basic genetic information can be gained from studies with small animals. Rats provide a ready source of genetic material with a short generation interval. In addition they are prolific and feed and care are relatively inexpensive. The information gained may be useful in other genetic studies. The information may also be used as guides in research on economically important farm animals.



II. OBJECTIVES

1. To compare the performance of the strain-cross with the performance of two strains of rats which had previously been selected for different characteristics. One strain was selected for high weaning weight (21 days) and the other for rapid rate of gain from weaning to 50 days.
2. Test the combining ability of the two lines.
3. Test the effect of full and limited (80 percent) feeding on both strains and the interaction between the strains and level of feeding with regard to rate of gain and feed efficiency.
4. Determine the relationship between rate of gain and mature weights.

III. REVIEW OF LITERATURE

HETEROSIS

The principle behind crossbreeding is to obtain hybrid vigor or heterosis. Animals who exhibit heterosis, according to Lush (1948), must have a level of performance that exceeds the average of the parental lines. East (1936) defines heterosis as a rise in the efficiency index. The above definitions agree in principle and define heterosis as it will be used in this thesis.

CROSSBREEDING IN SWINE

Crossbreeding swine has become an accepted practice in commercial pork production. In the majority of cases heterosis has been exhibited, Hazel (1961). Experiments on the crossbreeding of swine have been in progress for many years. Lush et al. (1939) reported on crossbreeding experiments at the Iowa Experiment Station which were started in 1926 and continued until 1937, using double and single matings. During this period 1,015 pigs were tested from 108 litters. The purebreds tested were Landrace, Poland China and Duroc. The first crosses made Poland China X Duroc were "double-mating" crosses, (boars of both breeds served each

sow). Yorkshire boar crossing was added next in the test and mated to Poland China and Duroc sows. After seven years of using these three breeds, the Danish Landrace breed was introduced and crossed with Poland China line. In all cases the purebred and straight cross breds were compared. The crossbred pigs gained from .09 to .12 pounds more per day than the average of the purebreds, a saving in time of 10 to 14 days to reach 225 pounds. The crossbreds also reached 225 pounds on 25 to 30 pounds less feed.

Men at the Missouri Agricultural Experiment Station (reported by Lush et al. 1939) crossed the Duroc and Poland China breeds. The crossbreds exceeded the best of the purebreds in rate of gain but not in efficiency of gain. The Durocs gained 1.08 pounds per day and used 317 pounds of feed per 100 pounds gain. The Poland Chinas gained 1.26 pounds per day on 300 pounds of feed per 100 pounds gain. The crossbreds gained 1.34 pounds per day on 320 pounds of feed per 100 pounds gain. The feed difference was not significant.

Roberts and Carroll (1939) compared 329 purebred Poland China and Duroc pigs with 308 crossbreds. They reported that the crossbreds average daily gain was 1.65 pounds and the purebreds was 1.59 pounds. The average pounds of feed per 100 pounds gain was 402 for the crossbreds and 409 for the purebreds. The difference in these figures was not significant.

During a six year study of the production of Wiltshire sides made by Hutton and Russell (1939), the crossbreds out-gained the purebreds and were more efficient in feed utilization than the purebreds. Yorkshires and Chester Whites were used to make this cross. The Yorkshires averaged 1.21 pounds daily gain and 375 pounds of feed per 100 pounds gain. The Chester Whites averaged 1.30 pounds daily gain and 403 pounds of feed per 100 pounds gain. The crossbreds obtained by mating Yorkshire boars to Chester White sows averaged 1.35 pounds daily gain and 371 pounds of feed per 100 pounds gain. The reciprocal cross, Chester White boars and Yorkshire sows, gained 1.33 pounds per day and 370 pounds of feed per 100 pounds gain.

Shaw and MacEwan (1936) in Canada, using various combinations of five breeds compared 325 crossbred pigs to 77 purebred pigs. The crossbreds made a daily gain of 1.24 pounds per day and required 429 pounds of feed per 100 pounds gain. The purebreds made 1.15 pounds daily gain and required 440 pounds feed per 100 pounds gain. In another experiment using Berkshires and Tamworths, the crossbreds excelled the purebreds by 0.29 pounds daily gain and 66 pounds less feed per 100 pounds gain.

A summary was made by Dickerson et al. (1950) of many different experiments comparing parental breeds and crossbreds. It showed that the crossbreds averaged 4 percent more daily gain and 2 percent more efficient use of feed than the purebreds.

CROSSES USING INBRED LINES OF SWINE

Inbred lines of swine have been developed with the principle value being to obtain advantages in crossbreeding, according to Craft (1953). Craft (1943) also reported that the better lines of inbreds have stayed almost comparable to the foundation stock. Traits, such as economy of gain, have improved.

Data from 13 lots of crosses between inbred and outbred swine favor the crossbreds (Winters et al. 1944). Rate of daily gain for the outbred pigs was 1.41 pounds, 1.53 for the crossed lines and 1.62 for the crossed lines and breeds. Winters et al. (1948) in a later experiment crossed 5 inbred Poland China lines found the offspring from crossing between lines were slightly superior in rate and efficiency of gain to the inbred line pigs.

An experiment reported by Dickerson et al. (1946) showed that pigs from crosses of inbred lines made 0.14 pounds a day more gain than did pigs within inbred lines. The crossbreds utilized feed with about the same efficiency as the purebreds but consumed more feed per day. A later report (Dickerson, 1949) covered a 2 year study of crossed inbred lines within a breed, lines between breeds, a line to another breed and compared them to the pure outbreds. The crossbreds grew more rapidly but required 5 percent more feed per 100 pounds gain than the purebreds.

Warwick and Wiley (1950) studied the effect of crossing an inbred strain from a bacon type breed with a line from an American breed. Comparisons were made between crosses of the two inbred lines, backcrosses to parental inbred lines and conventional crossbreds and purebreds. The purebreds and conventional crossbreds made an average daily gain of 1.52 pounds, the backcrosses averaged 1.48 pounds and the linecross pigs averaged 1.74 pounds. Linecross and backcross pigs were about equal in feed utilization. Both required about 11 pounds of feed less per 100 pounds gain than the purebreds and conventional crossbreds. The difference between the feed utilization of the linecross and conventional bred pigs was statistically significant.

CROSSBREEDING LINES OF RATS

Kidwell et al. (1960) crossed four inbred lines of rats. All 16 possible mating combinations were made. The data were analyzed for differences in 28 and 70 day weights. The heterosis effect was significant at 70 days of age but not at 28 days. General combining ability was significant at 28 days but not at 70 days. The effects of sex, lines and maternal ability on weight were highly significant at 28 and 70 days of age. There was an interaction of maternal effects and the mating system with respect to the 28-day weight.

Eight inbred lines of rats and a group of outbred rats were used by Craig and Chapman (1953) to investigate

weight differences at 13 weeks of age. The linecross offspring were found to be significantly heavier on the average than the component inbred lines. Although they did not, on the average, exceed the body weight of the heavier line or the outbred group involved in each specific cross.

BREED OR LINE-ENVIRONMENTAL INTERACTIONS

The joint effect of heredity and environment determine the performance of the individual. The interrelationship of these forces and their respective influences on the individual development are of interest and importance to students of breeding and nutrition. There are many methods of appraising their respective influences. One method is by subjecting similar genetic material to different environmental conditions. A second method is by subjecting different genetic material to similar conditions.

Many experiments have been set up to test various types of animals under various conditions. The purpose of these experiments was to learn how effective selection is for certain traits under different environments.

With regard to the effect of environment on the effectiveness of selection, Hammond (1947) stated, "From a survey of such results it would appear that the character required is best selected for under environmental conditions which favor its fullest expression and that once developed

it can also be used in other environments, provided that other characters, specially required by that new environment, are also present in an animal."

Falconer (1952) recommended that to obtain the best results, selection should be carried out under the environmental conditions in which the offspring will live. A superior genotype in one environment would not necessarily be superior in a different environment. There may be a genotype-environmental interaction. He suggests that when a single trait shows a genotype-environmental interaction under two different environments, it should be considered as two separate traits.

SWINE EXPERIMENTS

To learn the effects of feeding swine at different levels, Ellis and Zeller (1934) conducted six experiments. Different kinds of feed were also used. Two, three and four feeding levels were used in the different trials. In two of the trials the 70 percent of full fed lots made greater daily gain than the full fed lots. The reason for the difference was a heavier starting weight and a lighter finishing weight. (A different part of the growth curve was measured for the limited fed lot than for the full fed lot). In all other cases as the amount of daily feed was reduced the daily gain was also lower. In all six experiments the full fed

lots were the least efficient in converting feed to pounds of body weight.

Winters et al. (1949) fed four lots of pigs from weaning to 215 pounds and divided the feeding period on two lots. Lot one was full fed from weaning to 215 pounds (HH). Lot two was full fed from weaning to 125 pounds and limited fed from 125 to 215 pounds (HL). Lot three was limited fed from weaning to 125 pounds and full fed from 125 to 215 pounds. Lot four was limited fed for the whole period, weaning to 215 pounds. Limited fed was restricting the amount of feed to 3 percent of body weight. The results of the trial can be summarized in the following form.

Effect of plane of nutrition on the rate and economy of production

Lots	1(HH)	2(HL)	2(LH)	4(LL)
Ave. daily gain 1st period	1.22	1.21	.72	.72
Ave. daily gain 2nd period	1.61	1.17	2.16	1.24
Ave. days of age at end of trial	206	219	230	266
Feed per 100 lbs. gained to 125	339	337	334	338
Feed per 100 lbs. gained 125 to 215	423	422	444	391
Total feed per 100 lbs. gain	383	381	391	365

The fourth group fed the limited ration throughout the trial required less feed per 100 pounds gain and definitely less nutrients per unit of gain when maintenance was considered. The limited fed pigs also produced the leanest carcasses. This information led to the conclusion that less nutrients are required to produce a pound of lean meat than a pound of fat.

To determine the effect of restricting feed intake on market hogs during the finishing period, Crampton et al. (1954) fed out 120 Yorkshire pigs. The hogs were full fed from weaning at 56 days to a 100 pound weight. One-half of the pigs (60) were full fed a diet containing 13 percent protein from 110 to 200 pounds body weight. The other half were fed the same diet but restricted to 80 percent of the full fed pigs during the same period. The full fed lot averaged a daily gain of 1.73 pounds on 4.5 pounds of feed per pound of gain in 102 days. The restricted fed lot averaged 1.38 pounds daily gain on 4.6 pounds of feed per pound of gain in 114 days. The restricted feeding required more feed per pound of gain and more time to reach the required weight.

Fowler and Ensminger (1960) studied the interaction between genotype and plane of nutrition in selection for rate of gain in swine. Selection was made on a high and low (70 percent of full) plane of nutrition for nine generations. Six generations were tested on the one plane and then one-half of each lot was changed to the other plane and tested. Selection for increased rate of gain was successful under both planes. Feed efficiency was measured and found to vary with the plane of nutrition. The data covering the second to sixth generation showed that the limited fed groups (3.08 pounds feed per pound gain) were significantly more efficient in feed conversion than were the full fed lot (average 3.88

pounds feed per pound gain). In the sixth generation, feed efficiency still favored the limited fed group, 2.59 pounds compared to 2.65 pounds of feed per pound gain but the difference was not significant.

After six generations each line was divided into two sub-groups. Half of each group was changed to the opposite feed level. The other half remained on the original feeding schedule. The four sub-groups were continued for three more generations to evaluate the performance of each line on the other nutritional level. Average daily gain increased under selection in both lines, 0.043 pounds per generation for the full fed lot and 0.034 for the limited fed lot. A pooled genetic correlation between rate of gain on high plane and on low plane of nutrition was 0.70. The authors conclude, "Superior gains in the low plane may be due to superior feed efficiency as a result of lower thyroid activity. Superior gains in the high plane may be due to genes conditioning appetite, feed consumption, metabolic rate and/or over secretion of growth hormones."

To restrict the amount of nutrient intake, Merkel et al. (1958) used a high fiber ration. Sixty-four weaning pigs were divided into two lots. One lot was fed a ration containing 70 percent of the basal diet while the other was full fed. Restricting the total digestible nutrient level with fibrous feed decreased the average daily gain from 1.42 pounds to 1.16 pounds. The feed consumption per 100 pounds

gain increased on the restricted TDN diets. TDN consumption per 100 pounds gain was about equal, 299.3 pounds feed on the basal diet and 285.6 on the high fiber diet. The major significant difference was the number of days required to reach 210 pounds. There was a difference of 30 days favoring the pigs fed the basal diet, 152 days average for the pigs fed the high fiber diet and 122 days for the basal diet pigs.

Tribble et al. (1956) when studying the factors effecting growth and feed efficiency in swine, found that efficiency changed with the weight of the pigs. Two lots of 64 pigs each were fed in the experiment from weaning weight, 48 pounds to 208 pounds. One lot was full fed and the other limited to 85 percent of the full fed lot. Both the amount and the protein level were limited and tested in this trial. The full fed pig's average daily gain, 1.71 pounds per day was (highly significant) greater for the complete feeding period than the gain of the limited fed lot, 1.35 pounds per day. There was no difference between the groups in the feed efficiency up to 100 pounds body weight. From 100 pounds to finishing weight, the limited fed pigs made more efficient gain. The feed required for 100 pounds of gain was 399 pounds for the full fed group and 367 pounds for the limited fed group. This difference, 32 pounds in the feed requirement, was highly significant. There was a significant difference favoring the limited fed pigs in efficiency of gain when the whole feed period was considered.

Thirty-six pigs were divided into three equal lots by Thrasher, et al. (1963). One lot was self fed, the second and third lots were fed 90 percent and 85 percent of a full feed. Daily gains for full, 90 and 85 percent groups were 1.78, 1.56 and 1.48 pounds respectively. The feed required per pound of gain was 3.65, 3.77 and 3.68 pounds listed in the same order.

MICE EXPERIMENTS

To determine the effect environment had on selection for growth in mice from the period of 3 to 6 weeks of age, Falconer and Latyszewski (1952) selected animals fed on full and 75 percent of full rations. Growth rate increased under selection in both groups. Exchanges in nutritional levels were made after 5, 7 and 8 generations. Mice selected on a restricted diet and placed on an unlimited diet were just as heavy as those selected on a full diet. However, mice selected on the full diet and raised on a restricted diet showed no improvement over the unselected controls. The indications were that two different characters were selected. Mice on limited feed were selected for efficiency of feed utilization and mice on full feed were selected for a high appetite.

Falconer (1960) experimented by selecting mice for 13 generations for growth on a high and low plane of nutrition. The basis for selection was the growth rate during the period of 3 to 6 weeks of age. Both the high plane and low plane

mice were fed ad libitum. A 50 percent fiber diet was used to limit the nutrient intake of the low plane mice. All selection for growth rate was within litters. Selection for growth was effective for the high plane line when they were tested on either diet. Selection for growth was effective for the low plane line on the low plane diet only. During the selection period mice on the low plane ate less and wasted more or maybe ate more selectively. Efficiency of gain was much less on the high plane fed mice.

ADULT WEIGHT

Falconer and Latyszewski (1952) studied the effect of the plane of nutrition on body weight in mice. Two strains were selected in the same manner from a single foundation population for weight at 6 weeks of age. One strain was full-fed, the other was restricted to 75 percent of full-fed between the ages of 3 to 6 weeks. The limited diet caused a 10 percent reduction in the 6 weeks weight. From 6 to 9 weeks all the mice were full-fed. The mice were also mated at 6 weeks and littered at about 9 weeks of age. By this time the effects of the restricted diet had almost disappeared. There was little direct effect of the limited diet on the next generation through the mother. Selection was for increased size. The 3 week restricted feeding period did not affect mature size.

IV. MATERIAL AND PROCEDURE

EXPERIMENTAL STOCK

Two strains of rats were used that had been selected for different characteristics. One strain had been developed by the Michigan State University Endrocrine Laboratory and was selected for heavy weaning weight. A minimum weaning weight of 60 grams was required of each rat to be used as breeding stock. The line was developed in an air-conditioned laboratory. Since the strain was selected for heavy weaning weight, it will be referred to as the WW strain in this thesis.

The second strain of rats had been developed by the Michigan State University Animal Husbandry Department and selected for a fast rate of gain from weaning at 21 days to 50 days of age. They were developed in a non-air conditioned laboratory. The development of the line is reported in a PhD thesis by Pratt (1960). The strain was selected for rapid rate of gain and will be referred to as the RG strain in this thesis.

STATISTICAL METHODS

The statistical analysis was made using Harvey's (1960) least squares method of analysis of data with unequal

sub-class numbers. The other methods used have been described by Dixon and Massey (1957).

MANAGEMENT PROCEDURE

Base Generation

The base generation was produced to eliminate as much as possible past environmental condition effects and to adjust to the conditions under which the rats were to be raised. The strains were kept pure during the first mating. The original plan was to use five males and ten females from each strain. Due to breeding problems the desired number was not available in the WW strain. Six males and six females were used to produce the WW strain base generation. The RG base generation was produced as planned. Females were allotted to the males at random, keeping inbreeding at a minimun. All the breeding stock were from 90 to 120 days of age at the start of the experiment. Base generation matings were made October 5, 1961. The policy was to mate one male to two females whenever possible.

When the litter was born a record was made of the birth date, number born alive and the number dead. On the third day after birth the litter was reduced to eight, two males and six females if the numbers permitted. If this was not possible due to insufficient females, more males were retained to make up a litter of eight. The largest and most

vigorous rats were selected. A record was made on each litter of the number, sex and color.

At 21 days of age each rat was weighed and ear marked with a litter number in the right ear and an individual number in the left ear. If the average weaning weight of the litter exceeded 40 grams the litter was weaned. If not, the litter was not weaned until they averaged 40 grams. At weaning, the rats were allotted at random, four to a pen, disregarding sex.

All rats in the base generation were full fed ad libitum during the 28-day test period. At 49 days of age each rat was weighed and separated according to sex.

First test generation

The first test generation was selected from the offspring of the base generation.

WW strain

The 7 heaviest weaning weight males and the 14 heaviest weaning weight females of the WW strain were selected to produce the first test generation. Seven of the females were allotted to the RG males to produce the strain crosses.

RG strain

Seven males and 14 females that made the greatest gain during the 28-day feeding period were selected to



produce the first test generation of the RG strain. Seven of the females were allotted to the WW males to produce the strain crosses.

Strain crosses

The females to be crossbred were selected by assigning the heaviest weaning weight females in the WW strain litter to the pure strain matings and the second heaviest to the cross strain matings. The procedure was alternated for the second litter. This procedure was followed until all were assigned.

The same procedure was used in the RG strains except the rate of gain was used as the criteria for assigning each female to the pure or cross strain groups.

Matings and offspring

The matings were made on January 5, 1962 when the rats averaged 65 days of age. The rats were managed the same as the base generation except that 6, 2 males and 4 females, were saved. The same data were collected. The pure strains and cross strains were kept separate due to a size difference.

GENETIC-ENVIRONMENTAL INTERACTION

The rats used in the genetic-environmental interaction feed trial were all females. Two females nearest the average weaning weight were selected from the first six litters in each strain to reach weaning age. The heavier of

the two selected in the first litter weaned was assigned to the full-fed group and the lighter to the limited-fed group. The procedure was alternated for each litter. Single pens were used and the rats were allotted at random to the pens.

The WW limited-fed group are referred to in this thesis as WW L, the WW full-fed group as WW F, the RG limited-fed group as RG L, and the RG full-fed group as RG F.

Feeding methods

The full-fed rats were fed ad libitum at 3 and 4 day intervals (twice a week). At the end of each 3 or 4 day period the rats and the feed were weighed and the amount of feed eaten was determined.

The first three days the limited-fed group was fed a ration amounting to 8 percent of the rats body weight. After this period each rat was fed 80 percent of the amount that the rats on full feed ate, based on a comparable body weight. To determine the amount to be fed the limited group, the full-fed rat weights were grouped into 10 gram lots starting at 40 grams. The feed consumption was averaged for all the rats in each 10 gram weight group and the average used to determine the amount to be fed the limited-fed group. Each rat was fed twice daily.

At the end of the 28-day feeding period for the full-fed rats, a final body weight and the total amount of feed eaten was recorded. Each full-fed rat's limited fed litter



mate remained on the limited feeding trial procedure until it reached a similar body weight. A record was made of the days and the total amount of feed required. All the rats were placed on full feed as each finished the feed trial.

Second group, first generation

A second mating was made on March 5, 1961. The same males and females were mated together that produced the first group. The management procedures were the same.

There were only 4 full litters of 6 in the RG strain that could be used in the feed trial. The four females in 4 litters from each strain were allotted to the trials. The weaning weights were used to determine which rats in the litter were full or limited-fed. The rats were allotted so the combined weights of the two female pairs were approximately equal. When the average weight of the 2 limited-fed rats reached the average weight of the two 28-day full-fed litter mates, the feed trial was terminated.

The main purpose of the second litter in the first generation was to collect more data.

Second generation

The fastest gaining rats in the RG group and the heaviest weaning weight rats in the WW group were selected to produce the second generation. As much as possible the males were selected from different litters. Nine males and 20 females were used in each strain to produce the second

generation. The mating allotment method was the same as for the first generation. This procedure allotted two limited-fed females to each of the four breeding groups.

The matings were made April 28, 1961. The rats averaged 90 days of age. Due to the time required by the feeding trial, there was an average increase in age of 25 days over the rats in the first mating of the first generation.

The feed trial was conducted the same as the previous two, using 24 female rats. Two from each of 12 litters, six from each strain.

Second group, second generation

The second group of the first generation were mated to produce the second group of the second generation. There were 8 males and 16 females mated in each strain to produce this test group. The same procedures were used in this group as in the previous groups in selection for mating, culling, feeding and care. The feed trial group contained 24 rats. Four females from three litters from each of the two strains were allotted at random to the feeding trial.

MATURE WEIGHTS

First generation

The male mature weights were determined by taking at random half of all the males in the first generation and growing them out to maturity. After they reached

approximately 130 days of age they were individually weighed and weighed again each week thereafter until a fairly constant weight was reached which occured at about 150 days.

All the females in the feed trial were used to collect the female mature weight data. The female mature weights were obtained by weighing the females at the time their litter was weaned. The females were approximately 130 days of age. From this time on each rat was weighed once weekly until a fairly constant weight was reached, at about 150 days. The same procedure was used for both groups of the first generation.

Second generation

Originally it was decided the data collected on the first generation would be sufficient to establish mature weights. Later the decision was made to increase the numbers in the mature weight data. At the time the decision was made the rats in the first group of the second generation of the WW strain had been disposed of and mature weights could not be determined for this group.

The mature weight data from the second group in the second generation were included in the mature weight analysis. The male data were collected from the eight most rapid growing males in the RG strain and the 8 males with the heaviest weaning weights in the WW strain. The female data were from the 24 females included in the feed trial. The mature weights

used were the average of two weights taken at an average age of 147 to 153 days. The average age for mature weights was 150 days.

V. RESULTS AND DISCUSSION

GENERAL

The data collected from two generations of pure strain and cross strain rats were accumulated and analyzed. The number of rats, sex, average 21-day weights, average gain 21 to 49 days, average daily gain and the average 49-day weights are shown in Table 1. The data included the offspring from all four matings. The data collected from the 52 limited fed rats were not included in the average gain 21 to 49 days, average daily gain and the average 49-day weight. The sire is listed first in all the references to matings.

METHOD OF ANALYSIS

The method recommended by Harvey (1960) for the least squares analysis of data with unequal subclass numbers was used to analyze the data. The data were analyzed for significant differences in the 21-day weaning weight, the rate of gain from 21 to 49 days of age and final 49-day weight. Following is a linear mathematical model for the two way classification with interaction:

$$Y_{ijkl} = \mu + s_i + d_j + sd_{ij} + r_k + e_{ijkl}$$

$i = 1,2$
$j = 1,2$

TABLE 1. Comparison of pure strains and strain crosses showing number, sex, average weaning weight, average gain 21 to 49 days, average daily gain and average 49-day weight.

Mating	No.	Ave. 21 day wt. (gms.)[a]	Ave. gain 21-49 days (gms.)[a]	Ave. wt. 49 day (gms.)[a]	Ave. daily gain 21-49 days (gms.)
Males					
WW[b] X WW	60	37.5	142	179	5.05
RG X RG	40	51.4	201	252	7.17
RG X WW	40	39.0	167	206	5.96
WW X RG	49	51.3	186	237	6.64
	189				
Females					
WW X WW	73	35.4	103	138	3.66
RG X RG	50	49.5	155	204	5.49
RG X WW	75	37.3	124	161	4.42
WW X RG	82	48.4	131	179	4.64
	280				

a = Least squares means
b = The first two letters indicate the strain of the sire

TABLE 2. Comparison of difference in weaning weight of males and females of pure strain and cross strain rats showing weight differences and t test results.

Strain and cross comparison	Males		Females	
	Grams wt. difference	t.	Grams wt. difference	t.
RG - WW	13.9	10.69**	14.1	11.37**
WW X RG - RG X WW	12.3	8.98**	11.1	6.65**
WW X RG - WW	13.8	11.31**	13.0	11.71**
RG - RG X WW	12.4	8.55**	12.2	9.68**
RG X WW - WW	1.5	1.14	1.9	1.71*
RG - WW X RG	0.1	.07	1.1	.96

* Significant $P < 0.05$
** Highly significant $P < 0.01$

$k = 1,2,3,4$

Y_{ijkl} = the lth observation in the ith s class, the jth d class and the kth replicate

μ = the overall mean with equal subclass numbers

s_i = effect of the ith male parent strain

d_j = effect of the jth female parent strain

r_k = effect of the k replication

sd_{ij} = interaction effects

e_{ijkl} = random errors

The least squares procedure (Harvey, 1960) was used to make the analysis in Tables 3, 4, 6, 7, 9 and 10. Regular analysis of variance procedures (Dixon and Massey, 1957) were used to make all others.

WEANING WEIGHT

Strain Comparison

The WW strain had been selected for weaning weights of 60 grams or over in an air-conditioned laboratory. The RG strain had been selected for fast rate of gain from 21 to 50 days of age without considering weaning weights. This strain had been developed in an non air-conditioned laboratory. Under the non air-conditioned environment in which the experiment was conducted, the WW strain did not reach as heavy weaning weights as expected.

In Male Offspring

The offspring by the WW strain males (Table 1) had an average weaning weight of 37.5 grams compared to 51.4

grams for the offspring by RG strain males, a highly significant difference of 13.9 grams. Table 3 shows the analysis of variance of weaning weights. The difference between the male parent strains was not significant. There was no apparent paternal strain influence on weaning weight. There was a strong maternal strain influence on weaning weight as shown by the highly significant difference between the female parent strains.

Table 2 shows several comparisons between the means of the different groups. In cases where the comparisons are between groups having different female parent strains the difference between the groups is highly significant. In cases where the two groups are out of the same dam strain there was no significance between the groups. Thus the major strain effect on the weaning weight was the effect of mothering ability.

The reciprocal cross strains had highly significant different weaning weights. The WW X RG crosses were 12.4 grams heavier than the RG X WW crosses. The difference was almost equal to the difference between the pure lines (13.9 grams).

In Female Offspring

The estimates of difference between groups in weaning weights for the female offspring are shown in Table 1. The results were the same for the males. There was no significant

difference between the male parent strains. The maternal influence or the female parent strain effect on the female offspring was highly significant (Table 4).

Comparisons among different offspring groups are shown in Table 2. There was 14.1 gram difference between the WW strain and the heavier RG strain offspring. An 11.1 gram difference existed between the reciprocal crosses. When comparing RG maternal influence with the WW maternal influence the data also showed a highly significant difference, regardless of which males they were mated to.

Thus weaning weight of the offspring from the RG dams was always heavier than the offspring from the WW dams regardless of the breeding of the sire and of the sex of the offspring.

Interaction

The estimate of interaction between male and female parent strains was not significant for weaning weight. Table 3 shows the test results for males and Table 4 for females. Thus, there was no evidence of hybrid vigor for weaning weight.

Replications

The analysis of variance, Tables 3 and 4, shows that the differences among the replications for both males and females were highly significant.

The least squares estimates of the replicate effects, expressed as deviations from μ, for weaning weight of the males were:

1 = -3.3, 2 = 3.5, 3 = 1.1, 4 = 1.3; for the females 1 = -3.1, 2 = 2.1, 3 = 1.5, 4 = 0.5. The greatest difference existed by comparison of the second replication with any of the other replications.

The rats in the second replication were the second litter of the parents of the first replication. The female parent was more mature which most likely provided a superior maternal environment. Also they were produced during the spring months, March to May, which may have provided a more desirable climatic environment. These two facts are the most probable reasons for the highly significant variations in replications.

The first replication started January 5, 1962; the second, March 5, 1962; the third, April 28, 1962 and the fourth, June 23, 1962. The laboratory was subject to climatic changes throughout the period from January 5 to August 12 when the final weaning weights were taken.

The third and fourth replications were the first litter offspring of animals raised in replication 1 and 2 respectively. Replication 2 was the only second litter offspring in the experiment.

TABLE 3. Analysis of variance of weaning weight of males.

Source of variation	d.f.	Mean square	F
Between male parent strains	1	25.99	.64
Between female parent strains	1	7731.61	191.05**
Between replications	3	347.00	8.56**
Interaction between male and female parent strains	1	20.32	.50
Error	182	40.47	

**Highly significant P< 0.01

TABLE 4. Analysis of variance of weaning weight of females.

Source of variation	d.f.	Mean square	F
Between male parent strains	1	149.76	3.33
Between female parent strains	1	10128.43	225.03**
Between replications	3	357.52	7.94**
Interaction between male and female parent strains	1	13.20	.29
Error	273	45.01	

**Highly significant P < 0.01

GAIN

Strain Comparisons

The rate of gain was measured for a 28-day period, from 21 to 49 days of age. The data from the four replications were combined for the analysis of variance and the results are shown in Tables 6 and 7. Table 5 shows the results for comparing differences between gain between the strains and strain crosses and the difference in weight. The average grams gained for each mating group are shown in Table 1.

The estimates of difference between male parent strains and female parent strains were highly significant. The lack of parental influence which existed for weaning weight disappeared when the rate of gain was compared. The superior genes for growth in the RG strain increased the gain in both male and female offspring in all comparisons of the pure strains and cross strains. As shown in Table 5 all the comparisons were highly significant.

A comparison of the two pure strains show that the gain of the RG strain males was 59 grams and females 52 grams heavier. The difference is highly significant and also the largest numerical difference in the gain comparisons. The reciprocal cross comparison showed the WW X RG cross was highly significantly heavier than the RG X WW cross. (19 grams for males and 7 grams for females, Table 5). The RG

strain maternal influence shown in weaning weight is less apparent in this comparison but still must be responsible for the difference because on the average the genetic material would be the same in both cross strain groups.

The maternal influence is also shown by comparing WW pure strains to the WW X RG cross strain offspring. The WW X RG group males were 44 grams heavier and the females 28 grams heavier than the WW strain group. Part of the highly significant difference may be due to the superior genetic material for growth in the RG strain. A comparison of the RG pure strain with the RG X WW cross strain shows the RG strain is heavier, a highly significant difference of 34 grams for males and 31 grams for females. The difference indicates both genetic and maternal influence. The differences between the WW X RG - WW, 44 grams for males and 28 grams for females and RG X WW-WW, 25 grams for males and 21 grams for females, may be attributed to RG strain maternal influences on rate of gain.

The paternal influence on rate of gain was shown in the least squares estimate of the highly significant differences in the comparison of the male parent strains in Tables 6 and 7.

Interaction

The estimate of differences due to interaction between sires and dams was not significant. (Tables 6 and 7). Thus

TABLE 5. Comparison of difference in gain of males and females of pure strain and cross strain rats showing weight differences and t test results.

Strain and cross comparison	Males		Females	
	Grams wt. difference	t.	Grams wt. difference	t.
RG - WW	59	18.53**	52	20.63**
WW X RG - RG X WW	19	7.45**	7	3.12**
WW X RG - WW	44	15.63**	28	12.44**
RG - RG X WW	34	10.52**	31	12.16**
RG X WW - WW	25	4.52**	21	8.24**
RG - WW X RG	15	3.65**	24	9.52**

** Highly significant $P < 0.01$

TABLE 6. Analysis of variance of gain of males.

Source of variation	d.f.	Mean square	F
Between male parent strains	1	18550.58	50.11**
Between female parent strains	1	68105.81	183.97**
Between replications	3	1287.66	8.48**
Interaction between male and female parent strains	1	1163.18	3.14
Error	182	370.19	

** Highly significant $P < 0.01$

hybrid vigor was not expressed in gain from 21 to 49 days of age.

Replications

There was a highly significant difference due to replication in both males and females as shown in Tables 6 and 7. Comparing the 21 to 49-day gain, the least squares estimates of the replicate effects expressed as deviations from μ were: 1 = -3.3, 2 = 8.0, 3 = -4.6, 4 = -.1 for the males and 1 = -1.9, 2 = 4.5, 3 = -2.9, 4 = 0.3 for the females. The greatest difference was shown by comparing the second replication to the other replications. This replication was the second litter of the parents of the first replication, replications 3 and 4 were the first litter of animals in replications 1 and 2 respectively. The female parents were more mature and most likely provided a better maternal environment that influenced their gain from 21 to 49 days. The climatic environment may also have influenced the gain because the 28-day growth period for the second replication was during the spring months of April and May. The climate could have been more favorable to growth during this time. The rate of gain data for the four replications were collected from February 15 to September 15, 1962.

TABLE 7. Analysis of variance of gain of females.

Source of variation	d.f.	Mean square	F
Between male parent strains	1	33742.52	182.93**
Between female parent strains	1	54432.54	294.77**
Between replications	3	698.40	3.78**
Interaction between male and female parent strains	1	275.81	1.49
Error	273	184.66	

** Highly significant P< 0.01

TABLE 8. Comparison of difference in 49-day weight of males and females of pure strain and cross strain rats showing weight difference and t test results.

Strain and cross comparison	Males		Females	
	Grams wt. difference	t.	Grams wt. difference	t.
RG - WW	73	12.27**	66	19.88**
WW X RG - RG X WW	31	3.79**	18	6.08**
WW X RG - WW	58	9.69**	41	13.80**
RG - RG X WW	46	6.34**	43	12.80**
RG X WW - WW	27	5.14**	23	7.74**
RG - WW X RG	15	2.98**	25	7.53**

** Highly significant P< 0.01

FORTY-NINE DAY WEIGHT

Strain Comparisons

Table 1 contains the average 49-day weights for each group. Tables 9 and 10 show the results of analysis of variance for differences in 49-day weight between strains and strain crosses. Table 8 shows the results for comparing the difference between 49-day weight among different strain and strain crosses.

The differences due to male and due to female parent strains were highly significant as were all the comparisons between the pure strain and cross strain offspring. The analysis showed the RC strain had a higher frequency of genes for rapid growth and favorable mothering ability.

A study of the data on 49-day weight show similar results to those obtained for weaning weight and gain. The average 49-day weight of the males and females are shown in Table 1. The largest differences were between the two pure strains, 73 grams for the males and 66 grams for the females.

The reciprocal crosses had a weight difference of 31 grams (males) and 18 grams (females). The pre-weaning maternal influence still existed. The amount of genetic influence is shown by the WW X RG - WW (males, 58 grams and females, 41 grams) and the RG - RG X WW comparison (males, 46 grams and females, 43 grams). In all cases the offspring were heavier when the RG strain was the maternal parent.

The extent of RG strain genetic influence on 49-day weight rate was shown by the paternal influence. A comparison of the RG X WW - WW groups show that the RG strain sired (cross strain) males were 27 grams heavier than the pure WW males. The female difference was 23 grams heavier.

Interaction

There was no significant interaction in final weight for either males or females, according to the analysis of variance shown in Tables 9 and 10. Thus there was no evidence of hybrid vigor.

Replications

Differences among the four replications were statistically ($P < 0.01$) significant (Tables 9 and 10). The least squares estimates of the replicate effects expressed as deviations from μ were as follows for the males: 1 = -6.7, 2 = 11.5, 3 = -3.6, 4 = -1.2; for the females 1 = -5.0, 2 = 6.7, 3 = 1.4, 4 = 0.3. The second replication shows widest variation. The reasons for the differences would be the same that cause the difference in weaning weight and gain from 21 to 49 days. The second replications may have had a more favorable maternal and climatic environment than the other three replications.

TABLE 9. Analysis of variance of 49-day weight of males.

Source of variation	d.f.	Mean square	F
Between male parent strains	1	19965.35	36.02**
Between female parent strains	1	217306.89	392.10**
Between replications	3	2393.81	4.32**
Interaction between male and female parent strains	1	1490.96	2.69
Error	182	544.21	

** Highly significant $P < 0.01$

TABLE 10. Analysis of variance of 49-day weight of females.

Source of variation	d.f.	Mean square	F
Between male parent strains	1	38388.88	119.59**
Between female parent strains	1	111522.29	347.42**
Between replications	3	1377.73	4.29**
Interaction between male and female parent strains	1	183.17	.57
Error	273	321.00	

** Highly significant $P < 0.01$

GENETIC-ENVIRONMENTAL INTERACTION

General

Four groups of rats were tested under two environments, full or limited fed. The first, third and fourth groups contained 24 rats, 12 RG strain and 12 WW strain females. Six from each strain were full fed and 6 (80 percent of full) were limited fed. The second group contained 32 rats, 16 from each strain with 8 in each feed trial group. Table 11 shows the average of the four trials for weaning weight, 49-day weight, number of days on feed, daily gain, feed efficiency (grams of feed per gram gained) and daily feed consumption.

Daily gain

There was considerable difference in the average daily gain of the full-fed and limited-fed rats, both between strains and between treatments as shown in Table 11. The results of an analysis of variance calculated by a routine procedure, (Table 12) shows that these differences were highly significant. The RG strain exceeded the WW strain in all comparisons of daily gain. There was an average daily gain difference of 1.48 grams between RG F and RG L and 0.92 grams between WW F and WW L. The average daily gain difference between RG F and WW F was 1.77 grams feed and 1.21 grams for the RG L and WW L. There was a difference of 0.29 grams between RG L and WW F. Thus the RG strain grew more

rapid under limited feeding than did the WW strain with full feeding.

There was a significant difference in daily gain among replications as shown in Table 12. The cause most likely was due to environmental conditions, occuring in the second replication as described in the pure and cross strain comparisons.

The interaction between strains and treatment was highly significant (Table 12). A significant interaction exists because there was a different reaction to the levels of nutrition for the RG strain than for the WW strain.

Within group correlations between daily gain and feed efficiency were tested. The only significant difference was between the WW F group and the WW L group. The figures indicate there was a high correlation between feed efficiency and rate of gain in the RG L, WW F and WW L groups but a low correlation in the RG F group.

The limited feeding appeared to have a greater effect on the RG rats. The comparison of the RG full-fed rats with the limited-fed there was a decrease of 1.48 grams in daily gain. The WW F - WW L comparison showed a decrease of only .92 grams daily gain. The effect of changing from limited to full feeding was 60 percent greater in the RG group than in the WW group.



TABLE 11. Average comparison of 104 pure strain female rats in a genetic-environmental interaction feeding trial.

Strain and treatment	Ave. wean. wt. (gm.)	Ave. final wt. (gm.)	No. days on feed	Ave. daily gain (gm.)	Ave. feed efficiency[a]	Ave. daily feed (gm.)	Percent of full fed
RG F	51	210	28	5.67	2.88	16.33	
RG L	51	210	38	4.19	3.13	13.11	80
WW F	43	152	28	3.90	3.60	14.04	
WW L	43	151	37	2.98	3.70	11.04	79

a feed / gain

TABLE 12. Analysis of variance of daily gain for feeding trial experiments.

Source	d.f.	Mean Square	F
Between strains	1	55.68	359.25**
Between treatments	1	34.36	221.69**
Between replications	3	0.51	3.28*
Interaction between strains and treatments	1	2.18	14.10**
Error	97	0.15	

** Highly significant $P < 0.01$

* Significant $P < 0.05$

EFFICIENCY OF GAIN

Table 11 shows average efficiency of gain (grams of feed required per gram of gain). The difference in efficiency of gain between strains and between treatments was highly significant (Table 13). When comparing the RG F and WW F, there was a difference of 0.72 grams more of feed required by the WW strain rats to gain a gram of body weight. The same comparison of the limited-fed rats show a difference of 0.57 grams more feed required. The RG F and RG L rats showed a difference of efficiency of 0.25 grams more feed required by the limited-fed rats to put on one gram of gain. The difference between the WW F and WW L was only 0.10 grams more feed required. The WW F required 0.47 grams more feed per gram gained than the RG L. The RG strain was more efficient in gain in all comparisons than was the WW strain.

The differences among replications considering efficiency of gain were highly significant (Table 13). The cause very likely was due to the environmental conditions, that occurred in the second replications as described in the pure and cross strain comparisons.

CORRELATIONS BETWEEN DAILY GAIN AND FEED EFFICIENCY

The correlations within groups between daily gain and feed efficiency were: RG F, -.12; RG L, -.60; WW F, -.41; WW L, -.78. A comparison of the significant difference of

TABLE 13. Analysis of variance of efficiency of gain for feeding trial experiments.

Source	d.f.	Mean square	F
Between strains	1	10.64	115.16**
Between treatments	1	0.85	9.16**
Between replications	3	0.40	4.26**
Interaction between strains and treatments	1	0.04	.45
Error	97	0.09	

** Highly significant P < 0.01

TABLE 14. Comparison of differences between groups for the within group correlations of daily gain with feed efficiency.

Strain and treatment	Correlation		t.
RG F - WW F	-.12,	-.41	1.07
RG F - RG L	-.12,	-.60	1.94
WW F - RG L	-.41,	-.60	0.97
WW F - WW L	-.41,	-.78	2.08*
RG L - WW L	-.60,	-.78	1.21

* Significant P < 0.05

within group correlation between daily gain and feed efficiency is shown in Table 14. The only case where the correlations were significantly different between groups was the WW F - WW L comparison.

The wide differences in the correlation could be due to sampling variations. The difference could also be due to a difference in the relationship of fat to protein in rats under different treatments. If the full-fed rats were fatter than the limited-fed rats at similar weights, the correlation between daily gain and feed efficiency would be lower. Very likely the full-fed rats were fatter than the limited-fed rats at the end of the feed trial. No tests were made to determine the difference in body fat content. The difference in fat conditions was not readily visible but the size difference between the two strains was very noticeable.

RATE OF GROWTH CHARTS

Figures 1, 3, 5, and 7 show the growth rates of the rats in trials 1, 2, 3 and 4 respectively. The charts graphically show the growth rates for both strains and both treatments from weaning to the termination of the feed trial for each of the four feeding trials. Figure 9 shows the combined average of the four trials. There were only minor differences among the growth patterns of the rats on all four trials. The RG strain rats, both full and limited fed grew

faster than the rats of the WW strain. Within each strain the full-fed rats outgrew the limited-fed rats. The charts show, that as the rats grew older, the difference in weight became greater. The greater growth rate of the full-fed rats agrees with results found in similar swine and mice experiments. (Winters et al., 1949; Crampton et al., 1954; Tribble et al., 1956; Merkel et al., 1958; Falconer, 1960; Thrasher et al., 1963.

EFFICIENCY OF GAIN CHARTS

Figures 2, 4, 6 and 8 graphically show the average grams of feed required per gram of growth from weaning to end of feed trials 1, 2, 3 and 4 respectively. The charts covered the feeding period from weaning to the termination of the trial. Table 11 shows the final results of average efficiency. On the average after the rats were started more grams of feed were required to gain a gram in weight as they increased in age and weight. The efficiency of gain was determined by using data collected twice a week, (every third and fourth day) weighing the rats and the feed eaten. The grams gained and the grams of feed eaten during each of these periods were averaged out to determine the growth and efficiency pattern of each group. The efficiency line was developed starting at 40 grams and adding the average gain for each 3 or 4 day weighing period to the end of the feed period. The same method was used to develop the feed

required per gram gained that corresponded to the increase in weight. The two corresponding figures were used to determine the point on the graph. The same method was used to determine other points to draw the line. For example, in Trial 1 the WW F group required 2.5 grams of feed per gram of gain as they increased from 68 to 88 grams in weight. At 117 to 126 grams of body weight it took 4.9 grams (the average of 4.7 to 5.2 grams) of feed to gain a gram of weight.

The charts show that feed efficiency varied considerably during the feed trials and within the groups between the trials. The variation was most likely due to change in environmental conditions other than the feeding schedule and minor variations in genetic material from trial to trial. The charts also show that efficiency of gain was more variable than daily gain under the condition of this experiment. Figure 10 shows the average feed requirements per gram gained for each group for the four trials. The average curves were not as irregular as the individual trial curves but smoothed out and showed a more regular pattern. Table 11 shows the RG F group were the most efficient followed by the RG L, WW F and WW L groups.

SWINE AND RAT FEEDING EFFICIENCY

Various experiments (Ellis and Zeller, 1932; Winters, 1949; Fowler and Ensminger, 1960; Tribble et al., 1956) found that limited-fed swine were significantly more efficient at

converting feed to pounds of weight than were full-fed swine. Other researchers (Crampton, 1956; Merkel, 1958; Thrasher, 1963) found that limited-fed swine were either less efficient feed converters or the efficiency was about equal.

Tribble et al., (1956) found there was a difference in the efficiency of gain of full and limited-fed pigs before they reached 100 pounds, favoring the full-fed pigs. Significantly less feed was required per 100 pounds gain by the limited-fed pigs compared to full-fed pigs from 100 to 200 pounds gained. The information presented in Figures 2, 4, 6, 8 and 10 indicated that efficiency of gain did not improve with the increase in weight.

Falconer, (1960) found efficiency of gain was lower in full-fed mice.

MATURE WEIGHTS

A comparison of the average mature weights of RG strain full-fed females (364 grams) and the limited fed females (344 grams) shows a difference of 20 grams (Table 15). This difference was not statistically significant (Table 16). The difference between replications was significant (Table 16).

Both the full-fed and limited-fed groups of WW strain females weighed 259 grams (Table 15).

The difference between the mature weights of the two strains was highly significant ($P < 0.01$) for females (Table 17).

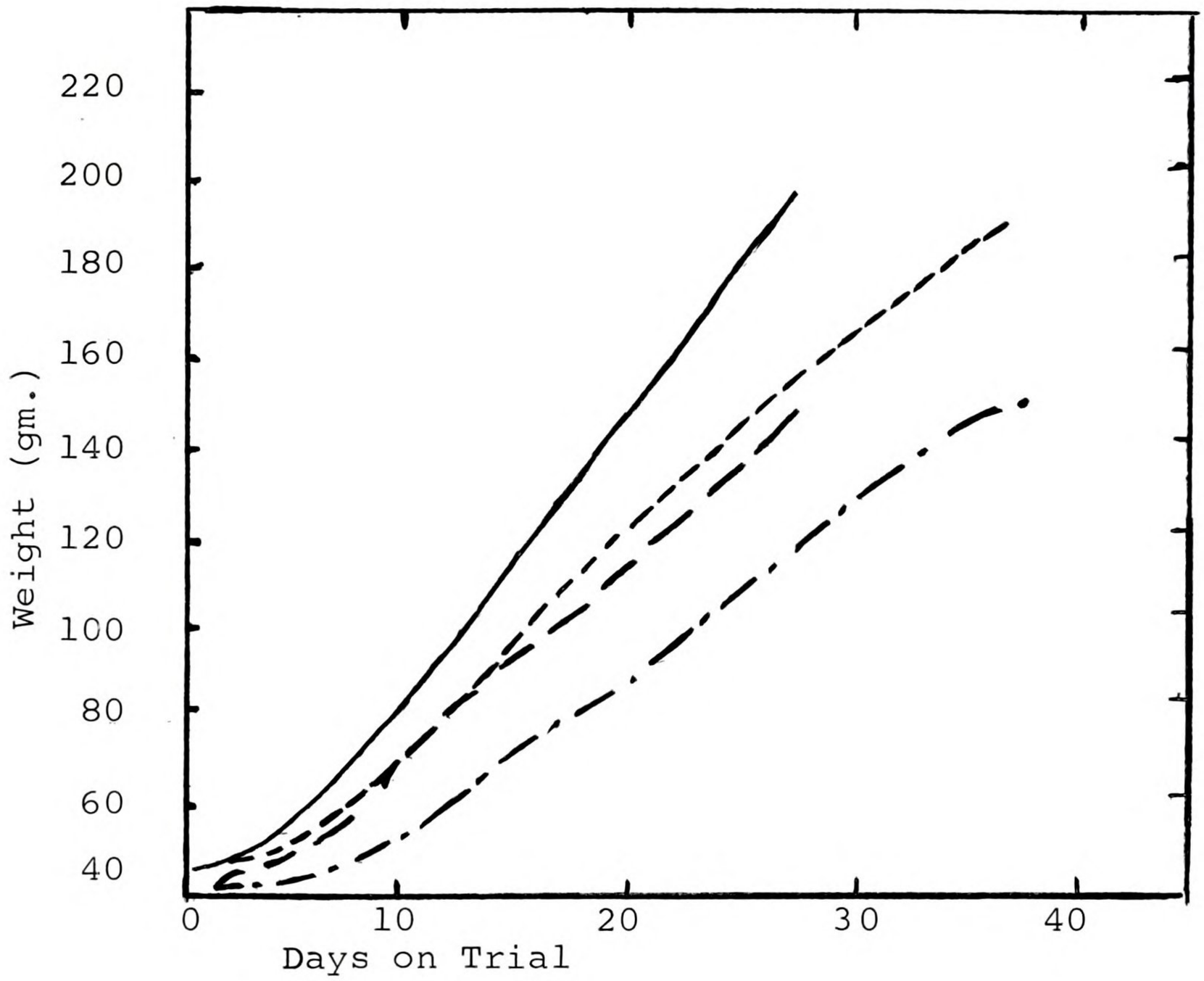


Fig. 1 - Trial 1 - Growth rate from weaning to end of feed trial.

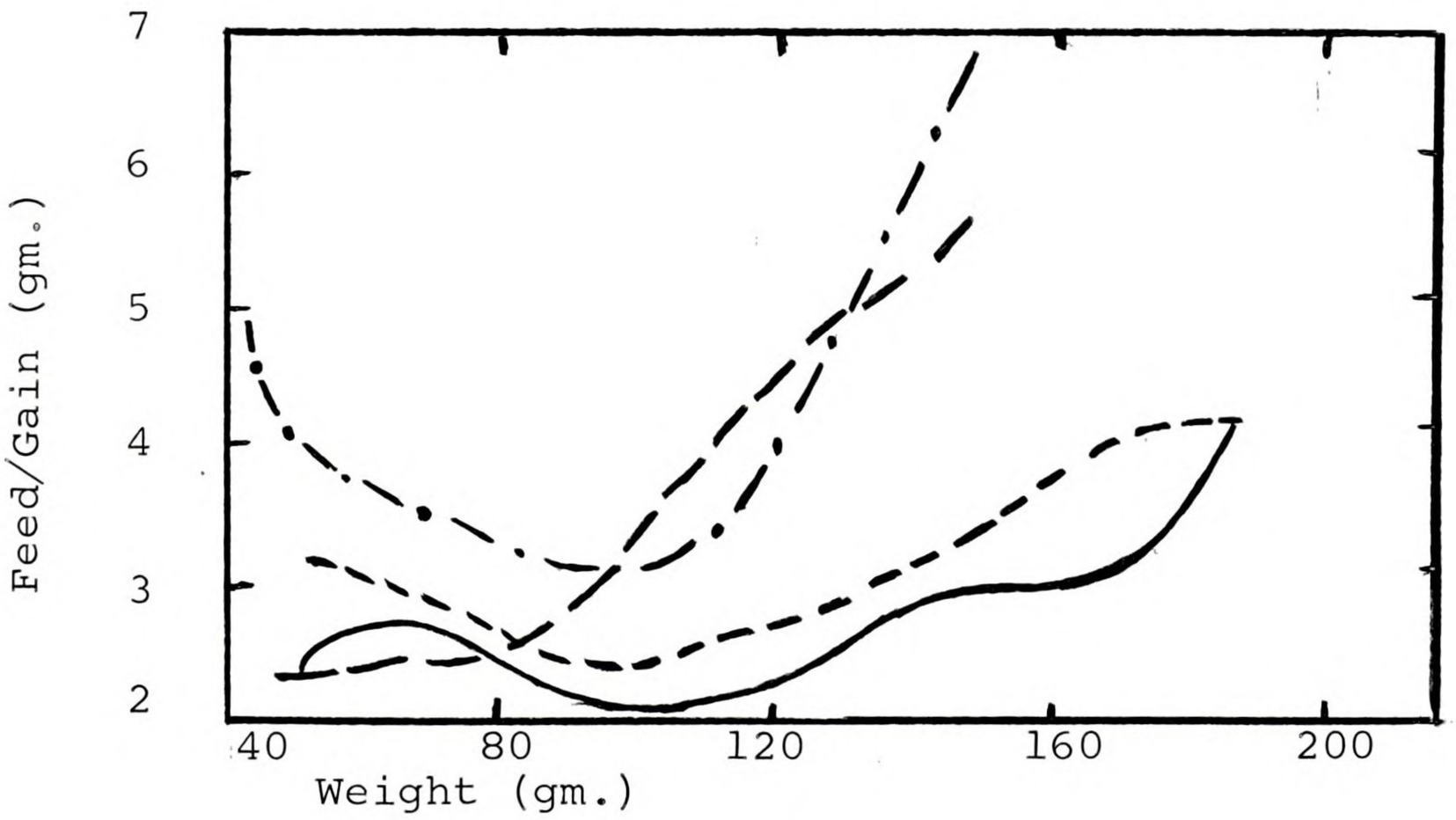


Fig. 2 - Trial 1 - Average grams of feed per day required per gram of growth from weaning to end of feed trial.

RG F RG L WW F WW L

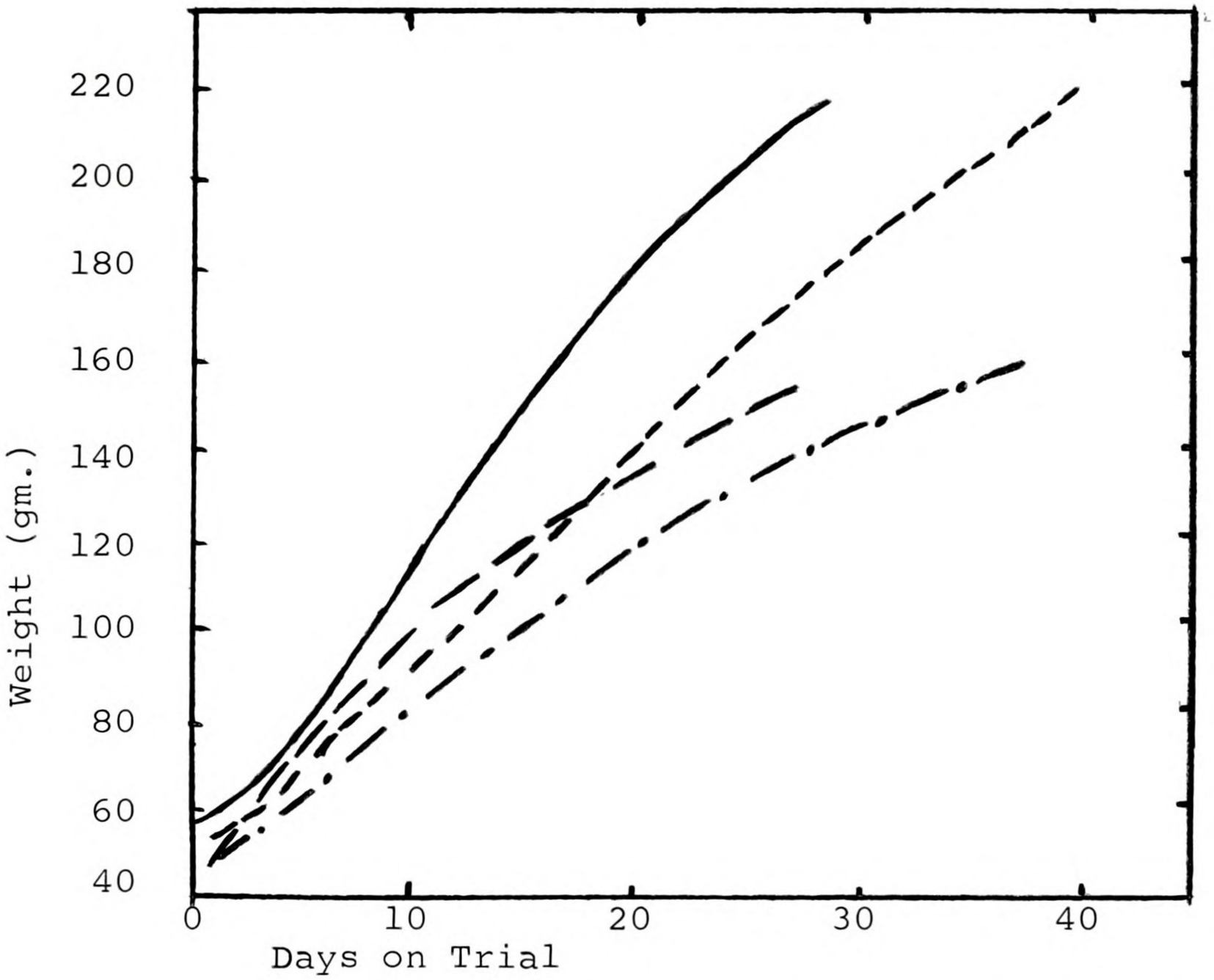


Fig. 3 - Trial 2 - Growth rate from weaning to end of feed trial.

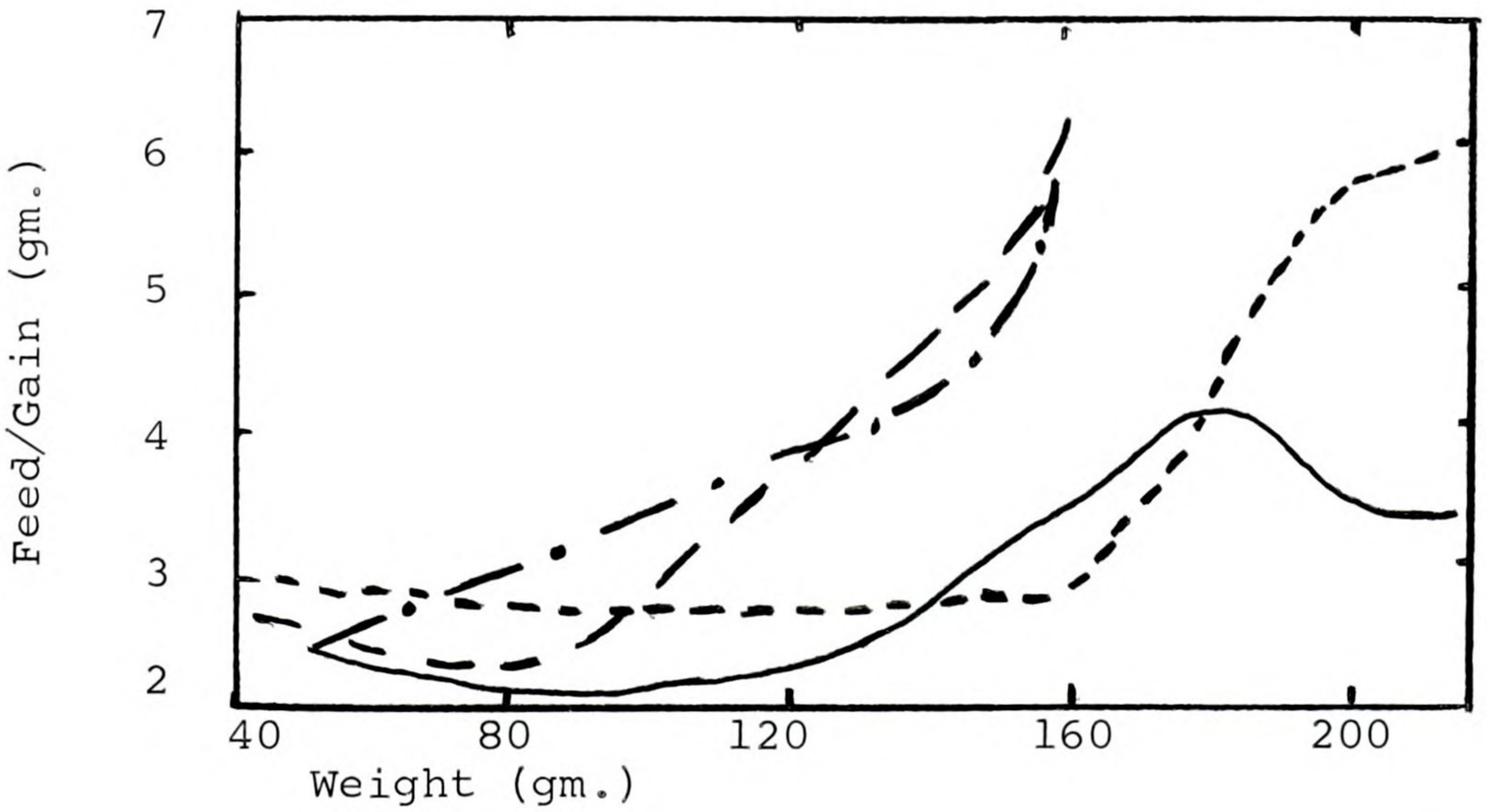


Fig. 4 - Trial 2 - Average grams of feed per day required per gram of growth from weaning to end of trial.

RG F RG L WW F WW L

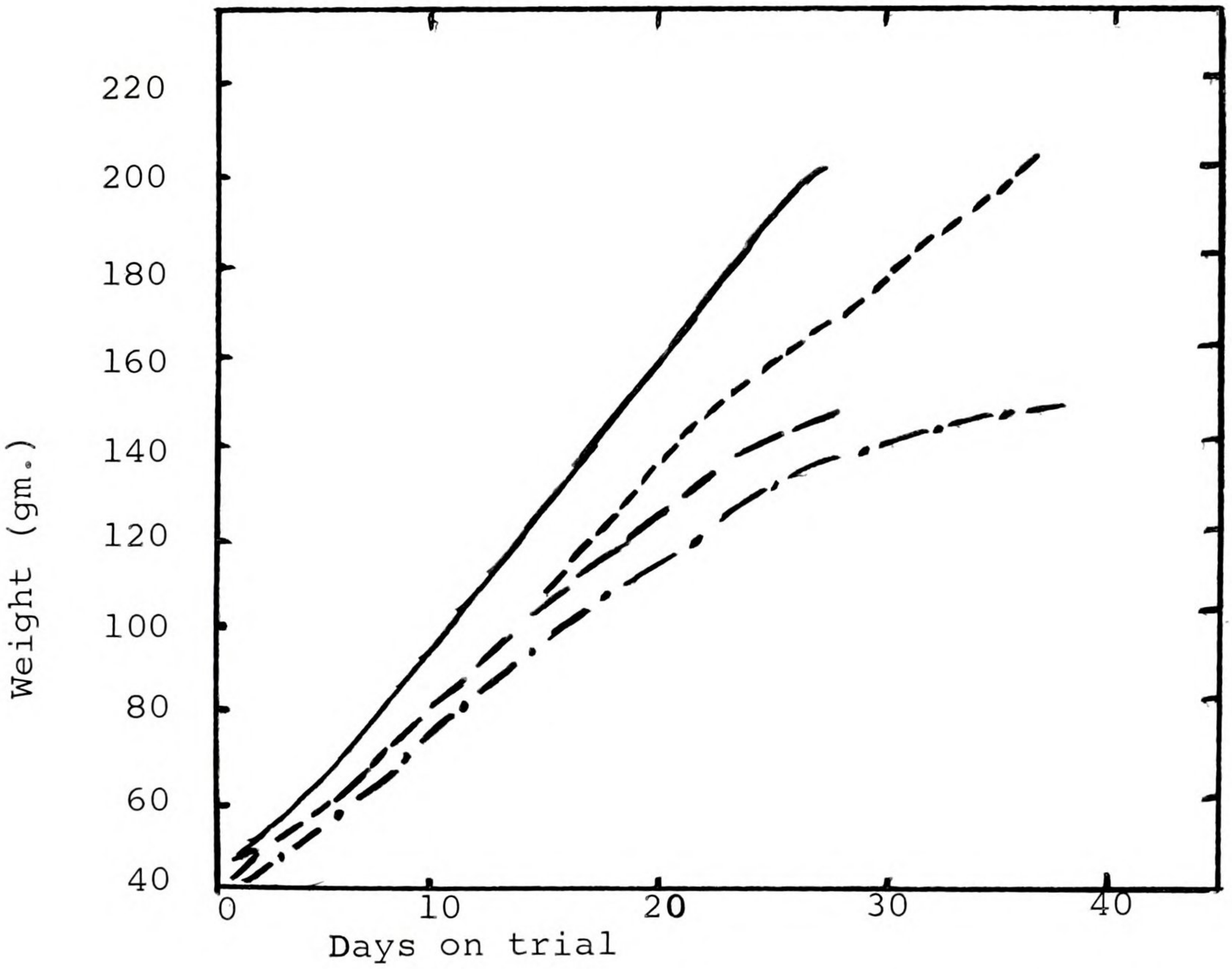


Fig. 5 - Trial 3 - Growth rate from weaning to end of feed trial.

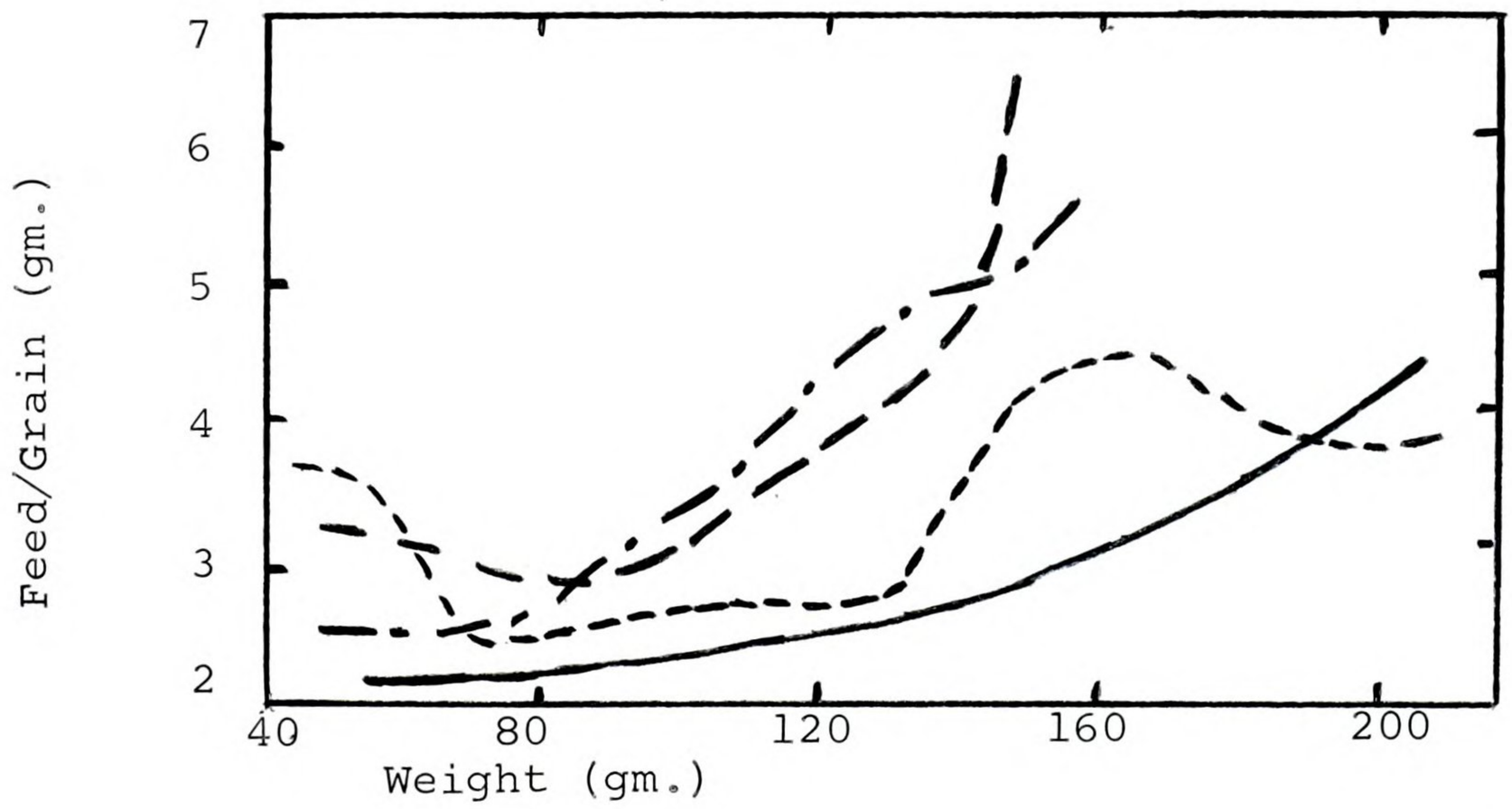


Fig. 6 - Trial 3 - Average grams of feed per day required per gram of growth from weaning to end of feed trial.

RG F RG L WW F WW L

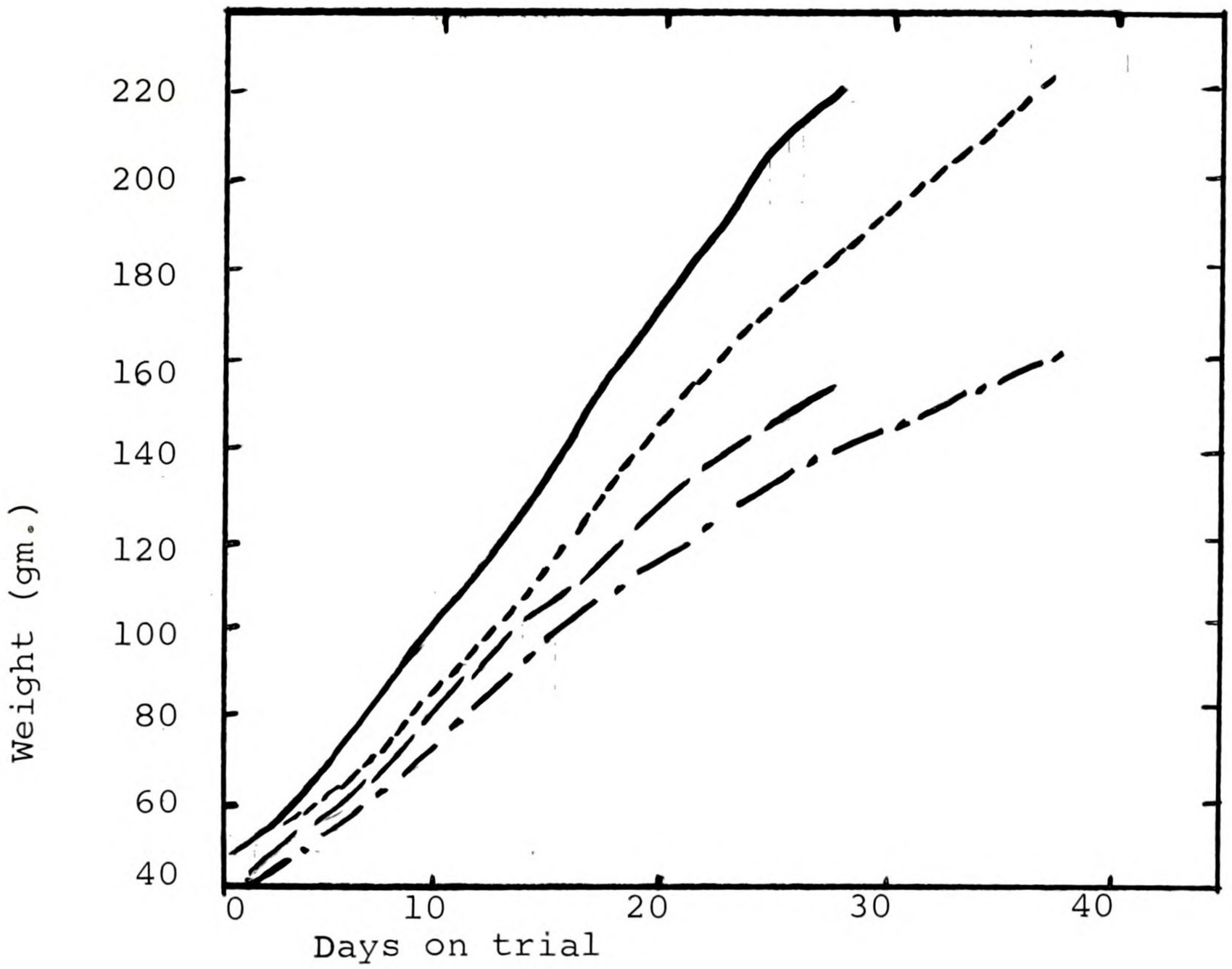


Fig. 7 - Trial 4 - Growth rate from weaning to end of feed trial.

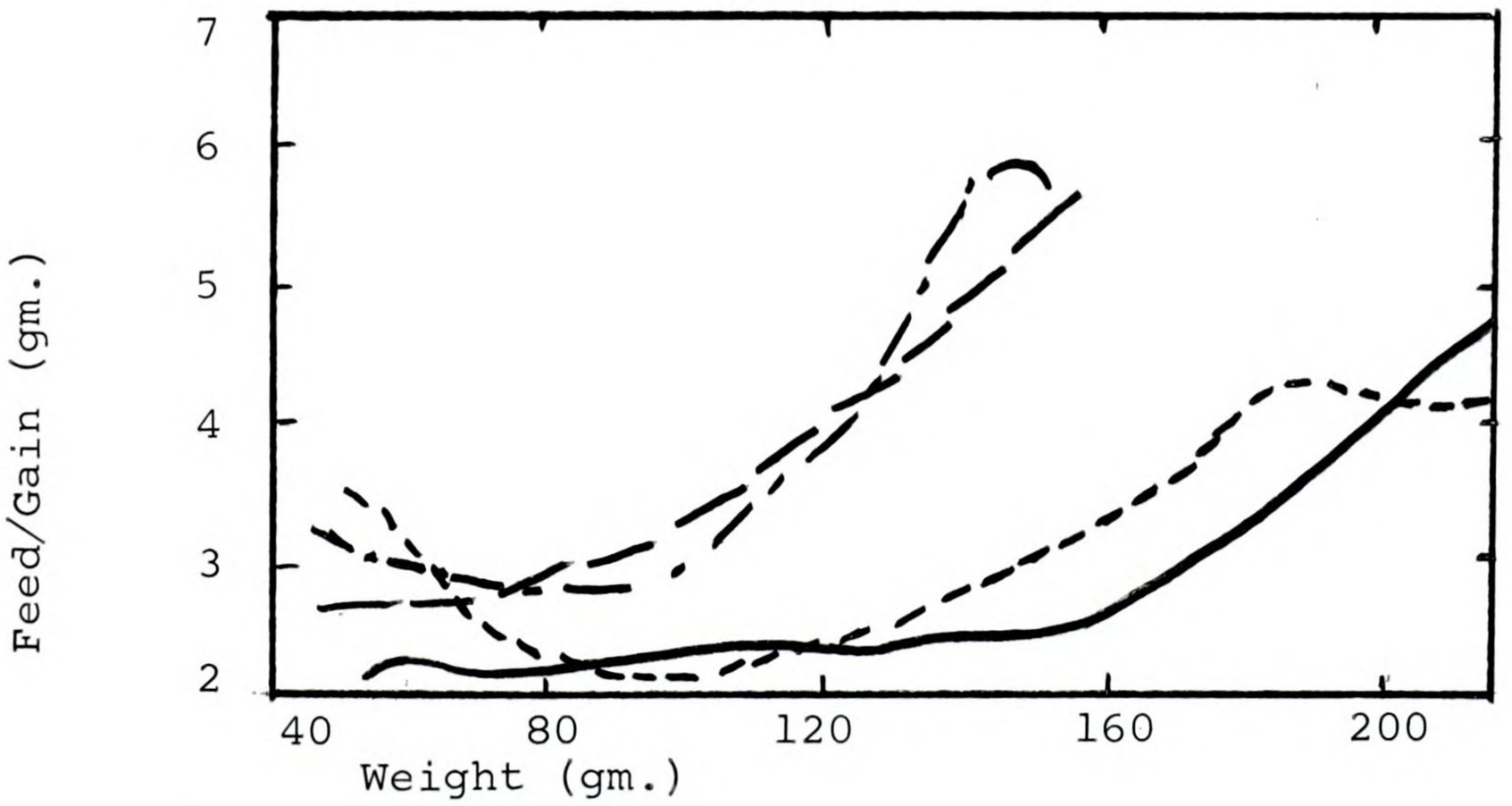


Fig. 8 - Trial 4 - Average grams of feed per day required per gram of growth from weaning to end of feed trial.

RG F RG L WW F WW L

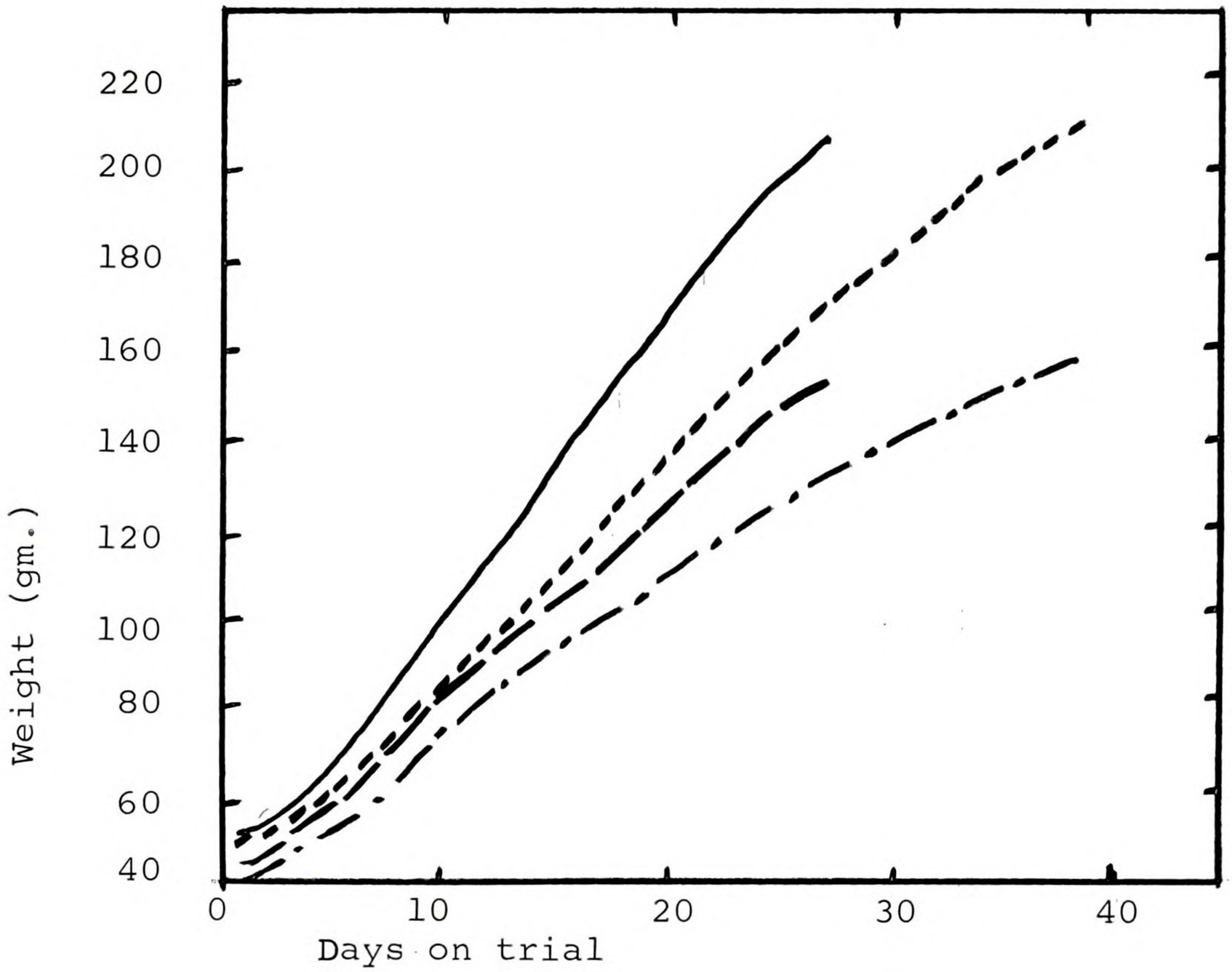


Fig. 9 - Average growth rate of 4 trials from weaning to end of feed trial.

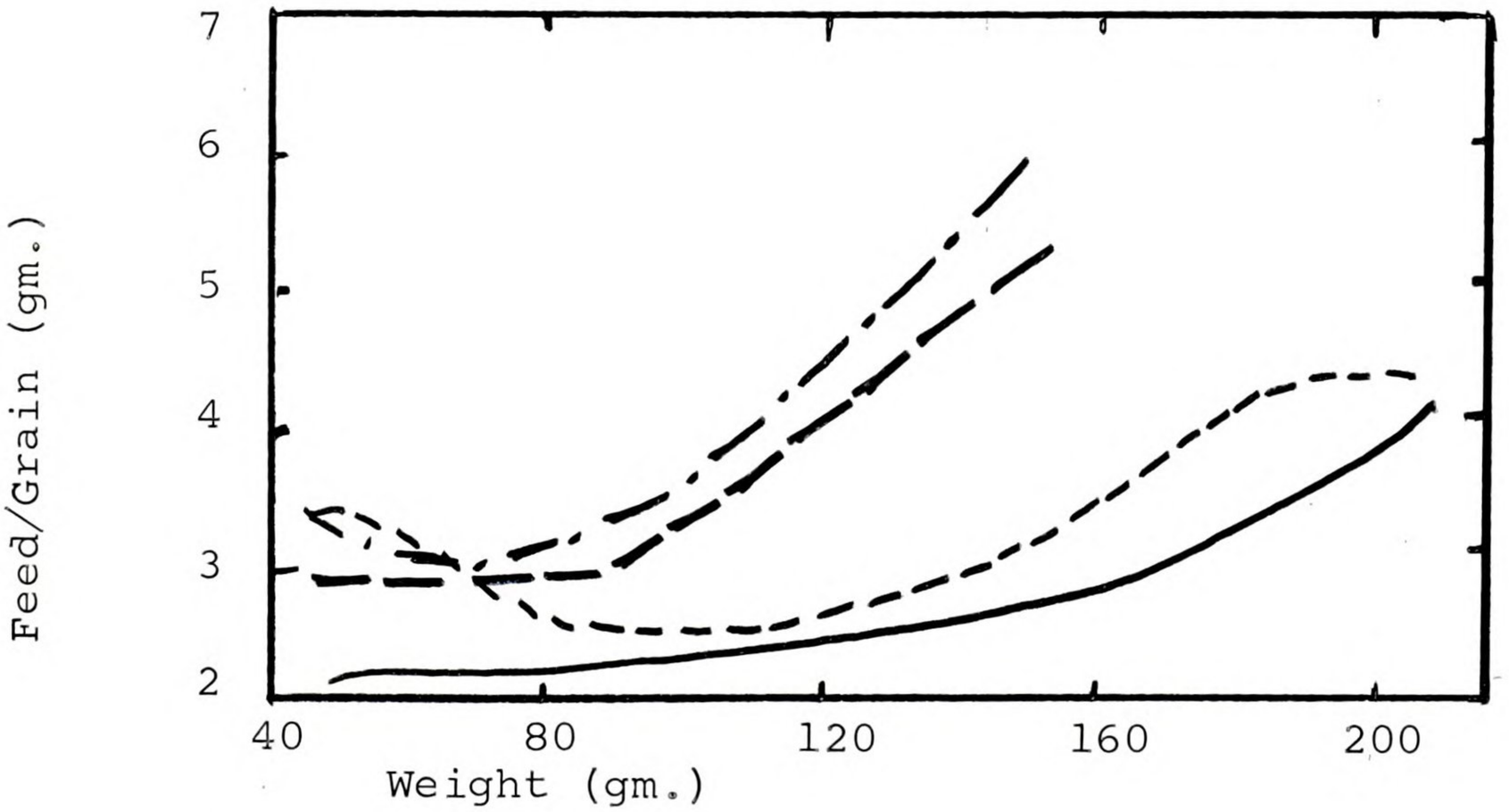


Fig. 10 - Average of 4 trials of average grams of feed per day required per gram of growth from weaning to end of feed trial.

RG F RG L WW F WW L

All 80 females were included for the analysis of variance of mature weights between the RG strain and WW strain because there was no significant difference between their mature weights due to treatment (Table 18). Table 18 shows there was a highly significant difference ($P < 0.01$) between the females of the two strains. Table 18 also shows that no significant difference existed between treatments and the interaction between strains and treatments was significant. The RG strain females averaged 354 grams; the WW strain females averaged 259 grams, a difference of 95 grams (Table 15). Differences between replications were also significant ($P < 0.01$). The females of group four were heavier because they had not littered during the time of data collection and were extra fat at the end of the five month period.

The most rapid growing strain (RG) in the experiment was consistantly the larger. These results agreed with Roberts (1961) findings when he selected for large strains and small strains of mice. He found the larger strains grew faster and matured larger.

Table 15 shows a comparison of mature weights of the full-fed males. Considerable differences existed between the mature weights of the two strains. The RG strain males averaged 646 grams and the WW strain males averaged 428 grams, a difference of 218 grams. This difference was highly significant (Table 17). The difference between replications was

also highly significant ($P < 0.01$), due mostly to environmental conditions. Considerable variation existed between the males of the fourth group when compared with group one and two. Group four were extra fat, probably because they were not used for breeding purposes before the close of the data collecting period.

TABLE 15. Comparison of mature weights of pure strain rats.

Strain	Number	Sex	Average weaning weight (gm.)	Average 49-day weight (gm.)	Average mature weight (gm.)
RG	18	M	53.0	262	646
WW	18	M	36.5	182	428
RG F	20	F	50.4	208	364
RG L	20	F	50.0	171	344
WW F	20	F	35.8	141	259
WW L	20	F	35.7	124	259

TABLE 16. Analysis of variance of mature weight differences between full and limited-fed RG strain females.

Source	d.f.	Mean square	F
Between treatments	1	4030	3.20
Between replications	2	5734	4.55*
Error	36	1259	

* Significant $P < 0.05$

TABLE 17. Analysis of variance of mature weight differences between RG strain and WW strain males.

Source	d.f.	Mean square	F
Between strains	1	427716	159.96**
Between replications	2	14506	5.42**
Error	33	2674	

** Highly significant $P < 0.01$

TABLE 18. Analysis of variance of mature weight differences between RG strain and WW strain females.

Source	d.f.	Mean square	F
Between strains	1	179836	206.94**
Between replications	2	6379	7.34**
Between treatments	1	1970	2.27
Interaction between strains and treatments	1	4030	4.64*
Error	74	869	

** Highly significant $P < 0.01$
* Significant $P < 0.05$

VI. SUMMARY AND CONCLUSIONS

MATERIAL

The pure-strain and cross-strain offspring from two strains of rats were tested. The strains had previously been selected for different characteristics, heavy weaning weight (WW) and rapid rate of growth from weaning to 49 days (RG). Differences between the strains with regard to genetic ability were evaluated on full feeding for weaning weight and growth after weaning. Hybrid vigor for the traits was also evaluated. Tests were also made of the effects of full and limited feeding the pure strains and interaction between level of feeding and strains with regard to rate of gain and feed efficiency. The relationship between growth rate and mature weights was also tested.

Two generations were used and two matings made in each generation. The data included 21-day weaning weights and 49-day weight. There were 189 male and 280 female rats used in the pure-strain and cross-strain comparisons.

PURE AND CROSS-STRAIN COMPARISONS

The RG strain averaged significantly heavier weaning weight than the WW strain (13.7 grams for males and 13.8

grams for females). The two reciprocal cross-strain groups showed a highly significant 12.7 grams difference for males and 10.7 gram difference for females in weaning weight favoring the WW X RG cross. The female parent strain was responsible for the difference. Thus it appears that all the differences in weaning weight were caused by differences in genetic composition of the two strains for maternal ability. There was no evidence of hybrid vigor. These experiments were conducted in a non air-conditioned laboratory while the WW strain was developed in an air-conditioned laboratory. This may account for the performance of the WW strain being lower in this experiment than it was in the air-conditioned laboratory.

The gain after weaning difference also was highly significant favoring the RG strain. The male offspring were 60 grams heavier and the female offspring were 52 grams heavier in the pure-strain comparisons. The differences between the strains used as male parents indicated there was a genetic superiority for growth present in the RG strain. The pre-weaning maternal influence effects were still present in the 21 to 49-day gain comparisons.

The results were basically the same for the 49-day weight. The interaction between the lines used as the female parent and used as the male parent were not significantly different between the strains and crosses in weaning

weight, rate of gain or 49-day weight. Thus there was no hybrid vigor for any of the trials.

Replication differences were highly significant for weaning weight, rate of gain and 49-day weight.

GENETIC-ENVIRONMENTAL INTERACTION

The two pure-strains were tested under two environments, full or limited-fed in four different replications. There were 104 female rats used. They were tested for growth rate and feed conversion. There was an average daily gain difference of 1.48 grams between the full and limited-fed group of the RG strain and 0.92 grams for the WW strain. The RG strain out-gained the WW strain 1.77 grams for the full-fed and 1.21 grams for the limited-fed. These differences between strains and between treatments were highly significant as was the interaction between strains and treatments.

The differences in efficiency of gain between strains and between treatment were highly significant. The feed efficiency difference between the RG F and RG L rats was 0.25 grams more feed required by the limited-fed group. The WW L group required 0.10 grams more feed to gain a gram of weight than the WW F group. The big difference was between strain comparisons. The RG F group required 0.72 grams less feed than the WW F group. A similar RG L to WW L comparisons gave a difference of 0.57 grams more feed required by the WW L group.

The interaction between strains and treatment was highly significant (Table 12). A significant interaction exists because there was a different reaction to the levels of nutrition for the RG strain than for the WW strain.

Within group correlations between daily gain and feed efficiency were tested. The only significant difference was between the WW F group and the WW L group. The figures indicate there was a high correlation between feed efficiency and rate of gain in the RG L, WW F and WW L groups but a low correlation in the RG F group.

RATE OF GROWTH

The growth rate charts show there are only minor differences among the growth rate pattern of the rats in all four replicates. The charts also show that as the rats grow older the difference in weight become greater.

The efficiency of gain charts show that efficiency varied considerably during the feed trial and also within the groups from one replication to another. In all cases the limited-fed rats were less efficient than the full-fed rats. As the size of the rats increased the feed efficiency decreased.

MATURE WEIGHTS

There was no significant difference in mature weights of the rats as a result of limited feeding during the 21 to 49-day period of their growth.

There was a significant difference in the average mature weight of the two strains. The WW strain females averaged 259 grams compared with 354 grams for the RG females. The RG and WW strain males averaged 646 grams and 428 grams, respectively.

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