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THE USE OF PREDICTION EQUATIONS IN THE ANALYSIS OF A PIG PRODUCTION EXPERIMENT

by

© BRYSON RAYMOND WILSON

A THESIS

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled, "The Use of Prediction Equations in the Analysis of a Pig Production Experiment" submitted by Bryson Raymond Wilson, M.Rur.Sc., in partial fulfilment of the requirements for the degree of Doctor of Philosophy.

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ABSTRACT

A pig production experiment was designed to investigate the effects on live performance and carcass composition of feeding three levels of a low energy, low protein diet to two breed groups of barrows and gilts slaughtered at either 68, 91 or 114 kg liveweight.

Equations for predicting total muscle content of pig carcasses were developed based on carcass measurements routinely made under the Canada hog carcass valuation system. By the addition of increasingly expensive predictors such as cavity fat, ham face tracings and individual muscle weights to the predictors furnished by the valuation system, standard errors of estimate for overall equations were reduced from 0.73 to 0.55 kg muscle. When prediction equations from one breed group were tested on the other in a process of cross-validation, standard errors of estimate increased. It was concluded that if used in experiments where the establishment of significant differences is considered of importance, the use of prediction equations in lieu of dissection could lead to the representation of misleading significance levels or could incorrectly indicate an absence of treatment effects. The use of inferences made from treatment effects on the predictors themselves led to similar conclusions arrived at by considering the treatment effects on actual muscle, but there were cases where the inferences would have been misleading.

Analyses of variance were used to examine the effects of treatments on such variables as daily liveweight gain, feed conversion ratios and carcass grades. Such analyses do not lead to the location of the combination of inputs (treatments) which result in high returns

to management. This problem was approached by the use of prediction equations or production functions whereby combinations of inputs which would yield high returns were determined. Variables needed in the economic analysis and not directly available in the present experiment, were obtained from an Alberta Department of Agriculture Hog Enterprise Analysis (1967 and 1968). The analysis revealed that the current pricing system, based on a grade index grid, had a strong influence on the combinations of feed level and slaughter weight within which high returns to management were possible.

The current hog valuation system was examined and found to result in payment of varying prices per kg of muscle depending on the level of backfat and carcass weight. When carcasses were arbitrarily valued according to their muscle content a new grid for grade indices resulted, which increased the spread between high and low quality carcasses. Also carcasses outside the currently accepted weight ranges would receive indexes more in line with their value based on muscle content. If these recommendations were followed (i.e. valuation of carcasses based on muscle content) further economic analyses indicated that producers would have much greater leeway in range of liveweights at slaughter over which high profits could be made.

The response surface approach used in this experiment was viewed as a valuable experimental tool for use by specialist research workers. However, the adaption to pig production of a simplified response surface approach currently in use in industrial applications is urged. Work on such adaptations is seen as a fruitful field of research which could lead to the implementation of routine operations research on individual commercial pig production units.

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In her usual competent fashion, Mrs. R. Brenner typed most of the material presented in this thesis.

The material presented in this thesis was derived from a research project conducted jointly by the author and Mr. R.J. Richmond.

The author's family shared the load.

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INTRODUCTION

Pig production research results are increasingly being reported in terms of efficiency of muscle production. Canada has a grading system originally based on measurements found to be related to muscle content but subsequently amended to encourage production of pigs within carcass weights and backfat levels specified by the packing industry. The development of an accurate prediction equation based on grading system measurements as predictors of carcass muscle content would enable Canadian research workers to readily estimate muscle production without the need to resort to expensive dissection.

Factorial analyses of treatment effects on variables such as muscle content, feed conversion ratios, daily gains and carcass grades yield isolated pieces of information difficult to co-ordinate as such into specific guidelines for use in commercial pig production units. The use of a response surface approach to analysing the measures of performance, together with integration into an economic analysis, would enable an interpretation of their combined effects and the effects of an amended grading system based strictly on muscle content.

Pig production research is comparable with the pilot plant stage of the development of manufacturing processes in secondary industry. Highly trained researchers use a pilot plant to define combinations of inputs which yield a marketable product. Because the pilot plant does not necessarily yield the optimum operating conditions for the scaled up process, the process is frequently amenable to further development and a system of routine production research has been developed for this purpose (Box and Draper, 1969).

In pig production, research workers currently select the channels - but who does the fine tuning? This thesis represents an approach towards the development of fine tuning techniques for use on commercial pig production units.

SOURCE OF DATA

A. The overall experiment

The experiment was designed to study the influence of feeding three levels of a low energy, low protein diet and sex on performance of two breed groups of pigs slaughtered at 68, 91 and 114 kg liveweight.

B. Housing facilities

The experiment was conducted in the Muttart Barn at the University of Alberta Livestock Farm. Eighteen pens in the barn were equipped with plywood divisions which converted pens providing group housing and feeding into pens giving group housing and individual feeding facilities. Each pen measured 1.8 by 3.1 metres deep with a dunging area occupying 1.7 metres of the pen depth. Each of the individual feeding stalls was 0.45 metres wide. One water bowl was provided in each pen and was not accessible to the pigs when they were locked in the individual stalls at feeding time. Straw bedding was renewed daily.

C. Animals

Two replicates of this experiment were conducted. Each replicate consisted of 36 pigs (4 blocks of 9 pigs) divided into two breed groups, two sexes, three levels of feeding and three slaughter weights. The breed groups were Yorkshire x Lacombe (YL) and Yorkshire x Lacombe-Yorkshire (YLY), while the two sexes were barrows and gilts. Slaughter weights were at 68, 91 and 114 kg liveweight.

A block of pigs consisted of 9 weaners of the same sex from the same breed group and selection was directed at achieving similar weights within blocks. The three feeding levels were randomly allocated to 9 pens on the north end of the barn. Pigs within a block were randomly allocated to slaughterweights. Pigs allocated to feeding levels were then randomly allocated to pens previously allocated to that feeding level. The same procedure was followed in allocating the remaining blocks of the first replicate. In this way each pen allocated to a particular feeding level contained a barrow and a gilt from each breed group. The pigs comprising the second replicate were allocated to the remaining pens as pigs became available.

Weaner pigs were given ad libitum access to a starter diet until they exceeded 22.7 kg and then they were transferred to the experimental diet. Pigs in the first replicate commenced entering the experiment on June 25, 1969 and were all on the experiment by July 30, with over half on experiment by July 9, 1969. In the second replicate, pigs commenced entering the trial on July 9, 1969, over half were on trial by July 23 and all were on trial by August 8, 1969.

D. Diet and feeding scales

The diet shown in Table 1 is the low energy diet used in the experiment reported by Skitsko, Bowland and Elliot (1969). In the highest level of feeding, pigs were placed in the feeding stalls for one hour in the morning, two hours around noon, and another hour in the afternoon. Care was taken to see that food was available at all times while the pigs were in the feeding stalls. The two lower levels of feeding were based on presenting the pigs with either 4 or 3.5 per

Table 1. Formulation and composition of low energy diet offered at three levels of feeding.

Ingredient	Per cent of diet
Wheat	9.88
Oats	47.5
Wheat bran	32.3
Stabilized tallow	2.0
Soybean meal (44%)	3.0
Fishmeal (herring, 72%)	3.0
Meat meal	1.0
Iodized salt	0.4
Ground limestone	0.6
Zinc sulphate	0.04
Trace mineral mix	0.08
Vitamin B-complex mix	0.12
Vitamins A and D	+
Aurofac 10	0.08
Calculated composition	
Digestible energy	2951 kcal per kg
Protein	15.5 per cent
Lysine	0.77 per cent
Methionine and cystine	0.50 per cent
Calcium	0.60 per cent
Phosphorus	0.68 per cent

cent of their liveweight as feed each day. Initially, the lowest level was 3 per cent but due to poor performance this level was raised to 3.5 per cent on September 3, 1969. The daily allowances of feed on each of the feeding scales is shown in Table 2. The daily allowance was divided equally and offered during a morning and an afternoon feeding period, each of one hour duration.

E. Live performance record collection

Pigs were weighed weekly and daily allowances were reviewed after weighing. Prior to being offered the revised allowance, the feed troughs were cleaned of remaining feed which was weighed enabling calculation of weekly feed intakes.

Performance records were commenced as soon as the pigs exceeded 22.7 kg liveweight. Liveweight changes and feed intakes were calculated on a weekly basis until the weigh day when the pigs were nearest 45 kg liveweight. The total feed intakes and average daily gains for the period of 23 to 45 kg were then calculated. This procedure was followed for each subsequent incremental period of approximately 23 kg. Individual performance was thus available for all 72 pigs for the periods 23 to 45 kg and 45 to 68 kg. At 68 kg 24 pigs were slaughtered so records of performance during the period 68 to 91 kg were available for 48 pigs. At 91 kg an additional 24 pigs were slaughtered so that records of performance for the final period of 91 to 114 kg were available for 24 pigs.

F. Realized level of feeding

A description of the three feeding levels used in terms of 3.5,

Table 2. Feed scales based on 3.5 and 4% of liveweight.

Weight of pig (kg)	Daily feed (kg) 3.5%	Daily feed (kg) 4.0%	Weight of pig (kg)	Daily feed (kg) 3.5%	Daily feed (kg) 4.0%
23.1-24.9 [1]	0.82 [2]	0.95	68.5-70.3	2.45	2.77
25.4-27.2	0.91	1.04	70.7-72.6	2.49	2.86
27.7-29.5	1.00	1.13	73.0-74.8	2.58	2.95
29.9-31.8	1.09	1.22	75.3-77.1	2.68	3.04
32.3-34.0	1.18	1.32	77.6-79.4	2.72	3.13
34.5-36.3	1.22	1.41	79.8-81.6	2.81	3.22
36.7-38.6	1.32	1.50	82.1-83.9	2.90	3.31
39.0-40.8	1.41	1.59	84.4-86.2	2.99	3.40
41.3-43.1	1.45	1.68	86.6-88.4	3.08	3.49
43.5-45.4	1.54	1.77	88.9-90.7	3.13	3.58
45.8-47.6	1.63	1.86	91.2-93.0	3.22	3.67
48.1-49.9	1.72	1.95	93.4-95.2	3.31	3.76
50.3-52.2	1.81	2.04	95.7-97.5	3.36	3.86
52.6-54.4	1.86	2.13	98.0-99.8	3.45	3.95
54.9-56.7	1.95	2.22	100.2-102.1	3.54	4.04
57.1-59.0	2.04	2.31	102.5-104.3	3.63	4.13
59.4-61.2	2.09	2.40	104.8-106.6	3.72	4.22
61.7-63.5	2.18	2.49	107.0-108.9	3.76	4.31
64.0-65.8	2.27	2.58	109.3-111.1	3.86	4.40
66.2-68.0	2.36	2.68	111.6-113.4	3.95	4.49
			113.8-115.7	3.99	4.58

[1] Pigs were weighed to the nearest lb, the figures given here are the nearest metric equivalents.

[2] Feed was weighed to the nearest 0.1 lb, figures given here are the nearest metric equivalent.

4.0 per cent of liveweight and "high" is adequate for interpretation of analyses of variance. However, in the response surface approach the plotting of performance curves derived from a prediction equation relating performance to slaughterweight and level of feeding requires a numerical description of the various feeding levels. Accordingly, a method was developed for calculating a figure called the "realized level of feeding" and was applied to the feed and liveweight records of pigs on all feeding levels. Weekly feed intakes were divided by 7 to give estimated daily feed intake. The weight of the pig at the beginning of a week was added to the weight of the pig at the next weekly weighing and divided by 2 to give an estimate of the mid-week weight of the pig. Daily feed intake was expressed as a percentage of the mid-week weight and the resulting figure was called the realized level of feeding.

The realized levels of feeding over the entire experiment were found to be 4.2, 3.7 and 3.2 per cent of liveweight corresponding to the nominal feed levels of high, 4.0 and 3.5 per cent. The feed levels throughout the thesis will be described in terms of the realized levels of feeding.

G. Carcass measurements

The pigs were slaughtered as close as possible to the allocated slaughterweight. Hot carcass weight was recorded at the packing plant. The carcasses were chilled overnight and transported from the packing plant to the Meats Laboratory at the Edmonton Research Station. The head, including jowls, was removed at the atlanto-occipital joint and the carcass split using a handsaw. The right sides were placed on a table and backfat measurements required under the carcass valuation system (Canada Department of Agriculture 1968) were made by staff of the Livestock Division, Production and Marketing Branch, Canada Department of Agriculture. Carcass length measurements and tracings of the loin eye area and ham face area were made in accordance with the R.O.P. specifications (Canada Department of Agriculture, 1967). Left sides of the carcasses were dissected into individual muscles, individual bones, skin, subcutaneous fat, intermuscular fat and cavity fat using modifications of the procedure of Butterfield and May (1965). The right sides were processed into boneless retail cuts and the bones trimmed of tissue to the same tolerances observed on the left sides.

EXPERIMENTAL

I. THE DEVELOPMENT AND TESTING OF EQUATIONS FOR PREDICTING TOTAL MUSCLE CONTENT IN PIG CARCASSES

A. Introduction

Since pigs are produced primarily for their muscle content, the determination or estimation of total muscle content gives an important parameter for the interpretation of market pig production research.

An objective of this work was to develop equations for predicting total carcass muscle content of pig carcasses based on measurements routinely made under Canada's new hog carcass valuation system (Canada Department of Agriculture 1968). Increasingly expensive independent variables (predictors) such as cavity fat, ham face tracings and individual muscle weights were added to valuation system measurements.

The use of prediction equations on test carcasses not included in developing the equations could lead to a reduction in predictive accuracy as the regression coefficients are moulded to minimize the sums of squares of differences between observed and estimated values in the original data. While many equations have been developed for predicting carcass muscle content (see for example, McMeekan, 1941; Bowman, Whatley and Walters, 1962; Buck, Harrington and Johnson, 1962; Holme, Coey and Robinson, 1963; Joblin, 1966; Cuthbertson and Pease, 1968), there have been few reports of results of testing prediction equations (Harrington, 1962; Adam and Smith, 1964, 1966). Accordingly, a further objective of this study was to examine what changes took place when prediction equations were used on test data and to relate these changes to a statistically estimated loss of accuracy (Darlington, 1968). Finally, the estimated values for muscle content in test data were subjected to analyses of variance and the treatment means and significance levels indicated were compared with analyses of the actual data.

B. Statistical analyses

For the purposes of this study the overall experiment was treated as consisting of two experiments; one experiment being considered to be the YL breed group and the other to be the YLY breed group.

There were three stages in the statistical analyses of the data.

(1) In the first stage equations for estimating total left side muscle weight were developed from the combined as well as the separate breed group data. A basic equation was developed using the valuation measurements of hot carcass weight and total backfat depth as the predictors. Subsequent equations contained these basic predictors in association with increasingly expensive predictors (Table 3).

Two statistics were computed to assess the predictive accuracy of the equations; the squared coefficient of multiple correlation (R^2) between observed and estimated values of total left side muscle and the standard error of estimate (SE) as follows:

$$SE = \sqrt{\frac{\text{sum of squares of differences between observed and estimated values}}{N - 1 - n}}$$

where

N = number of observations

n = number of predictors

Table 3. Predictors used to develop equations for estimating total muscle weight in pigs.

Equation Number	Predictors			
1	Total backfat depth	Hot carcass weight		
2	Total backfat depth	Hot carcass weight	Cavity fat weight	
3	Total backfat depth	Hot carcass weight	Loin eye area	Ham muscle area
4	Total backfat depth	Hot carcass weight	M. gracilis weight	
5	Total backfat depth	Hot carcass weight	Distal hind muscle weights*	
6	Total backfat depth	Hot carcass weight	3 large muscle weights**	
7	Total backfat depth	Hot carcass weight	3 large muscle weights	Distal hind muscle weights

* Butterfield (1963)

** M. biceps femoris + m. semimembranosus + m. semitendinosus.

Initially, it was proposed to use the method outlined in Guilford (1965) to adjust both R^2 and SE to give an estimate of the predictive accuracy of the population regression equations based on the sample regression equations. However, Darlington (1968) pointed out that a more appropriate procedure is to adjust the R^2 and SE determined in the samples to estimate the accuracy of the regression equations in other samples of the population. Accordingly, an algebraic rearrangement by Darlington (1968) of a factor proposed by Stein (1960) was used in the formulas outlined in Guilford (1965) to give an estimate of the validity of a sample regression equation when used on another sample. The adjustments were made as follows:

$$R^2_{\text{adjusted}} = 1 - (1 - R^2) \left(\frac{N - 2}{N - n - 2} \cdot \frac{N + 1}{N - n - 1} \right)$$

$$SE_{\text{adjusted}} = SE \sqrt{\left(\frac{N - 2}{N - n - 2} \cdot \frac{N + 1}{N - n - 1} \right)}$$

(2) In the second stage of the analysis the prediction equations were used on test carcasses so that the predictive accuracy under these conditions could be compared with the statistical estimate of the expected reduction in accuracy. The YL equations were tested on the YLY group of carcasses and v_ce versa; a technique known as double cross-validation (Kelly, Beggs and McNeil, 1969). The prediction equations developed from the combined breed groups were used to estimate total muscle content within each breed group of carcasses to enable comparisons with cross-validation results. In each test the correlation between observed and predicted values was obtained. The standard deviation (s) of the differences between observed and estimated values was determined as follows:

$$s = \sqrt{\frac{\text{sum of squares of differences between observed and estimated values}}{N - 1}}$$

(3) In the third stage of the analysis the estimates of carcass muscle content given by the various equations were subjected to analysis of variance. That is, the combined breed group equations were used to estimate total muscle in the YL and YLY breed groups separately; YL equations were used on YL and YLY breed groups; and YLY equations were used on YLY and YL breed groups. All factors were considered fixed in the analysis of variance. The treatment means and significance attributed to treatment effects derived from analysis of variance of the various estimates of muscle content were compared with analyses of variance of the actual data for the two breed groups.

C. Results and Discussion

Means, standard deviations and coefficients of variation of the carcass characteristics are shown in Table 4. The characteristics were highly variable with coefficients of variation for total muscle, muscle weight, hot carcass weight and total backfat ranging from 17.0 to 23.1 per cent. Area tracings were least variable while the highest coefficients of variation were in cavity fat weights.

Simple correlation coefficients between predictors and total left side muscle weight are shown in Table 5. Fat measures were positively correlated with total muscle. Measures of fat characteristics were not as highly correlated with total muscle as were measures of muscle characteristics and hot carcass weight. Correlations found in the combined breed groups were similar in value to those found in

Table 4. Means, standard deviations and coefficients of variation for carcass characteristics of 36 YL pigs, 36 YLY pigs, and the two breed groups combined.

Characteristic	Unit	Yorkshire x Lacombe			Yorkshire x Lacombe - Yorkshire			Combined Breed Groups		
		Mean	s	CV	Mean	s	CV	Mean	s	CV
Total muscle	kg	14.96	3.00	20.0	15.64	3.14	20.1***	15.30	3.07	20.0
Hot carcass weight	kg	68.85	15.49	22.5	69.98	16.20	23.1*	69.42	15.74	22.7
Total backfat	mm	65.64	12.96	19.7	63.75	13.02	20.4	64.8	12.94	19.9
Cavity fat	g	669.7	295.97	44.2	721.1	327.26	45.4	695.4	310.88	44.7
Loin eye area	sq cm	29.5	4.82	16.3	30.7	4.93	16.1	30.1	4.87	16.2
Ham muscle area	sq cm	136.0	19.73	14.5	135.8	19.62	14.4	135.9	19.54	14.4
M. gracilis	g	150.7	32.55	21.6	153.1	34.09	22.3	151.9	33.12	21.8
Distal hind muscles (a)	g	605.6	102.90	17.0	617.1	108.51	17.6	611.4	105.16	17.2
Three large hind muscles (b)	g	2089.7	430.80	20.6	2145.0	438.76	20.4	2117.3	432.6	20.4

(a) Butterfield (1963)
(b) (M. biceps femoris + m. semimembranosus + m. semitendinosus)

* Breed difference significant at $P<0.05$
*** Breed difference significant at $P<0.005$

Table 5. Simple correlation coefficients between predictors and total left side muscle weight in 36 Yorkshire x Lacombe (YL) carcasses, 36 Yorkshire x Lacombe - Yorkshire (YLY) carcasses, and the two breed groups combined.

Breed Group Predictor	YL	YLY	Combined
Hot carcass weight	0.9513	0.9513	0.9392
Total backfat	0.5851	0.5851	0.5602
Cavity fat	0.7493	0.7493	0.7282
Loin eye area	0.8362	0.8362	0.8328
Ham muscle area	0.8632	0.8632	0.8317
M. gracilis	0.9140	0.9140	0.9175
Distal hind muscles	0.9378	0.9378	0.9361
Three large hind muscles	0.9748	0.9748	0.9674

the separate breed groups.

(i) Development and cross-validation of prediction equations

The regression equations for estimating total left side muscle weight (kg) are shown in Table 6.

Squared coefficients of multiple correlation, adjusted R^2 and cross-validated R^2 are shown in Table 7(a). Table 7(b) shows the standard errors of estimate, adjusted SE and the standard deviation of differences when equations were cross-validated.

The R^2 values generally increased and the SE's decreased as the probable cost of the predictors increased. Highest R^2 values and lowest SE's were obtained when the three large muscles constituting over 13 per cent of the left side muscle weight were included.

Equations derived from the YL breed group yielded slightly lower R^2 values when used on the YLY carcasses than those obtained by using the YLY equations. The YL breed group equations gave higher standard deviations of differences between actual and estimated muscle weight when used on the YLY carcasses than the SE obtained by using the YLY equations. A slight reduction in R^2 and a slightly elevated standard deviation of differences relative to the SE was also found when YLY equations were cross-validated on the YL breed group. However, when YL equations were cross-validated on the YLY carcasses which had a slightly higher standard deviation in muscle weight, there were cases where the R^2 values were slightly higher than those obtained when the YL equations were used on the YL carcasses. In this validation, all equations, with the exception of number 3, gave slightly higher standard deviations of differences between actual and estimated

Table 6. Regression equations predicting total left side muscle weight of pigs.

Equation Number	Breed Group	Intercept	BF	CW	CF	LEA	HMA	G	DHM	LGM
1	YL	3.833	-0.06884	0.2273						
	YLY	5.215	-0.1158	0.2548						
	Combined	4.555	-0.09287	0.2415						
2	YL	3.152	-0.06509	0.2468	-0.001355					
	YLY	4.269	-0.1102	0.2818	-0.00801					
	Combined	3.787	-0.08902	0.2640	-0.001504					
3	YL	1.462	-0.05318	0.1806		0.0932	0.01324			
	YLY	1.648	-0.07574	0.1932		0.1317	0.009351			
	Combined	1.562	-0.0658	0.1871		0.1242	0.009395			
4	YL	3.043	-0.05298	0.1839				0.01815		
	YLY	4.294	-0.09392	0.2043				0.01992		
	Combined	3.702	-0.07454	0.1948				0.01913		
5	YL	2.014	-0.06230	0.1660					0.009261	
	YLY	3.230	-0.08696	0.1966					0.006816	
	Combined	2.480	-0.07306	0.1780					0.008501	
6	YL	1.811	-0.02991	0.1064						0.003724
	YLY	3.341	-0.08537	0.1583						0.003114
	Combined	2.464	-0.05902	0.1358						0.003331
7	YL	1.287	-0.03274	0.0966					0.004205	0.003169
	YLY	2.791	-0.07764	0.1455					0.002404	0.002864
	Combined	1.806	-0.05352	0.1177					0.004685	0.002798

BF - Total backfat
CW - Carcass weight
CF - Cavity fat
LEA - Loin eye area
HMA - Ham muscle area
G - M. gracilis
DHM - Distal hind muscles
LGM - Mm. biceps femoris, semimembranosus and semitendinosus

Table 7. (a) Squared multiple correlation coefficients and adjusted R^2 of equations for predicting total muscle weight, together with R^2 between actual and estimated muscle weight when the prediction equations were used in test data.

(b) Standard errors of estimate and adjusted standard errors of estimate of equations for predicting total muscle weight (kg), together with standard deviations of differences between actual and estimated muscle weight when the prediction equations were used in test data.

	Yorkshire x Lacombe			Yorkshire x Lacombe - Yorkshire			Combined breeds			
(a) Equation Number	R^2	Adj. R^2	Test on YLY R^2	R^2	Adj. R^2	Test on YL R^2	R^2	Adj. R^2	Test on YLY R^2	Test on YL R^2
1	0.944	0.933	0.942	0.956	0.948	0.927	0.945	0.940	0.953	0.939
2	0.949	0.942	0.952	0.966	0.962	0.932	0.952	0.946	0.962	0.944
3	0.954	0.946	0.965	0.972	0.967	0.949	0.961	0.955	0.970	0.952
4	0.951	0.945	0.952	0.964	0.959	0.937	0.953	0.947	0.962	0.947
5	0.957	0.953	0.962	0.964	0.959	0.952	0.959	0.954	0.964	0.956
6	0.970	0.966	0.965	0.981	0.979	0.952	0.970	0.966	0.978	0.965
7	0.972	0.967	0.974	0.982	0.979	0.958	0.974	0.970	0.980	0.970
(b)	S.E.	Adj. S.E.	Test on YLY s	S.E.	Adj. S.E.	Test on YL s	S.E.	Adj. S.E.	Test on YLY s	Test on YL s
1	0.73	0.80	0.82	0.68	0.74	0.84	0.73	0.76	0.70	0.75
2	0.71	0.90	0.78	0.60	0.96	0.83	0.69	0.73	0.62	0.73
3	0.68	0.92	0.66	0.56	0.76	0.71	0.62	0.67	0.55	0.67
4	0.70	0.88	0.76	0.62	0.79	0.80	0.68	0.72	0.63	0.71
5	0.65	0.81	0.67	0.62	0.79	0.70	0.64	0.67	0.61	0.64
6	0.54	0.69	0.66	0.45	0.57	0.70	0.54	0.57	0.49	0.58
7	0.53	0.72	0.59	0.44	0.60	0.65	0.51	0.55	0.46	0.54

muscle weight than the SE obtained when the YL equations were used on the YL carcasses. Conversely, when the YLY equations were tested on the YL population with a slightly lower standard deviation in total muscle weight, there were consistent but slight decreases in the values of R^2 relative to those obtained when the YLY equations were used on YLY carcasses. Along with these changes in R^2, there were consistent increases in the standard deviation of differences between actual and estimated muscle weight relative to the SE's obtained when the YLY equations were used on YLY carcasses.

When combined breed group equations were tested on the individual breed groups, the YLY carcasses again gave slightly elevated R^2 values while the YL carcasses produced slight reductions in the values of R^2. Use of the combined breed group equations on the separate breed groups resulted in a decrease in the standard deviation of differences between observed and predicted values in the YLY breed group relative to the SE of the overall equations, while there was an increase in the YL breed group.

Darlington (1968) pointed out that an extremely important property of the formulas for validating sample regression equations is that the estimate for validity is low when the number of predictors is large in relation to the number of observations in the sample from which the equation was derived. In this study R^2 sometimes increased slightly when validated and where R^2 decreased the reduction was not related to the number of predictors. The adjusted values for the SE more accurately estimated the cross-validated statistics than did the unadjusted statistics in 15 of the test cases while the unadjusted statistics more accurately estimated the validated statistics in the remaining 13 test situations.

(ii) Analyses of variance of predicted vs. actual total left side muscle

(a) Combined breed group equations

Treatment means of effects of feed level, slaughter weight and sex on actual and estimated left side muscle weight in the YL and YLY breed groups are shown in Table 8.

When the actual data for the YL breed group was subjected to analysis of variance, there was no significant effect of feed level on left side muscle weight. The effect of slaughter weight on left side muscle weight was significant ($P < 0.005$) and there was a significant effect of sex on muscle weight ($P < 0.05$). In the YLY breed group the effect of feed level was significant ($P < 0.05$), and the effects of slaughter weight and sex were significant ($P < 0.005$).

The absence of a feed level effect in the YL breed group using equations 4, 5 and 7 agreed with analyses of the actual data. Use of the other equations for estimating muscle weight indicated an effect of feed level significant at either the 0.05 or 0.01 level. There was agreement with the actual data analyses in indicating a significant ($P < 0.05$) effect of sex on the YL breed group when equations 2, 3, 6 and 7 were used.

Use of equations 3, 6 and 7 agreed with the analyses of actual data by indicating the presence of a feed level effect ($P < 0.05$) on muscle weight in the YLY breed group. The 0.005 level of significance attributed to the sex effect in the YLY breed group was also indicated at this level when equations 2, 3 and 4 were used; the remaining equations attributing different significance levels to the sex effect.

Table 8. Actual ($\pm$ standard error) and estimated treatment means of effects of feed level, slaughter weight and sex on actual and predicted left side muscle weight in two breed groups of pigs.

Equation Number	Breed Group	Feed Level 4.2	Feed Level 3.7	Feed Level 3.2	Slaughter weight 68	Slaughter weight 91	Slaughter weight 113	Sex B	Sex G
1	YL	14.83	14.84	15.56 **	11.65	15.05	18.53 ***	14.91	15.24
	YLY	15.18	15.67	15.70	11.94	15.51	19.10 ***	15.21	15.82 *
2	YL	14.88	14.83	15.61 **	11.68	15.08	18.56 ***	14.88	15.34 *
	YLY	15.11	15.58	15.77	11.87	15.58	19.01 ***	15.12	15.85 ***
3	YL	14.88	14.67	15.64 **	11.59	15.03	18.57 ***	14.96	15.16
	YLY	15.13	15.60	15.86 *	11.94	15.65	19.00 ***	15.04	16.02 ***
4	YL	14.92	14.96	15.40	11.64	15.10	18.55 ***	14.85	15.34 *
	YLY	15.24	15.61	15.64	11.91	15.50	19.08 ***	15.13	15.86 ***
5	YL	14.94	14.91	15.40	11.56	15.19	18.49 ***	14.93	15.24
	YLY	15.18	15.60	15.76	11.86	15.67	19.00 ***	15.20	15.82 *
6	YL	14.72	14.92	15.58 *	11.57	15.10	18.55 ***	14.79	15.36 *
	YLY	15.22	15.39	15.94 *	11.88	15.70	18.98 ***	15.22	15.82 **
7	YL	14.80	14.94	15.49	11.53	15.17	18.53 ***	14.82	15.34 *
	YLY	15.22	15.40	15.94 *	11.84	15.76	18.95 ***	15.22	15.82 *
	Mean $-s_{\bar{x}}$	14.51	14.40	15.21	11.25	14.71	18.16	14.41	15.06
YL	Mean	14.76	14.65	15.46	11.50	14.96	18.41 ***	14.63	15.28 *
	Mean $+s_{\bar{x}}$	15.01	14.90	15.71	11.75	15.21	18.66	14.85	15.50
	Mean $-s_{\bar{x}}$	15.02	15.37	15.89	11.70	15.69	18.89	14.98	15.95
YLY	Mean	15.23	15.58	16.10 *	11.91	15.90	19.10 ***	15.15	16.12 ***
	Mean $+s_{\bar{x}}$	15.44	15.79	16.31	12.12	16.11	19.31	15.32	16.29

The prediction equations for estimating muscle content in the individual carcasses from which the above treatment means were calculated were derived from the two breed groups combined.

Means significantly different at * $P<0.05$
** $P<0.01$
*** $P<0.005$

It was no surprise to find that in both separate breed groups, the combined breed groups prediction equations estimated a significant ($P < 0.005$) effect of slaughter weight on left side muscle weight agreeing with the large effect detected in analysis of the original data.

(b) Separate breed group equations

Treatment means of effects of feed level, slaughter weight and sex on actual and estimated left side muscle weight in the YL and YLY breed groups are shown in Table 9.

The YLY breed group equations used on that breed gave results in equations 1, 2, 3, 6 and 7 similar to analysis of the actual data, except that equation 6 attributed a higher level of significance to feed level ($P < 0.01$ as opposed to $P < 0.05$). The significant effect attributed to sex was detected by all equations in the YLY breed group, but equations 5 ($P < 0.05$) and 1 ($P < 0.01$) underestimated the level of significance found in the actual data ($P < 0.005$).

The YL breed group equations used on that breed group gave results attributing a significant effect on muscle weight due to feed level in equations 1, 2 and 3 while analysis of the actual data indicated no effect of feed level. Equations 1, 3 and 5 failed to attribute significance to the effect of sex on muscle weight while the effect was significant in analysis of the actual data.

Again, the large effect of slaughter weight on left side muscle weight was detected using the prediction equations.

(c) Cross-validation estimations

Treatment means of effects of feed level, slaughter weight and

Table 9. Actual (± standard error) and estimated treatment means of effects of feed level, slaughter weight and sex on actual and predicted left side muscle weight in two breed groups of pigs.

		Treatment means of predicted left side muscle weight (kg)							
Equation	Breed	Feed Level			Slaughter weight			Sex	
Number	Group	4.2	3.7	3.2	68	91	113	B	G
1	YL	14.82	14.74	15.30 *	11.50	14.97	18.40 ***	14.84	15.07
	YLY	15.16	15.82	15.92 *	12.05	15.67	19.19 ***	15.26	16.01 **
2	YL	14.84	14.71	15.32 *	11.51	14.98	18.38 ***	14.76	15.13 *
	YLY	15.13	15.75	16.03 *	11.99	15.78	19.14 ***	15.19	16.08 ***
3	YL	14.83	14.61	15.43 *	11.50	14.98	18.39 ***	14.88	15.03
	YLY	15.18	15.72	16.02 *	12.01	15.77	19.13 ***	15.10	16.17 ***
4	YL	14.88	14.84	15.14	11.48	15.00	18.39 ***	14.76	15.15 *
	YLY	15.27	15.77	15.87	12.05	15.68	19.19 ***	15.20	16.07 ***
5	YL	14.86	14.80	15.21	11.44	15.09	18.34 ***	14.82	15.09
	YLY	15.24	15.75	15.91	11.99	15.78	19.14 ***	15.30	15.97 *
6	YL	14.70	14.84	15.33	11.45	15.04	18.38 ***	14.71	15.20 *
	YLY	15.20	15.56	16.15 **	11.97	15.84	19.11 ***	15.26	16.01 ***
7	YL	14.74	14.85	15.28	11.43	15.08	18.36 ***	14.72	15.19 *
	YLY	15.23	15.56	16.13 *	11.95	15.87	19.10 ***	15.28	16.00 ***
YL	Mean $-s_{\bar{x}}$	14.51	14.40	15.21	11.25	14.71	18.16	14.41	15.06
	Mean	14.76	14.65	15.46	11.50	14.96	18.41 ***	14.63	15.28 *
	Mean $+s_{\bar{x}}$	15.01	14.90	15.71	11.75	15.21	18.66	14.85	15.50
YLY	Mean $-s_{\bar{x}}$	15.02	15.37	15.89	11.70	15.69	18.89	14.98	15.95
	Mean	15.23	15.58	16.10 *	11.91	15.90	19.10 ***	15.15	16.12 ***
	Mean $+s_{\bar{x}}$	15.44	15.79	16.31	11.12	16.11	19.31	15.32	16.29

The prediction equations for estimating muscle content in the individual carcasses from which the above treatment means were calculated were derived separately from each breed group and used on the breed group of origin.

Means significantly different at * $P<0.05$
** $P<0.01$
*** $P<0.005$

sex on actual and estimated left side muscle weight in the YL and YLY breed groups are shown in Table 10.

When YLY equations were used to estimate muscle weight in YL carcasses, significant effects of feed level ($P < 0.05$, 0.01 and 0.005) were indicated while analysis of the actual data did not attribute any significant effect of feed level on muscle weight. A significant ($P < 0.05$) effect of sex in the actual data was not indicated in the estimates made by equations 1, 3 and 5 and was attributed with a higher level of significance by equation 4 ($P < 0.005$).

When YL equations were used to estimate muscle weight in YLY carcasses, significant effects of feed level were detected only by equation 6. Muscle weight estimates provided by equation 5 failed to attribute an effect on muscle weight to sex while other equations indicated a lower level of significance (1, 2, 4, 6 and 7) or the same (3) level as was found in analysis of the actual data.

Once again, the large effect of slaughter weight on left side muscle weight was detected using the prediction equations.

The trend for gilts to have more muscle than barrows was reflected by all predication equations in the cross-validation procedure.

Comparison of the results of significance levels attributed to treatment effects by use of estimated data and actual data is but one way of assessing the usefulness of prediction equations. Another way is to determine the percentage of estimated treatment means falling within $\pm$ one standard error of the treatment means calculated from the analysis of variance of the actual data. Tables 5, 6 and 7 have the treatment means $\pm$ one standard error of the mean obtained from analysis of variance of the actual data. When the combined breed group

Table 10. Actual and predicted left side muscle weight by level of feeding, slaughter weight, breed and sex.

Equation Number	Breed Group	Feed Level 4.2	Feed Level 3.7	Feed Level 3.2	Slaughter weight 68	Slaughter weight 91	Slaughter weight 113	Sex B	Sex G
1	YL	14.79	14.88	15.76 ***	11.74	15.07	18.61 ***	14.93	15.36
	YLY	15.13	15.46	15.41	11.77	15.30	18.94 ***	15.10	15.57 *
2	YL	14.89	14.90	15.85 ***	11.80	15.15	18.69 ***	14.92	15.50 *
	YLY	15.05	15.35	15.45	11.69	15.33	18.83 ***	15.00	15.56 *
3	YL	14.90	14.72	15.78 **	11.63	15.08	18.69 ***	15.01	15.25
	YLY	15.06	15.42	15.60	11.80	15.47	18.80 ***	14.98	15.74 ***
4	YL	14.93	15.03	15.61	11.76	15.16	18.65 ***	14.90	15.48 ***
	YLY	15.17	15.39	15.35	11.73	15.28	18.90 ***	15.01	15.60 **
5	YL	14.97	14.98	15.59	11.63	15.24	18.61 ***	15.00	15.36
	YLY	15.08	15.43	15.58	11.73	15.53	18.83 ***	15.08	15.64
6	YL	14.68	14.94	15.78 **	11.63	15.12	18.65 ***	14.80	15.46 *
	YLY	15.18	15.14	15.68 *	11.74	15.50	18.74 ***	15.10	15.56 *
7	YL	14.75	14.97	15.72 *	11.62	15.17	18.65 ***	14.84	15.45 *
	YLY	15.15	15.18	15.71	11.72	15.58	18.74 ***	15.10	15.59 *
YL	Mean $-s_x$	14.51	14.40	15.21	11.25	14.71	18.16	14.41	15.06
	Mean	14.76	14.65	15.46	11.50	14.96	18.41 ***	14.63	15.28 *
	Mean $+s_x$	15.01	14.90	15.71	11.75	15.21	18.66	14.85	15.50
YLY	Mean $-s_x$	15.02	15.37	15.89	11.70	15.69	18.80	14.98	15.95
	Mean	15.23	15.58	16.10 *	11.91	15.90	19.10 ***	15.15	16.12 ***
	Mean $+s_x$	15.44	15.79	16.31	12.12	16.11	19.31	15.32	16.29

The prediction equations for estimating muscle content in the individual carcasses from which the above treatment means were calculated were derived separately from each breed group and used on the other breed group in a process of double cross-validation.

Means significantly different at * $P < 0.05$
** $P < 0.01$
*** $P < 0.005$

equations were used to estimate the composition of the YL and YLY breed groups separately, 73 per cent of the estimated treatment means fell within the range of ± one standard error of the treatment means of the actual data. Use of prediction equations within the breed group from which they were derived was more accurate in reflecting treatment effects since 93 per cent of the estimated treatment means fell within the range of ± one standard error of the actual treatment means. However, in cross validation the percentage dropped to 47.

Clark, Dudzinski, Butterfield and Bennett (1964) updated an equation based on 24 beef carcasses by adding the results of dissection of 3 beef carcasses from an experiment so that the composition of remaining carcasses from the experiment could be estimated by the updated equation. The resulting estimated values were subjected to analysis of variance. The use of a combined breed group equation on the separate breed groups in this study can be regarded as the ultimate in updating since all carcasses of the breed group on which the combined equation was used contributed to the equation in addition to the members of the other breed group. Viewing updating in this way it can be seen that inclusion of carcasses other than those from the group on which the equation was used resulted in a reduction of the number of estimated treatment means falling within ± one standard error of the treatment means in the actual data (93 per cent down to 73 per cent).

Harrington (1962) found that the use of a prediction equation on carcasses from which the equation was derived underestimated the actual treatment differences while the differences were overestimated when an equation was used on test data. In the current study there was overestimation and underestimation of significance levels of treatment effects when equations were used on the breed groups from which they were developed. Also, there was no consistent overestimation of significance levels when equations were used on test data since there was overestimation, underestimation or agreement with significance levels derived from analysis of the actual data.

This study has demonstrated that there are difficulties in forecasting the validity of prediction equations. The formulas for estimating the validity of an equation when used in another sample assume that there will be a reduction in accuracy of prediction while it was found in this study that a prediction equation can have a slightly higher R^2 when used on test data than was obtained when the equation was used on the carcasses from which it was derived.

The adjusted values of R^2 and SE gave no more precision in estimating the change which would occur when the equations were used on test data than did the unadjusted values for R^2 and SE. However, there is a difficulty in comparing the SE's and the standard deviation of differences found in test runs. The SE is derived from the sums of squares of differences between observed and predicted values divided by N - 1 - the number of predictors. When an equation is tested the sums of squares of differences is divided by N - 1 and the square root taken to give the standard deviation of differences. Hence, the SE on original data and the standard deviation of differences found on test are not quite comparable statistics. While the effect of the difference in divisors between the SE and standard deviation of differences may be unimportant in large samples, it does have importance in this study where test groups consisted of only 36 carcasses.

In experiments where the establishment of significance of treatment effects is considered of importance the use of a prediction equation in lieu of dissection could lead to the representation of misleading significance levels or could incorrectly indicate an absence of treatment effects. In this context, the advice of McMeekan (1941) is worth repeating -

"Any application of the regression functions developed in respect to both sample joints and measurements, to pigs other than the strain from which these have been derived requires considerable caution".

It is an objective of the two subsequent chapters of this thesis to explore, to some extent, the degree of caution required in applying regression functions in material other than that from which they were derived.

II. THE APPLICATION OF PREDICTION EQUATIONS IN STUDYING THE INFLUENCE OF FEEDING THREE LEVELS OF A LOW ENERGY, LOW PROTEIN DIET ON CONVENTIONAL MEASURES OF PERFORMANCE OF BARROWS AND GILTS FROM TWO BREED GROUPS OF PIGS SLAUGHTERED AT 68, 91 AND 114 KG

A. Introduction

Results of pig production experiments are commonly reported in tabular form listing the effects of treatments on such variables as daily liveweight gain, feed conversion ratios, carcass grades (where applicable) and indices of and actual composition. Less commonly reports include prediction equations expressing the relationship between inputs and outputs in pig production experiments (for recent examples see Holder, Wilson and Williams, 1969; and Dent, English and Raeburn, 1970). The need for such relationships has been stressed by Lucas (1964) who concluded:

"the major impact upon practice where specific recommendations can rarely be given..... is likely to be by economists searching for feeding systems giving maximum financial returns. For such work quantitative data on input-output relationships are needed to allow rapid assessment of a changing economic situation by the use of computers".

The objectives of this section were to examine conventional measures of performance using analysis of variance and response surface techniques. Prediction equations were developed giving general relationships between time to slaughter, grade index and feed consumption with inputs of feed level offered and liveweight at slaughter.

In addition, a suggestion by Harrington (1963) that indices of carcass composition be examined instead of analysing estimates of carcass composition was explored. Results obtained by examining indices were compared with those obtained using actual dissection results and estimates of carcass composition predicted by two techniques developed in section I.

B. Statistical analyses

(i) Variables used

Actual carcass components (muscle and fat) were calculated by multiplying the weight of each component obtained from left side dissection by two. In the case of bone, total carcass bone was derived by adding left side bone weight to right side bone weight.

Estimated values for muscle were obtained by two procedures. One of the better prediction techniques determined in section I was the use of the separate breeds prediction equation number 7 on the separate breed groups. This technique was used to estimate left side muscle weight and that weight was multiplied by two to yield estimated total carcass muscle weight. These estimates were used in analysis of variance and compared with analysis of the actual left side muscle weight multiplied by two. The same procedure was followed using one of the less reliable prediction techniques; that of using the YL equation number 1 on the YLY breed group and vice versa.

Carcass component weight gains were obtained by subtracting final minus estimated initial component weight. Initial components were estimated by using prediction equations developed from dissections of 17 pigs slaughtered between 23 and 32 kg liveweight (Richmond and Berg, 1971). Description of these 17 pigs and the regression equations for estimating total muscle and fat from liveweight measurements are in Table 11. The skin was included with the fat tissue in the dissections of the weaner pigs. Consequently, fat gain was estimated from total fat weight at slaughter less estimated initial weight of fat plus skin.

(ii) Methods of analysis

Table 11. Description of 17 pigs used to develop equations for estimating composition of pigs when placed on trial together with the equations for estimating total carcass muscle and fat.

Variable	Mean	s	Minimum	Maximum
Live weight (kg)	26.8	2.74	22.7	32.2
Left side muscle weight x 2 (kg)	9.32	1.103	7.31	12.16
Left side fat weight x 2 (kg)	4.16	0.906	2.63	5.85

Prediction equations:	R^2	R^2 adj.	SE	SE* adj.
Total muscle = 0.1749 + 0.3419 (liveweight)	0.724	0.645	0.60	0.80
Total fat = -3.8340 + 0.2989 (liveweight)	0.819	0.767	0.40	0.53

* Adjusted using the method outlined on page 13.

The variables were analysed by analyses of variance and by response surface techniques.

(a) Analysis of variance

All factors were considered fixed and treatment means were separated using Duncan's new multiple range test (Duncan, 1955).

(b) Response surface approach

There were three stages in the response surface approach.

(1) In order to determine appropriate regression coefficients, the variable of interest was entered as the dependent variable in a multiple regression analysis with the independent variables being (level of feeding), (slaughterweight), $(\text{level of feeding})^2$, $(\text{slaughterweight})^2$ and (level of feeding x slaughterweight).

(2) For those variables with R^2 values exceeding 70 per cent, the method outlined by Dillon (1968) was used to solve for slaughterweight in terms of feed level at constant, specified values of the dependent variable. Details of steps not fully described in Dillon (1968) have been provided by Weingardt (1971, personal communication) and are given in the appendix.

(3) These equations were used to generate contours of constant, specified values of the dependent variable. This was done by joining 100 solved points over the range of feeding levels using the "Calcomp" plotter at the computing centre of the University of Alberta.

While not always plotted, there were three types of contour diagrams for the dependent variable. These were for the overall data, within breeds and within sexes.

C. Results and Discussion

(i) Analyses of variance of live performance characteristics

(a) Realized level of feeding

Treatment means of realized feeding level by nominal feeding level, slaughter weight, breed and sex are shown in Table 12. The realized feeding level decreased as the nominal feeding level decreased but the differences became less clear cut as liveweight increased and were not significant during the final period. The number of pigs per feeding level during the final period was 8 and this may have contributed to the lack of significance. Taken over the whole experiment the level of feeding realized by pigs slaughtered at 114 kg was less than that of those killed at 68 kg ($P < 0.05$). As liveweight increased there was a trend towards reduced realized level of feeding within the nominal feeding levels of high and 4.0 per cent.

The realized level of feeding achieved by the YL breed group was significantly higher than that of the YLY pigs during the whole experiment and in the first three periods considered separately ($P < 0.01$ or $P < 0.05$). This trend was still apparent in the final period although it was non-significant.

Barrows tended to consume more feed daily than gilts but this was not significant in the initial or final period.

Interactions among main effects on realized feeding levels are shown in Table 13. During the initial period it appeared that there was no difference in realized feeding level between sexes in the YLY breed group while in the YL breed group barrows achieved a higher level of feeding than gilts.

Table 12. Treatment means of realized feeding level (%) by nominal feeding level, slaughter weight, breed and sex.

Period	Nominal feed level			Slaughter weight			Breed		Sex	
	High	4.0%	3.5%	68	91	114	YL	YLY	B	G
Initial to 45 kg	4.57^{A} [1]	3.73^{B}	3.08^{C}	3.79	3.75	3.84	3.90^{A}	3.69^{B}	3.83	3.75
45 to 68 kg	4.23^{A}	3.71^{B}	3.37^{C}	3.79	3.71	3.81	3.83^{A}	3.71^{B}	3.85^{A}	3.68^{B}
68 to 91 kg	3.85^{aA}	3.62^{bB}	3.35^{cB}		3.59	3.62	3.68^{a}	3.52^{b}	3.70^{A}	3.50^{B}
91 to 114 kg	3.43	3.25	3.21			3.30	3.33	3.26	3.40	3.20
Initial to slaughter	4.24^{A}	3.66^{B}	3.20^{C}	3.78^{a}	3.69^{ab}	3.63^{b}	3.78^{A}	3.62^{B}	3.77^{A}	3.63^{B}

1. Means having different superscripts within the same treatment classification differ significantly at $P<0.05$ (a,b,c) and $P<0.01$ (A,B,C).

Table 13. Interactions among main effects on realized feeding levels.

(a) Interaction (P<0.01) of sex and breed group on realized level of feeding from initial to 45 kg liveweight.

	Sex	
Breed Group	B	G
YL	4.02	3.64
YLY	3.77	3.74

(b) Interaction (P<0.01) of level of feeding and sex on realized level of feeding between 45 and 68 kg liveweight.

	Nominal feed level		
Sex	H	4.0	3.5
B	4.42	3.76	3.38
G	4.03	3.67	3.35

(c) Interaction (P<0.05) of breed and level of feeding on realized level of feeding between 45 and 68 kg liveweight.

	Nominal feed level		
Breed Group	H	4.0	3.5
YL	4.35	3.77	3.38
YLY	4.11	3.66	3.35

(d) Interaction (P<0.005) of level of feeding and slaughter weight on realized level of feeding from initial to slaughter weight.

	Nominal feed level		
Slaughter weight	H	4.0	3.5
68	4.50	3.68	3.16
91	4.14	3.72	3.21
114	4.07	3.59	3.23

The interaction between nominal feeding level and sex on realized level of feeding between 45 and 68 kg liveweight supports findings by Bell (1963) and Plank and Berg (1963) that barrows have a tendency to consume more feed each day than gilts if given the opportunity as was the case on the nominal high feeding level in this experiment (Table 13b).

A breed difference in realized level of feeding in the 45 to 68 kg period decreased as the level of feeding decreased (Table 13c).

Taken over the whole experiment there was a trend for realized level of feeding to decrease on the nominal high level but the opposite trend appeared on the nominal 3.5 per cent level (Table 13d). The low realized feeding level up to the 68 kg slaughter weight on the 3.5 per cent level was probably mainly the result of the initial 3.0 per cent nominal feeding level offered during the early part of the experiment.

Dillon (1968) pointed out that where feed level is a factor in a response surface investigation it is advisable to have an *ad libitum* level and other levels spaced below this. Bowland (1962) noted that the use of two one hour feeding periods per day probably resulted in restriction of feed intake as compared to *ad libitum* feeding from self feeders. In an effort to more closely approach *ad libitum* feeding while still retaining individual feed intake data an extra feeding period of two hours around noon was included in the experimental design.

Some factors affecting voluntary feed intake in pigs were examined by Cole, Duckworth and Holmes (1967) using diets ranging from 2,970 to 3,910 kcal of digestible energy per kg over a liveweight range of 38 to 105 kg. They found that voluntary intake of digestible energy by pigs could be related to liveweight by the equation:

$$Y = 575\ X^{0.675\ (\pm\ 0.048)}$$

where Y = daily intake of digestible energy (kcal) and X = liveweight (kg).

The mean daily intake of pigs on the current experiment was estimated for the four liveweight periods. This was done by multiplying the mean realized level of feeding within each period by the approximate midpoints of each liveweight period; i.e. 34, 56, 79 and 102 kg. Expressed as digestible energy it was found that as liveweight increased the intakes of pigs on the nominal high level of feeding more closely approached the intakes achieved by the barrows in the experiment of Cole, Duckworth and Holmes (1967), being 73.8, 80.3, 81.7 and 79.1 per cent of the intake achieved by their barrows for the successive liveweight periods. When similar comparisons were made using mean intakes for barrows obtained from the sex by energy interaction, the barrows in this experiment achieved slightly higher intakes of 74.8, 84.0, 86.0 and 83.3 per cent in the respective periods.

Hence, even with four hours of access to feed each day the pigs in the current experiment only achieved about 80 per cent of *ad libitum* digestible energy intake using as a reference the relationship established by Cole, Duckworth and Holmes (1967). It is suggested that lack of access to water while being offered dry feed in individual feeding stalls could have been an important factor in restricting feed intake in the current experiment.

(b) Daily liveweight gains

Means of daily liveweight gains by feed level, slaughter weight, breed and sex are shown in Table 14. Differences in daily gains closely followed the pattern of differences in realized feeding level described in the previous section. Taken over the whole experiment daily gains increased as slaughter weight increased ($P < 0.05$).

Although YL pigs tended to attain a significantly higher level of feeding than the YLY pigs in most periods, the YL pigs out-gained the YLY pigs significantly ($P < 0.05$) only during the period of 45 to 68 kg. Again, while barrows tended to achieve a higher level of feeding than gilts and this was significant in three periods, gilts tended to outgain barrows although the differences did not reach significance.

Interactions among main effects on daily liveweight gains are shown in Table 15. During the initial period a trend for YL pigs to grow faster than YLY pigs on the 4.2 and 3.7 per cent feeding levels was reversed on the 3.2 per cent feeding level (Table 15a). A similar interaction occurred in the 45 to 68 kg liveweight period (Table 15b) and this closely follows the interaction of the same factors on realized feeding level described earlier (Table 13c). For the overall period the trend persisted (Table 15c).

During the period between 45 and 68 kg liveweight, barrows of the YLY breed group tended to outgain gilts of that breed but this sex effect did not occur in the YL breed group (Table 15d). While there appeared to be little sex effect on daily liveweight gain on the 4.2 and 3.7 per cent feeding levels, the barrows on the 3.2 per cent level gained more slowly than the gilts (Table 15e).

Daily liveweight gains are important as they give an indication of the time required to reach slaughter weight. Figure 1

Table 14. Mean daily gains (kg) of pigs by feed level, slaughter weight, breed and sex.

Period	Feed level			Slaughter weight			Breed		Sex	
	4.2	3.7	3.2	68	91	114	YL	YLY	B	G
Initial to 45 kg	0.52^{A} [1]	0.41^{B}	0.27^{C}	0.40	0.39	0.40	0.40	0.40	0.39	0.41
45 to 68 kg	0.71^{A}	0.66^{B}	0.53^{C}	0.63	0.64	0.62	0.66^{a}	0.61^{b}	0.62	0.64
69 to 91 kg	0.78^{A}	0.77^{A}	0.66^{B}		0.71	0.76	0.74	0.74	0.73	0.75
91 to 114 kg	0.66	0.64	0.70			0.68	0.69	0.64	0.64	0.69
Initial to slaughter	0.63^{A}	0.55^{B}	0.42^{C}	0.49^{aA}	0.54^{bB}	0.58^{cB}	0.54	0.53	0.52	0.55

1. Means having different superscripts within the same treatment classification differ significantly at $P<0.05$ (a,b,c) and $P<0.01$ (A,B,C).

Table 15. Interactions among main effects on daily liveweight gains.

(a) Interaction ($P<0.05$) of breed group and level of feeding on liveweight gain per day from initial to 45 kg liveweight.

	Feed level		
Breed Group	4.2	3.7	3.2
YL	0.54	0.42	0.25
YLY	0.50	0.40	0.29

(b) Interaction ($P<0.005$) of breed group and level of feeding on liveweight gain per day between 45 and 68 kg liveweight.

	Feed level		
Breed Group	4.2	3.7	3.2
YL	0.75	0.70	0.51
YLY	0.67	0.61	0.55

(c) Interaction ($P<0.005$) of breed group and level of feeding on liveweight gain per day between initial and slaughter weight.

	Feed level		
Breed Group	4.2	3.7	3.2
YL	0.66	0.58	0.40
YLY	0.61	0.53	0.44

(d) Interaction ($P<0.05$) of breed group and sex on liveweight gain per day between 45 and 68 kg liveweight.

	Sex	
Breed Group	B	G
YL	0.62	0.62
YLY	0.69	0.60

(e) Interaction ($P<0.005$) of sex and level of feeding on liveweight gain per day between 45 and 68 kg liveweight.

	Feed level		
Sex	4.2	3.7	3.2
B	0.71	0.67	0.49
G	0.71	0.64	0.57

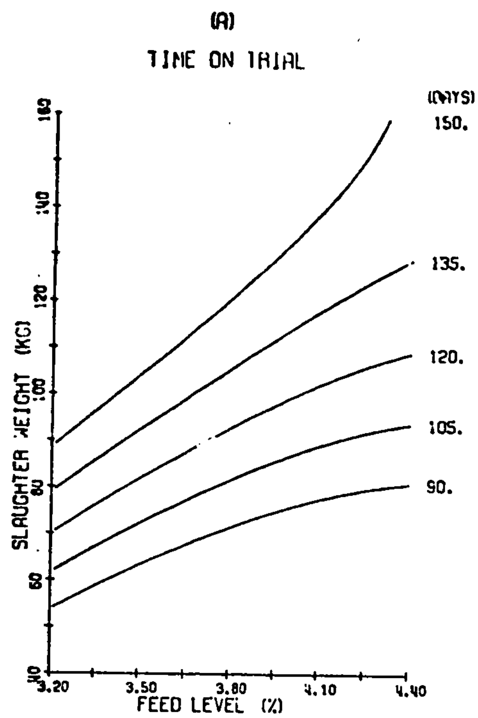
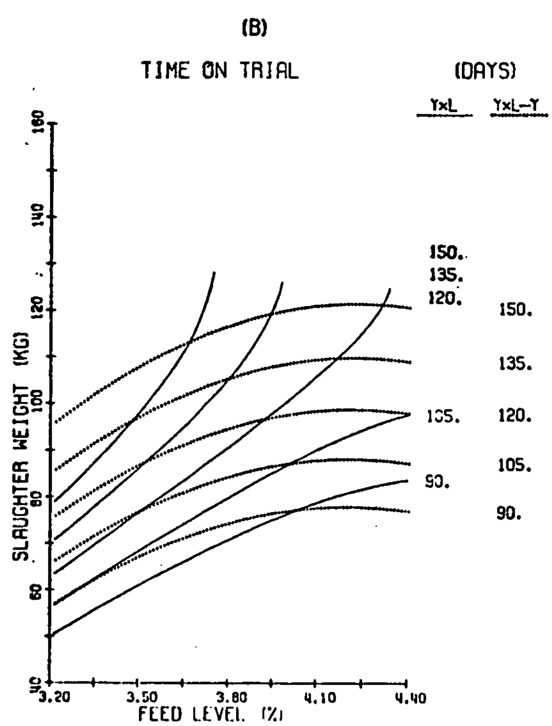
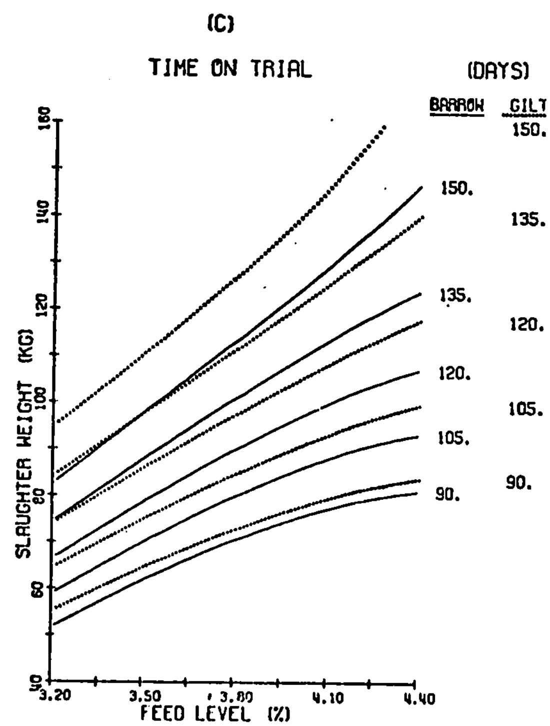


Figure 1. Isoquants for days on trial showing the combinations of feed level and slaughter weight estimated to produce slaughter pigs in 90, 105, 120, 135 and 150 days. Isoquants are shown for the overall experiment (a), for the YL and YLY breed groups (b), and for barrows and gilts (c).

Plot	R^2	S.E.
Overall	0.786	17.8
YL	0.812	19.2
YLY	0.854	13.9
Barrows	0.795	19.5
Gilts	0.851	14.4





shows the isoquants for days on trial. The regression equations on which the isoquants are based are given in the Appendix table 1.

Considering the overall experiment isoquants in figure 1 (a) it can be seen that as the level of feeding increases fewer days are required for pigs to reach a given slaughter weight.

Figure 1 (b) suggests that there are differences between breed groups in their response to changes in feed level and slaughter weight. However, there was no significant three way interaction between slaughter weight, feed level and breed group in the analysis of variance. The isoquants in 1 (c) indicate that in a given number of days gilts will achieve a higher weight than barrows thus illustrating the sex effects on daily gains noted in Table 14.

(c) Feed conversion ratios

Means for feed consumed per kg liveweight gain are shown in Table 16. The feed consumed per kg liveweight gain did not differ between the 4.2 and 3.7 per cent feeding levels during any period, but in the first period and from initial to slaughter the 3.2 per cent fed pigs were less efficient than those fed at higher levels ($P < 0.01$). The significant reduction in feed efficiency observed in lowering the feed level to 3.2 per cent in the first period together with a non-significant reversal of this effect in the final period tends to support the finding of Blair, Dent, English and Raeburn (1969) that reduced feed intake decreased feed efficiency in pigs between 22 and 45 kg while the reverse trend occurred in heavier pigs.

Taken over the whole experiment feed conversion to liveweight gain became less efficient as slaughter weight increased ($P < 0.05$).

Table 16. Means of feed conversion ratios (kg feed per kg liveweight gain) by feed level, slaughter weight, breed and sex.

Period	Feed level			Slaughter weight			Breed		Sex	
	4.2	3.7	3.2	68	91	114	YL	YLY	B	G
Initial to 45 kg	3.04^{A}[1]	3.10^{A}	3.86^{B}	3.32	3.38	3.30	3.44	3.23	3.46^{a}	3.20^{b}
45 to 68 kg	3.39^{AB}	3.22^{B}	3.64^{A}	3.43	3.38	3.45	3.39	3.45	3.55^{a}	3.29^{b}
68 to 91 kg	3.93	3.90	4.04		4.14	3.77	4.05	3.86	4.05	3.85
91 to 114 kg	5.43	5.31	4.65			5.13	4.96	5.31	5.43	4.84
Initial to slaughter	3.57^{A}	3.48^{A}	3.88^{B}	3.38^{aA}	3.62^{bA}	3.93^{cB}	3.66	3.63	3.78^{A}	3.51^{B}

1. Means having different superscripts within the same treatment classification differ significantly at $P<0.05$ (a,b,c) and $P<0.01$ (A,B,C).

This result is in agreement with work conducted by O'Grady (1966) who found that as slaughter weight increased from 81 through 88 to 95 kg, overall feed efficiency declined.

The trend for barrows to require more feed per unit liveweight gain was significant from initial to slaughter weight and for the first two periods when all 72 pigs contributed to the means ($P < 0.05$). Superior conversion in gilts has been reported by Charette (1961), Lucas, Livingstone and McDonald (1962) and Bell (1963) but was not found in other studies (O'Grady, 1966; Holme and Coey, 1967). The lack of agreement in this area could be due to breed or differences in the level of feeding used.

Interactions among main effects on feed conversion ratios are shown in Table 17. In the period of 45 to 68 kg liveweight and from initial to slaughter weight barrows from the YL breed group were less efficient than the gilts but the same difference was not observed in the YLY breed group (Table 17 a, b).

In the period of 45 to 68 kg liveweight and from initial to slaughter weight pigs from the YL breed group tended to be more efficient than those from the YLY breed group on the 4.2 and 3.7 per cent feed levels while YL pigs were less efficient on the 3.2 per cent feeding level. This interaction is closely related to the interaction of breed group and level of feeding on liveweight gain for the same two periods (Table 15 b, c) where a trend for the YL pigs to grow faster than the YLY pigs on the 4.2 and 3.7 per cent feeding levels was reversed on the 3.2 per cent level.

The two factors used to derive feed conversion ratios are the weight of feed consumed and the liveweight gained. The regression

Table 17. Interactions among main effects on feed conversion ratios.

(a) Interaction (P<0.005) of sex and breed on feed conversion ratio between 45 and 68 kg liveweight.

Breed group	Sex B	Sex G
YL	3.68	3.09
YLY	3.42	3.48

(b) Interaction (P<0.05) of sex and breed on feed conversion ratio between initial and slaughter weight.

Breed Group	Sex B	Sex G
YL	3.91	3.41
YLY	3.65	3.61

(c) Interaction (P<0.01) of breed group and level of feeding on feed conversion ratio between 45 and 68 kg liveweight.

Breed Group	Feed level 4.2	3.7	3.2
YL	3.27	3.04	3.86
YLY	3.52	3.40	3.43

(d) Interaction (P<0.005) of breed group and level of feeding on feed conversion ratio between initial and slaughter weight.

Breed Group	Feed level 4.2	3.7	3.2
YL	3.52	3.39	4.07
YLY	3.61	3.58	3.69

equations giving the quantitative relationships between feed consumed, weight gained and feeding level and slaughter weight are given in Appendix table 1. The R^2 values for these relationships were 0.896 and 0.995 for feed consumed and weight gained respectively.

(ii) Analyses of variance and response surface studies of carcass characteristics

(a) Carcass composition and grade index

Means of main effects on carcass composition characteristics and grade index are shown in Table 18.

There was a trend for total muscle weight to increase as the level of feeding decreased and pigs fed at the 3.2 per cent level contained more muscle than those fed the higher levels ($P < 0.01$). Total fat weight tended to decrease as level of feeding decreased and pigs fed at the 4.2 per cent level contained more fat than those fed at the 3.2 per cent level ($P < 0.01$). Similar results applied in the weights of muscle and fat gained during the experiment. Tribble et al (1956) and Holder, Wilson and Williams (1969) reported that feed restriction increased carcass muscle content. In a literature review, Vanschoubroek, de Wilde and Lampo (1967) concluded that while restriction reduced linear fat measurements, the decreases in thickness of backfat became relatively smaller as restriction became more intense. O'Grady (1966) reported that in one of two experiments, increasing the level of feeding by 15 per cent above that of a control which steadily decreased from 4.6 per cent of liveweight at 23 kg to 2.9 per cent of liveweight at 100 kg, resulted in carcasses having increased linear measures of carcass fatness. However, in a second

Table 18. Means of carcass characteristics (kg or kg per day) by feed level, slaughter weight, breed and sex.

Characteristic	Feed level			Slaughter weight			Breed		Sex	
	4.2	3.7	3.2	68	91	114	YL	YLY	B	G
Total muscle	30.00^{A} [1]	30.22^{A}	31.56^{B}	23.40^{A}	30.86^{B}	37.52^{C}	29.91^{A}	31.27^{B}	29.78^{A}	31.40^{B}
Total muscle gained	21.38^{A}	21.67^{A}	23.16^{B}	15.00^{A}	22.30^{B}	28.91^{C}	21.38^{A}	22.75^{B}	21.32^{A}	22.82^{B}
Muscle gained/day	0.209^{A}	0.181^{B}	0.145^{C}	0.166^{A}	0.183^{B}	0.186^{B}	0.176	0.181	0.168^{A}	0.188^{B}
Wt. feed/wt. muscle gained	10.98	10.69	11.32	10.06^{A}	10.78^{A}	12.15^{B}	11.36^{a}	10.63^{b}	11.78^{A}	10.22^{B}
Total fat	21.03^{A}	19.63^{AB}	18.26^{B}	11.68^{A}	19.04^{B}	28.20^{C}	19.77	19.50	20.84^{A}	18.44^{B}
Total fat gained	17.48^{A}	16.13^{AB}	14.89^{B}	8.31^{A}	15.54^{B}	24.66^{C}	16.30	16.04	17.42^{A}	14.91^{B}
Fat gained/day	0.162^{A}	0.130^{B}	0.091^{C}	0.094^{A}	0.128^{B}	0.162^{C}	0.132	0.124	0.137^{A}	0.118^{B}
Total bone	5.10	5.15	5.27	4.10^{A}	5.20^{B}	6.22^{C}	5.08^{a}	5.27^{b}	5.06^{A}	5.29^{B}
Grade Index	92.8	93.7	95.3	87.0^{aA}	105.4^{bB}	89.4^{cA}	93.6	94.2	93.4	94.4

1. Means having different superscripts within the same treatment classification differ significantly at $P<0.05$ (a,b,c) and $P<0.01$ (A,B,C).

experiment using the same two feeding levels, increased feeding level had no effect on carcass composition.

As expected, muscle and fat gained per day consistently and significantly decreased ($P < 0.01$) as the level of feeding decreased. The daily gains of muscle are very similar to those obtained on 4 levels of restricted feeding over the same liveweight ranges by Blair, Dent, English and Raeburn (1969).

The weight of feed consumed per unit muscle gained was not affected by feeding level. However, in each of the liveweight ranges of 23 kg to 45, 68 and 91 kg, Blair, Dent, English and Raeburn (1969) found a significant increase in the weight of feed consumed per unit weight of muscle gained as the level of feeding increased but the same trend was not significant in the range of 23 to 114 kg.

Grade index was not significantly altered by level of feeding although total muscle content of the 3.2 per cent fed pigs was higher than from pigs fed at the higher levels.

As expected, weights of tissues and tissue weights gained from initial weight to slaughter increased as slaughter weight increased. Weight of fat gained per day consistently and significantly ($P < 0.01$) increased as slaughter weight increased and this trend was also present in calculations done on the data presented by Brooks et al (1964). However, the trend for increasing rate of fat deposition with increasing slaughter weight was not present in calculations done on data presented by O'Grady (1966) and Stant et al (1968).

The weight of muscle gained per day to 114 kg was not significantly different to that gained per day to 91 kg. Calculations made on the data in the report by O'Grady (1966) indicated that muscle gained per day from 23 kg to slaughter was little affected by increasing the slaughter weight from 81 through to 102 kg. On the restricted feeding schedules used by Blair, Dent, English and Raeburn (1969) daily gain in lean tended to increase as slaughter weight increased to 45, 68, 91 and 114 kg. Recalculations of the data of Stant et al (1968) indicated a trend for decreasing lean gain per day as slaughter weight increased from 45 to 68 to 91 kg and calculations done on the data published by Brooks et al (1964) suggested that in their study the daily gains in lean had peaked between 68 and 91 kg liveweight.

The weight of feed consumed per unit weight of muscle gained tended to increase as slaughter weight increased with pigs slaughtered at 114 kg requiring significantly ($P < 0.01$) more feed per unit muscle gained than those killed at lower weights. Similar trends towards increased consumption of feed per unit weight of muscle gained were reported by Blair, Dent, English and Raeburn (1969) and were evident in calculations done on data presented by Brooks et al (1964) and O'Grady (1966).

Pigs killed at 91 kg had significantly ($P < 0.01$) higher grades than those killed at lower and higher weights. The grading system schedule (Appendix table 2) is arranged to encourage production of pigs having carcass weights between 57 and 82 kg. Because of this, all carcasses from pigs slaughtered at 68 kg liveweight were assessed at an index of 87 regardless of backfat depth. Of the 24 pigs allocated to the slaughter weight of 114 kg, 11 and 12 could not be assessed at more than an index of 91 and 85 respectively. On the other hand, pigs from the slaughter weight group of 91 kg could score a minimum index of 88 provided there were no demerits. Because all pigs slaughtered at 68 kg were assessed at an index of 87, pigs from that weight group were excluded from the data used to calculate the regression equations relating grade index to feeding level and slaughter weight given in Appendix table 1.

Pigs from the YL breed group contained less muscle and gained less muscle than YLY pigs ($P < 0.01$) and also had less bone ($P < 0.05$). The YL breed group pigs required more feed per unit weight of muscle gained than did YLY breed group pigs ($P < 0.05$). While there were breed effects on muscle weight there was no significant effect of breed on grade index although there was a trend for YLY to have slightly higher indices than carcasses from the YL breed group.

Barrows contained less and gained less muscle ($P < 0.01$) than gilts and contained more and gained more fat ($P < 0.01$) than gilts. The greater rate of muscle deposition in the gilts ($P < 0.01$) agrees with trends found by Blair, Dent, English and Raeburn (1969) as does the requirement by gilts of less feed per unit weight of muscle gained ($P < 0.01$). Despite the sex difference in muscle and fat content there was no significant effect of sex on grade index although there was a trend for gilts to have a higher index than barrows.

Interactions among main effects on carcass composition characteristics are shown in Table 19. A trend for continued increase in muscle gained per day on the 3.2 per cent feeding level as slaughter weight increased was not present on the higher feeding levels (Table 19 a). The continued increase in muscle gained per day on the 3.2 per cent feeding level as opposed to the relative constancy on the 4.2 per cent feeding level may possibly be related to the maintenance by 3.2 per cent fed pigs of a constant level of feeding as slaughter

Table 19. Interactions among main effects on carcass composition characteristics.

(a) Interaction ($P < 0.05$) of slaughter weight and level of feeding on muscle gained per day.

Feed level	Slaughter weight 68	91	114
4.2	0.207	0.215	0.204
3.7	0.163	0.192	0.189
3.2	0.128	0.142	0.167

(b) Interaction ($P < 0.05$) of breed group and level of feeding on muscle gained per day.

Breed group	Feed level 4.2	3.7	3.2
YL	0.213	0.182	0.134
YLY	0.205	0.180	0.157

(c) Interaction ($P < 0.05$) of breed group and level of feeding on total fat weight.

Breed group	Feed level 4.2	3.7	3.2
YL	21.04	19.81	18.46
YLY	21.02	19.44	18.05

(d) Interaction ($P < 0.05$) of breed group and slaughter weight on total fat weight.

Breed group	Slaughter weight 68	91	114
YL	11.41	20.37	27.54
YLY	11.94	17.71	28.86

(e) Interaction ($P < 0.05$) of sex and level of feeding on fat gained per day

Sex	Feed level 4.2	3.7	3.2
B	0.181	0.140	0.091
G	0.143	0.120	0.090

weight increased while on the 4.2 per cent feeding level the realized level of feeding decreased as slaughter weight increased (Table 13 d).

A trend for YLY pigs to gain more muscle per day than the YL pigs on the 3.2 per cent feeding level was not present on the other feeding levels (Table 19 b). This closely followed the interaction between breed group and level of feeding on daily liveweight gains (Table 15 c) in which YLY pigs grew faster than the YL pigs on the 3.2 per cent level but not on the higher levels.

As the level of feeding decreased there was an increasing trend for YLY pigs to have less fat than YL pigs (19 c). While YLY pigs slaughtered at 91 kg had less fat than YL pigs, the reverse trend was apparent at other slaughter weights (Table 19 d). Although the effect of feed level on fat gained per day was the opposite to that of muscle gained per day, there was an interaction such that the difference between barrows and gilts decreased as the level of feeding decreased (Table 19 e).

Figure 2 shows the isoquants for total carcass muscle weight. Considering the overall experiment isoquants (a) it can be seen that as the level of feeding increases pigs have to be taken to a higher slaughter weight to maintain a given output of total carcass muscle. The increase in slaughter weight required to maintain a given weight of muscle appeared to become larger as slaughter weight increased but there was no significant interaction of feeding level and slaughter weight on total muscle weight in the analysis of variance.

Considering the within breed diagram (b) it can be seen that the general response in terms of muscle weight is similar for both breeds and appeared to become more so as level of feeding increased. However,

(a)

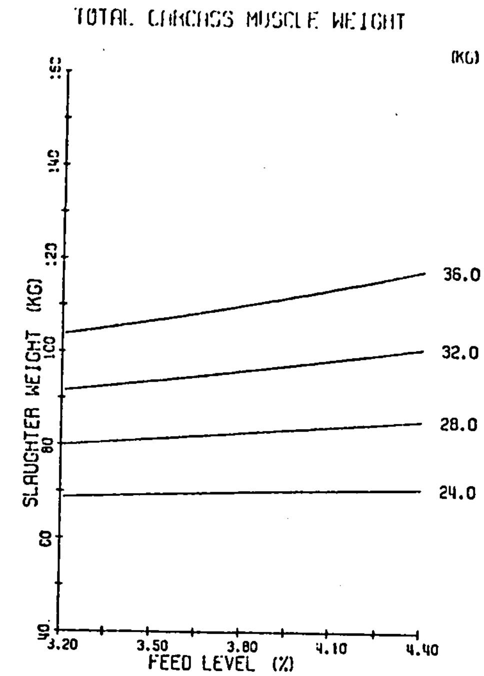
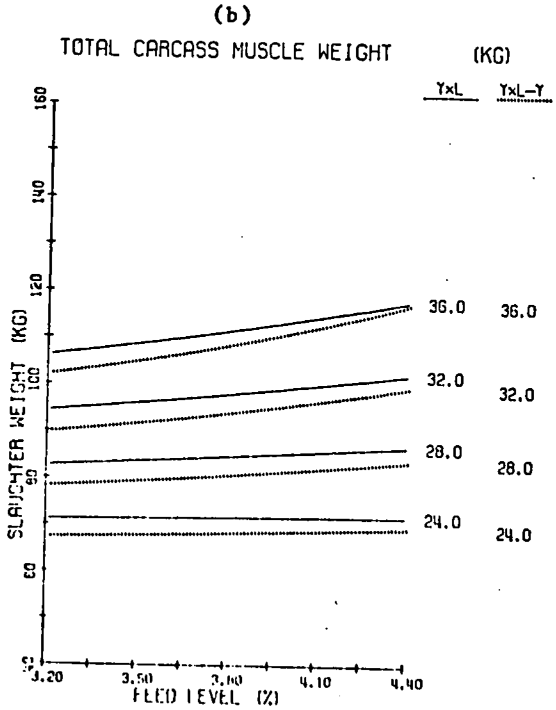


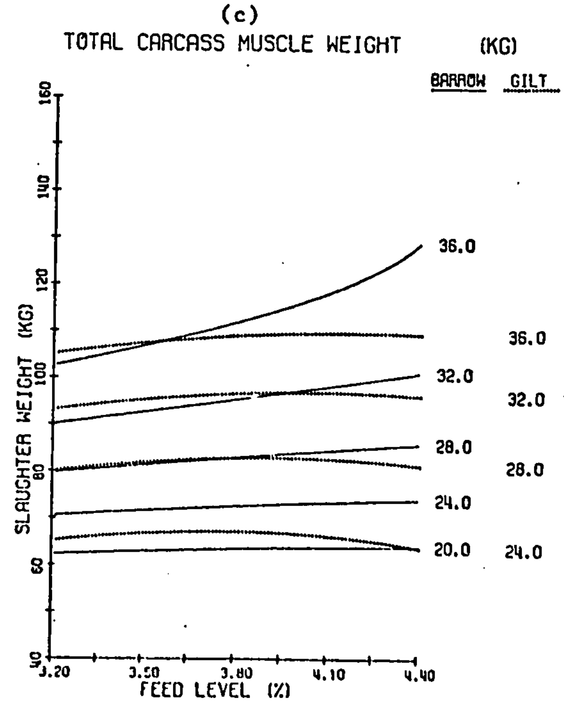
Figure 2. Isoquants for total carcass muscle weight showing the combinations of feed level and slaughter weight estimated to produce 20, 24, 28, 32 and 36 kg of muscle in pig carcasses. Isoquants are shown for the overall experiment (a), for the YL and YLY breed groups (b), and for barrows and gilts (c).

Plot	R^2	S.E.
Overall	0.932	1.66
YL	0.959	1.31
YLY	0.921	1.91
Barrows	0.958	1.36
Gilts	0.941	1.56

(b)



(c)



in the analysis of variance the interaction between slaughter weight, feed level and breed was not significant. The YL pigs required feeding to a higher slaughter weight in order to yield the same weight of muscle as YLY pigs.

Sex effects were quite marked. To maintain a given output of muscle weight, barrows had to be slaughtered at heavier weights as the level of feeding increased and this effect appeared to become more pronounced as slaughter weight increased. The isoquant estimates indicated that at low slaughter weights barrows had less muscle than gilts but as slaughter weight increased barrows had slightly more muscle than gilts at low levels of feeding and less muscle than gilts as feeding level increased. However, the analysis of variance revealed no significant interaction of feeding level, slaughter weight and sex.

The isoquants for total muscle gained were very similar to those for total carcass muscle except that they were lower by the amount of muscle estimated to be in the pigs at the time they were placed on experiment. Isoquants for weight of muscle gained are in Appendix figure 1.

Figure 3 shows the isoquants for total carcass fat weight. In the overall diagram (a) it can be seen that to maintain a given weight of fat in a carcass as feeding level increases requires a reduction in the slaughter weight or the opposite of the situation found with total carcass muscle weight.

The separate breed group plots (b) indicate that at slaughter weights below 110 kg, YLY pigs could be taken to a higher slaughter weight than YL pigs but yield the same amount of fat and that this

(a)

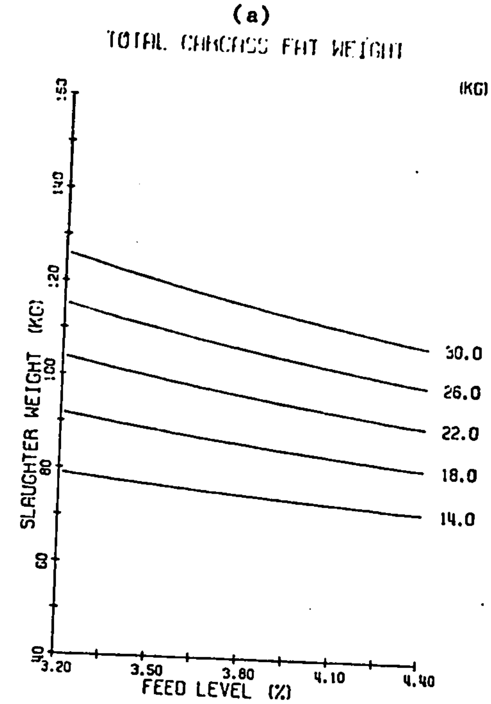
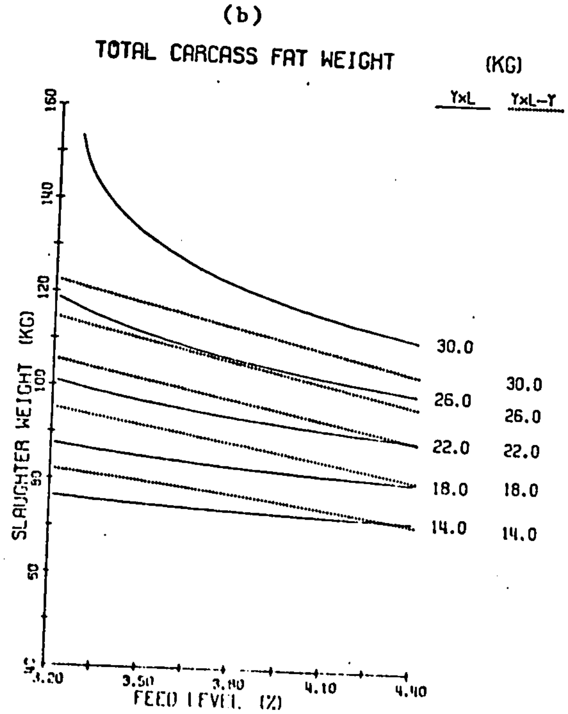


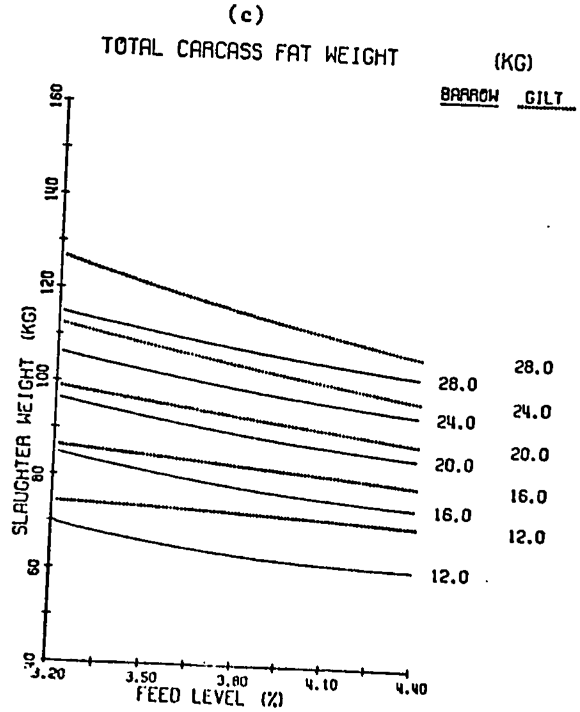
Figure 3. Isoquants for total carcass fat weight showing the combinations of feed level and slaughter weight estimated to produce 12, 14, 16, 18, 20, 22, 24, 26, 28 and 30 kg of total carcass fat weight. Isoquants are shown for the overall experiment (a), for the YL and YLY breed groups (b), and for barrows and gilts (c).

Plot	R^2	S.E.
Overall	0.856	2.96
YL	0.868	2.84
YLY	0.877	2.98
Barrows	0.880	2.94
Gilts	0.881	2.64

(b)



(c)



effect disappeared at the high level of feeding. This plot illustrates the interaction among breed group and feeding level on fat weight discussed previously (Table 19 c).

Analysis of variance showed a significant ($P < 0.01$) effect of sex on fat weight and this effect is clearly shown in the sex effect diagram (c). At any slaughter weight across all feeding levels, gilts had less fat than barrows.

Isoquants for total fat gained are in the appendix figure 2.

Figure 4 shows the isoquants for total bone weight. In the overall diagram (a) it can be seen that as level of feeding increases the maintenance of a given bone weight requires slaughter at an increased slaughter weight.

The significant ($P < 0.05$) breed effect on total bone weight detected in the analysis of variance (Table 18) is shown in the breed diagram (b) where it can be seen that the YLY breed group attain a given bone weight at a lower slaughter weight than the YL breed group pigs.

Diagram (c) shows the significant ($P < 0.01$) effect of sex on bone weight detected in analysis of variance. At any given slaughter weight gilts tended to have more bone than barrows.

(b) Predictors of carcass composition

Treatment means of effects of feed level, slaughter weight, breed and sex on carcass characteristics are shown in Table 20. The characteristics shown are those used as predictors of carcass muscle in section I together with actual total muscle weight and total muscle weight predicted using two techniques developed in section I.

The results of using prediction equations to estimate total

(a)

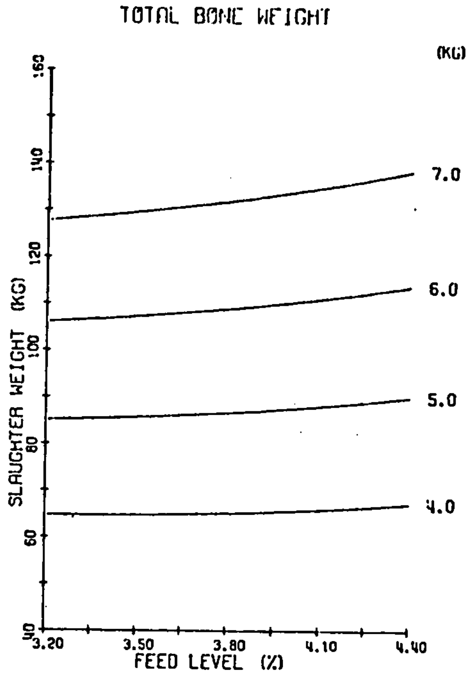
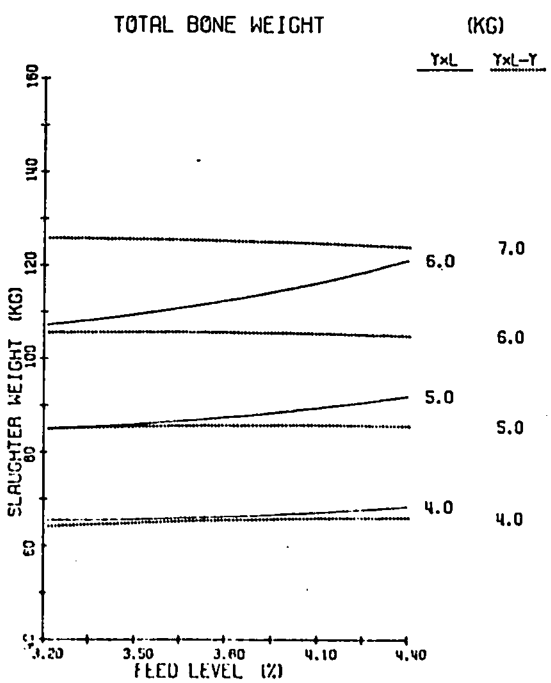


Figure 4. Isoquants for total bone weight showing the combinations of feed level and slaughter weight estimated to produce 3, 4, 5, 6 and 7 kg of bone in pig carcasses. Isoquants are shown for the overall experiment (a), for YL and YLY breed groups (b), and for barrows and gilts (c).

Plot	R^2	S.E.
Overall	0.891	0.32
YL	0.848	0.39
YLY	0.954	0.22
Barrows	0.888	0.34
Gilts	0.923	0.28

(b)



(c)

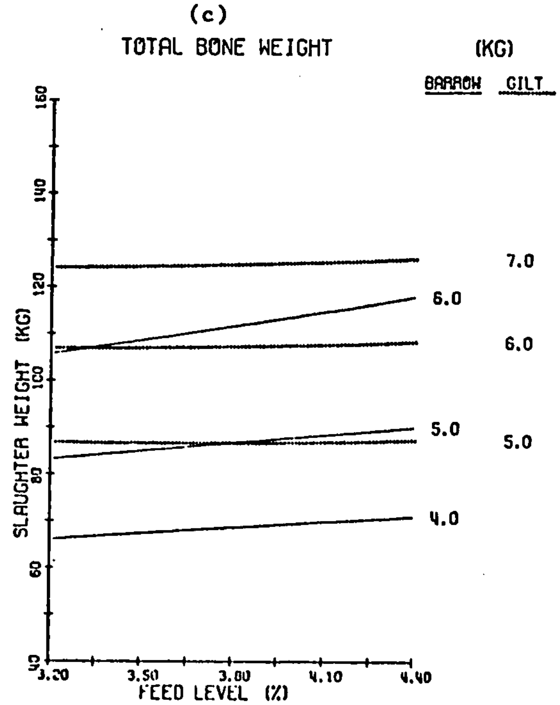


Table 20. Means of total muscle, predicted total muscle and predictors of total muscle by feed level, slaughter weight, breed and sex.

Characteristic		Feed level			Slaughter weight			Breed		Sex	
		4.2	3.7	3.2	68	91	114	YL	YLY	B	G
Total muscle	kg	30.00^{A}[1]	30.22^{A}	31.56^{B}	23.40^{A}	30.86^{B}	37.52^{C}	29.91^{A}	31.27^{B}	29.78^{A}	31.40^{B}
Estimated muscle Equation no. 1	kg	29.93^{aA}	30.34^{aAB}	31.17^{bB}	23.52^{A}	30.37^{B}	37.55^{C}	30.28	30.67	30.03^{A}	30.92^{B}
Equation no. 7	kg	29.97^{aA}	30.40^{aAB}	31.41^{bB}	23.38^{A}	30.95^{B}	37.46^{C}	29.91^{A}	31.27^{B}	30.00^{A}	31.19^{B}
Hot carcass weight	kg	70.41^{a}	69.16^{a}	68.68^{b}	50.52^{A}	69.39^{B}	88.34^{C}	68.85^{a}	69.98^{b}	69.46	69.37
Total backfat	mm	70.42^{aA}	64.46^{bB}	59.21^{cB}	53.12^{A}	64.83^{B}	76.12^{C}	65.64	63.75	67.36^{A}	62.03^{B}
Cavity fat	g	731.6	724.9	629.6	397.9^{A}	661.6^{B}	1026.6^{C}	699.7	721.1	744.2^{a}	646.5^{b}
Loin eye area	sq.cm	29.50^{a}	29.22^{a}	31.59^{b}	25.82^{A}	30.06^{B}	34.43^{C}	29.53	30.68	29.06^{A}	31.15^{B}
Ham muscle area	sq.cm	133.2^{a}	133.9^{a}	140.4	113.0^{A}	142.2^{B}	152.5^{C}	136.0	135.8	136.2	135.6
M. gracilis	g	152.9	153.0	149.9	115.8^{A}	152.9^{B}	187.1^{C}	150.7	153.1	145.7^{A}	158.1^{B}
Distal hind muscles [2]	g	611.7	609.6	612.8	487.1^{A}	628.9^{B}	718.1^{C}	605.6	617.1	606.1	616.6
Three large hind muscles [3]	g	2081^{A}	2081^{A}	2190^{B}	1612^{A}	2152^{B}	2589^{C}	2099	2145	2075^{A}	2160^{B}

1. Means having different superscripts within the same treatment classification differ significantly at $P<0.05$ (a,b,c) and $P < 0.01$ (A,B,C).
2. Butterfield (1963)
3. (M. biceps femoris, m. semimbranosus + m. semitendinosus)

carcass muscle reflected the accuracy of the two techniques. The more accurate technique was the use of equation number 7 within the breed group from which it was derived and in section I it was shown that this technique gave R^2 values of 0.982 and 0.972 on the YLY and YL breed groups respectively. Equation number 1 developed for each breed group and then applied to the other breed group produced R^2 values of 0.942 and 0.927 on the YLY and YL breed groups respectively. Although the standard errors of the actual dissection treatment means are not given in Table 20 it was found that the use of equation number 7 for estimating carcass muscle content yielded treatment means which all fell within $\pm$ one standard error of the actual main effect treatment means. In the case of the less accurate cross-validated equation number 1, half of the estimated treatment means were outside the range of $\pm$ one standard error of the main effect treatment means.

Had a significance level of 5 per cent been rigidly adhered to in assessing main effects of treatments the use of prediction equation number 7 would have given the same classification of treatment effects as use of the actual muscle dissection data. Apart from underestimating the significance of the breed effect, use of equation number 1 would have given almost comparable results even though half of the estimated treatment means fell outside $\pm$ one standard error of the actual means of treatment main effects.

Interactions of treatments were indicated by both equations although no interactions were indicated in analysis of the actual data (Table 21 a, b). Both equations indicated an interaction ($P < 0.01$) of sex and level of feeding on total muscle weight and in both cases the interactions appeared to result from a smaller difference between

Table 21. Interactions among main effects on predictors and predictions of carcass muscle weight.

(a) Interaction ($P < 0.01$) of sex and level of feeding on total muscle weight estimated by use of equation number 1.

	Feed level		
Sex	4.2	3.7	3.2
B	28.80	31.12	30.50
G	30.18	31.05	31.22

(b) Interaction ($P < 0.01$) of sex and level of feeding on total muscle weight estimated by use of equation number 7.

	Feed level		
Sex	4.2	3.7	3.2
B	28.63	31.22	30.67
G	30.14	31.30	31.60

(c) Interaction ($P < 0.05$) of sex and slaughter weight on total muscle weight estimated by use of equation number 7.

	Slaughter weight		
Sex	68	91	114
B	22.37	30.94	36.67
G	24.38	30.95	38.24

(d) Interaction ($P < 0.05$) of sex and level of feeding on total backfat depth.

	Feed level		
Sex	4.2	3.7	3.2
B	76.50	66.17	59.42
G	64.33	62.75	59.00

(e) Interaction ($P < 0.005$) of breed group and sex on loin eye area.

	Breed group	
Sex	YL	YLY
B	29.64	28.48
G	29.42	32.87

sexes on the 3.7 per cent feeding level than on the other two feeding levels. When the estimated subplot means were compared with the actual subplot means ± one standard error, it was found that 2 and 4 of the 6 means fell within this range when estimated by use of equations 1 and 7 respectively. Further to this, an interaction ($P < 0.05$) between sex and slaughter weight on total muscle weight estimated by using equation number 7 was indicated even though all interaction means fell within ± one standard error of the interaction means of the actual dissected total muscle weight (Table 21 c).

Loin eye area, ham muscle area and the three large hind muscles, three characteristics previously found to be positively correlated with carcass muscle weight, were significantly ($P < 0.05$, 0.05 and 0.01 respectively) affected by feed level in the same way as was total muscle weight (Table 20). Harrington (1963) suggested that instead of using a prediction equation to estimate the magnitude of treatment effects on the predictant it may be wise to go no further than saying, for instance, that "there was a significant difference in X (predictor) between treatments, which implies a real difference in Y (predictant)". Thus, this approach would have been appropriate for loin area, ham muscle area and the three large hind muscles. However, m. gracilis and the distal hind muscles were not affected by feeding level and it would have been misleading to have used this absence of effect as implying that feed level did not have an effect on total muscle weight.

A significant ($P < 0.01$) reduction in total backfat in the 3.7 per cent feeding level relative to that found in pigs fed at the 4.2 per cent level implied a difference in muscle content present, but not significant, in analysis of treatment effects on total muscle weight

(Table 20).

An interaction ($P < 0.05$) between sex and level of feeding on depth of total backfat is shown in Table 21 such that differences between sexes decreased with feeding level. Such an interaction was not found with total carcass muscle weight but it was found in both fat gained per day (Table 19 e) and realized level of feeding (Table 13 b) that the difference between barrows and gilts decreased as the level of feeding decreased. The interaction of decrease in difference in realized feeding level between sexes as the nominal feeding level decreased may have produced the interactions in total backfat depth and fat gained per day as well as the non-significant trend for decreased differences in fat and muscle weight between sexes as the feeding level decreased.

A breed effect on total muscle weight ($P < 0.01$) was appropriately reflected in the hot carcass weight ($P < 0.05$) but no other predictors were affected by breed (Table 20). An interaction ($P < 0.05$) of breed group and sex on loin eye area (Table 21 c) was not reflected by a similar interaction of these treatment on total carcass muscle weight.

All predictors except ham muscle area and distal hind muscles were significantly ($P < 0.05$ and 0.01 respectively) affected by sex in such a way as to imply that barrows had less muscle than gilts which was found to actually be the case in the analysis of sex effect ($P < 0.01$) on total muscle weight (Table 20).

While there were cases where appropriate inferences about treatment effects on total muscle could be made by discussing the treatment effect on predictors, there were other occasions where the implications would have been misleading. Harrington (1963) pointed out that the use of a predictor as an index of the effect of treatments on the predictant implies that the relationship between the predictor and the predictant is the same over all treatments. Wilson (1968) found that nutritional treatment had a significant effect on the relationship between individual muscles and total muscle in the pig and also that these relationships were affected by sex (Wilson, 1966, 1968). Studies with cattle have suggested that different treatments require different prediction equations (Seebeck and Tulloh, 1969).

The quantitative relationships established between inputs and outputs will be used in section III in an economic analysis. In the estimation of such relationships, Dillon (1968) drew attention to the need to use a spread of feeding levels, stressing the need to take account of sub ad libitum feeding treatments. While sub ad libitum intakes were deliberately used in this experiment it is not likely that the highest feeding level used closely approached ad libitum intakes.

The conventional measures of performance indicated that the highest feeding level produced the greatest daily gains and thus this level would enable a greater output of pigs from a given set of facilities in a year. The highest muscle content was achieved by pigs fed at the lowest feeding level but these were the least efficient in converting feed to liveweight gain. However, conversion of feed to muscle weight gain was not significantly affected by level of feeding. Due to the bias in the grade index the 91 kg slaughter weight produced the highest carcass indices. However, the grade index did not reflect the higher lean content of gilts nor the higher muscle content of pigs fed at the 3.2 per cent feeding level.

Gilts tended to grow faster than barrows while barrows tended to achieve a higher daily feed intake. Barrows were less efficient than gilts in converting feed to liveweight gain and muscle gain and gilts gained more muscle per day than barrows.

The conventional measures of performance suggested that there were differences due to breed group, sex, slaughter weight and level of feeding. The importance of these effects in pig production can only be realistically assessed by putting economic weights on the various measures of performance and this will be done in section III.

III. THE USE OF ACTUAL PERFORMANCE RECORDS AND PREDICTED PERFORMANCE IN AN ECONOMIC EVALUATION OF THE PIG PRODUCTION EXPERIMENT

A. Introduction

To assist in putting together the pieces of production (daily gains, feed conversion ratios, carcass grade etc.) increasing attention is being given to economic analyses of the results of pig production studies (see for examples, Bellis and Taylor, 1961; Braude, Townsend and Harrington, 1963; Frape, Wolf, Wilkinson and Chubb, 1968; Battese, Duloy, Holder and Wilson, 1968; Frape, Wilkinson, Chubb and Wolf, 1970; Harris, 1970).

The performance records for each pig on the current experiment were used in an economic analysis with the objectives of determining the returns to management and returns to management per pen space per year under conditions of high, medium and low feed costs and high, average and low market prices for carcasses. With the objective of making the analysis relevant to Alberta conditions, a provincial hog enterprise analysis (Hackett and Reddon, 1967) was used as the basis for the economic analysis. A similar analysis, but restricted to medium feed cost and average carcass values, was done using regression equations relating inputs and outputs developed in section II.

Preliminary analyses (Richmond, Berg and Wilson, 1970) indicated that carcasses from pigs slaughtered at 91 kg liveweight received a higher grade than those from pigs slaughtered at 68 or 114 kg when scored under Canada's new hog valuation system (Canada Department of Agriculture, 1968). A further objective of this section was to examine the influence that this bias could have on return per pen space per year by valuing muscle from all carcasses at the mean price paid per kg of muscle from pigs slaughtered at 91 kg liveweight.

It was pointed out in section II that the hog valuation system was designed to encourage production of pigs yielding hot carcass weights between 57 and 82 kg. A final objective of this section was to draw up a grading system schedule which would ignore the present bias and pay producers for the quantity of muscle or of muscle plus intermuscular fat in the carcass.

B. Methods

(i) Description of terms used in the Alberta Hog Enterprise Analysis and adjustments made for the current economic analysis

The Economics and Animal Industry Divisions of the Alberta Department of Agriculture prepare an annual hog enterprise analysis. The 1968 analysis (mimeo, Anon) was based on 21 farms selected from a larger sample on the basis of accuracy and completeness of records. The economic analysis in this thesis was based on the records of the 7 high production hog feeder enterprises in that sample which sold an average of 848 hogs per year. (The description of terms used are given in greater detail on pages 4 - 6 of Hackett and Reddon, 1967).

The average costs and returns per 100 pounds (45.5 kg) liveweight gain are given in Table 22.

a) Gross returns

Gross return is equal to the value of hogs produced by the enterprise and is calculated as follows:

Value received for all hogs sold during the year, plus market value of hogs on inventory at the end of the year, plus market value of hogs slaughtered for home use, less value paid for hogs purchased during the year, less market value of hogs on inventory at the beginning of the year. The gross return for the enterprise has been divided by the hundredweights (45.4 kg) of production to determine gross return per unit of output.

It will be noted that the gross return of $18.01 given in

Table 22. Cost and return details of the high production group of farms reported in the 1968 Alberta Hog Enterprise Analysis. The figures given are on the basis of costs and returns per hundred pounds (45.4 kg) of liveweight gain produced in hog operations in which weaneers are purchased and fed to market weight.

<u>Gross return</u>	
Sales	
Average weight per head (lb)	199 (90.3 kg)
Average value per head	$43.43
Purchases	
Average weight per head (lb)	42 (19.1 kg)
Average value per head	$16.12
Gross return	$18.01
<u>Operating expenses</u>	
Total feed cost	$11.11
Veterinary and medicine	$ 0.22
Other direct	$ 0.05
Other variable	$ 0.80
Total variable cost	$12.18
<u>Overhead expenses</u>	
Depreciation and insurance	$ 1.31
Interest on buildings and equipment @ 6%	$ 0.71
Interest on livestock @ 6%	$ 0.43
Total overhead expenses	$ 2.45
<u>Labour cost</u>	
0.84 hours at $1.45 per hour	$ 1.22
Total production cost	$15.85
Return over variable cost	$ 5.83
Return to labour, management and investment	$ 4.52
Return to labour and management	$ 3.38
Return to management	$ 2.16

Table 22 is not simply the value of the hog sold less the value of the weaner purchased expressed on a per hundredweight (45.4 kg) basis. This is due to factors such as inventory changes and slaughterings for home use.

In the current analysis gross return has been calculated as the value of the pig sold less the cost of the purchased weaner valued at the weight at which individual pigs were placed on experiment.

Carcass value was calculated in two ways:

(1) Grade index method. The product of the grade index and hot carcass weight was multiplied by one of three prices per 100 pounds of hot carcass of grade index 100. The three market prices were:

$36.00 (highest price paid in 1970)

$28.37 (average price paid in 1970)

$20.00 (lowest price paid in 1970)

These prices were supplied by the Alberta Hog Producers Marketing Board.

(In the actual computations used in this study the market prices used were $0.79, $0.62 and $0.44 per kg of hot carcass weight corresponding to the highest, average and lowest price of 1970).

(2) Muscle content method. The total muscle weight of all carcasses determined from actual values was multiplied by the average price paid per kg of muscle in pigs slaughtered at 91 kg.

The prices paid for weaners were calculated by a formula provided by Mr. Art Reddon, Livestock Supervisor, Swine, of the Animal Industry Division of the Alberta Department of Agriculture. The formula provided was:

$$\text{Weaner price} = \frac{(\text{market price for 100 grade index})}{2} + \$1.00 + \$0.20 \text{ per lb in excess of 30 lb.}$$

Calculations of weaner prices were made on the assumption that the market price at which the feeder pig was sold was the market price in operation at the time the weaner was purchased.

In the actual computations used in this study the cost of a weaner was derived from:

$$22.7 \times \text{market price/kg} + \$1.00 + \$0.44/\text{kg in excess of } 13.6 \text{ kg}$$

For example, the cost of a 25.4 kg weaner purchased when the market price for a slaughter hogs was average for 1970 was:

$$22.7 \times \$0.62 + \$1.00 + \$0.44(25.4 - 13.6) = \$20.27.$$

(b) Variable costs

Variable costs include feed, veterinary, medicine, equipment operating, building maintenance, utility and other direct cash costs.

In the current analysis feed cost is feed consumption during the trial period multiplied by one of three feed prices per pound. The feed prices used were 1.8, 2.0 and 2.2 cents per pound and the corresponding metric equivalents were 3.97, 4.41 and 4.85 cents per kg.

The other variable costs include the costs of equipment operation, building maintenance and utilities. For the purpose of this analysis the other variable costs of $0.80 per 100 lb liveweight gain and veterinary and medicine costs of $0.22 per 100 lb liveweight gain given in Table 22 were combined giving a cost of $1.00 per 100 lb liveweight gain. In the actual computations used in this study the cost was $0.022/kg liveweight gain.

It was considered that the cost of $0.05 given in Table 22 for other direct costs per 100 lb liveweight gain was inadequate to cover the marketing costs. Accordingly, in the current analysis other direct costs were calculated assuming that the pigs were produced 100 miles from Edmonton and were marketed through an assembler. Marketing costs incurred under the assumed conditions were supplied by Mr. Orville Anderson of the Alberta Hog Marketing Board. These were:

Assembler's fee	$0.50 per pig
Insurance	$0.10 per pig
Transport	$1.32/100 kg hot carcass weight
Marketing fees	$0.30 per pig

(c) Depreciation and insurance

In the hog enterprise analysis depreciation is charged on all hog barns, storage facilities, processing facilities, material handling equipment and other machinery used by the hog enterprise. Since depreciation costs depend on the time a pig occupies the facilities it was necessary for the purposes of this current analysis to calculate depreciation on a daily basis. The details reported in Table 22 do not give an estimate of the time required to gain 100 lb liveweight. An estimate of the days required was calculated by the following method:

It was assumed that the interest charge on livestock per 100 lb liveweight gain was approximated by the function:-

$$\text{Interest charge} = \text{average inventory} \times \frac{6}{100} \times \frac{(\text{days to gain 100 lb})}{365}$$

Using figures from Table 22.

$$\$0.43 = \frac{(16.12 + 43.43)}{2} \times \frac{6}{100} \times \frac{(\text{days to gain 100 lb})}{365}$$

By rearranging the equation

$$\text{Days to gain 100 lb} = \frac{0.43 \times 100 \times 365 \times 2}{(16.12 + 43.43) \times 6}$$

$$= 87.85 \text{ days.}$$

The value of $1.31 given in the hog enterprise analysis was divided by 87.85 giving $0.0149 as an estimate of the daily cost of depreciation and insurance. Thus the cost of depreciation and insurance in the current analysis was determined by multiplying the days on trial by $0.0149.

(d) Interest charges

In the hog enterprise analysis interest is calculated at 6 per cent of the investment in buildings and equipment allocated to the hog enterprise. In Table 22 the cost of interest on buildings and equipment was given as $0.71 per 100 lb liveweight gain. This was converted to a daily basis by dividing by 87.85 days (derived in item 3) giving a daily estimate of $0.0081. Interest on buildings and equipment in the current analysis was derived by multiplying days on trial by $0.0081.

In addition, the hog enterprise analysis charges interest at 6 per cent on the year end inventory of hogs. For the purpose of the current analysis, interest on livestock was derived by using an average inventory (weaner cost + carcass value)/2 x (days on trial/365) x interest at 6 per cent.

(e) Labour cost

Labour has been charged at $1.45 per hour in Table 22 with a total input of 0.84 hours per 100 lb of liveweight produced in the reporting farms. The cost of labour input has been converted for this analysis to cost per day by dividing $1.22 by 87.85 giving a daily labour cost of $0.0139 per pig per day.

(f) Total production cost

The total production cost is the sum of variable costs, depreciation, insurance, interest and all labour charges.

(g) Return to management per pig

The return to management is equal to gross return per pig, less variable cost, depreciation, insurance, interest and labour costs per pig produced.

(h) Return to management per pen space per year

The return to management per pig space per year is equal to

$$(\text{return to management per pig}) \quad \times \quad \frac{365}{\text{days on trial}}$$

This method of calculation assumes that the pig space is not rested for a period after the pig is sold.

(ii) Use of prediction equations to compute carcass value and return per pen space per year

The four overall regression equations relating feed level and slaughter weight to feed consumption, days on trial, hot carcass weight and grade index are shown in Appendix table 1. Values for each variable were computed at slaughter weights of 68, 91 and 114 kg while the feeding levels used were the interactions among feed level and slaughter weight shown in Table 13. Liveweight gain was computed by subtracting the overall mean weight of pigs when placed on trial (24.41 kg) from the final slaughter weight. The computed values for feed consumed, days on trial, hot carcass weight and grade index, together with the derived values for liveweight gain, were subjected to an economic analysis using costs and prices given in section III (i) under conditions of average carcass price and medium feed cost. Grade index of pigs slaughtered at 68 kg was assumed to be 87.

(iii) Preparation of an amended table of differentials based on payment for muscle content

Two prediction equations were developed for all 72 carcasses described in section I. In the first, carcass muscle weight was predicted using the grading system measurements of warm carcass weight and total backfat as predictors (based on the combined equation number I in section I). The second prediction equation estimated the weight of muscle plus intermuscular fat (defined as lean) in the carcass using the same grade measurements as predictors. Using these prediction equations the muscle and lean content of carcasses was predicted at the midpoint of backfat and carcass weight for each cell of the table of differentials (Appendix table 2). The original valuation schedule was designed around a "key cell" (index of 100 for carcasses in the cell midpoints of 82.6 and 70.06 for total backfat and warm carcass weight respectively). The value of the carcass for this "key cell" was computed using the average bid price of $28.37 paid in Alberta during 1970. The carcass value so obtained was divided by the predicted weight of muscle and lean for that cell. This procedure was followed for all cells in the table.

Following the steps outlined below, the table of differentials was amended to provide that carcasses in each cell were valued according to predicted muscle and lean content.

In the "key cell" it was found that the price paid per kg of muscle and lean was \$1.587 and \$1.380 respectively.

Considering muscle as a basis:

$$\text{Carcass value} = \text{index} \times \text{carcass weight} \times \text{bid price of } \$0.62$$

$$= \$1.587 \times \text{muscle weight}$$

Thus:

$$\text{Index} \times \text{carcass weight} \times \$0.62 = \text{muscle weight} \times \$1.587$$

$$\text{Index} = \frac{\text{muscle weight} \times \$1.587}{\text{carcass weight} \times \$0.62}$$

An amended index was calculated for each cell in the table of differentials using this formula and the predicted muscle content of each cell.

A similar procedure was followed for amending the table on the basis of lean content.

(iv) Statistical analyses

(a) Variables used

Grade index was calculated and analyses done on all carcasses. Using the first method outlined in section III B (i) (a), carcass value and price paid per kg of muscle was computed for all carcasses.

Cost per kg muscle marketed was derived by the following:

$$\text{Cost per kg muscle marketed} = \frac{(\text{Total production cost} + \text{cost of weaner})}{\text{Total carcass muscle}}$$

C. Results and Discussion

(i) Economic analyses

(1) Grade index method of computing carcass value

Returns to management per pig produced are shown in Table 23 by slaughter weight, level of feeding, sex and breed. There were nine combinations of prices involving three feed costs and three carcass prices. When carcass prices were low (the lowest price bid in Alberta during 1970) returns to management per pig were negative under the conditions of this experiment. Greatest losses were made on the lowest feeding level ($P < 0.01$) and losses were least at 91 kg slaughter weight while larger losses were made by slaughtering at 68 kg than at 114 kg ($P < 0.01$ and 0.05). Losses tended to be lower in the YLY breed group than with YL pigs and barrows lost more than gilts ($P < 0.05$).

At the average bid price for carcasses during 1970, the pattern of returns was similar to those described for the low carcass price. However, positive returns were made at the higher feeding levels and at the higher slaughter weights ($P < 0.01$). Barrows were less profitable than gilts ($P < 0.05$). Again, the most profitable slaughter weight was at 91 kg ($P < 0.01$).

Similar patterns to those described at the lower carcass prices were present at the high carcass price, but even at this high price pigs slaughtered at 68 kg produced a negative return. While the returns from pigs killed at 114 kg were still less than those from pigs slaughtered at 91 kg (P 0.01) the differences were not as great in magnitude as those present at the lower carcass prices. The

Table 23. Means of returns to management ($) per pig produced at three carcass values and three feed prices by feed level, slaughter weight, breed and sex.

Carcass value per kg	Feed cost per kg	Feed level			Slaughter weight			Breed		Sex	
		4.2	3.7	3.2	68	91	114	YL	YLY	B	G
$0.44	$0.0397	-4.12^{A}[1]	-4.69^{A}	-6.77^{B}	-8.47^{A}	-1.61^{B}	-5.50^{C}	-5.50	-4.89	-5.69^{a}	-4.70^{b}
$0.44	$0.0441	-5.18^{A}	-5.73^{A}	-7.93^{B}	-9.12^{A}	-2.66^{B}	-7.04^{C}	-6.59	-5.96	-6.80^{a}	-5.75^{b}
$0.44	$0.0485	-6.23^{A}	-6.76^{A}	-9.08^{B}	-9.77^{aA}	-3.72^{bB}	-8.58^{cA}	-7.67	-7.04	-7.92^{a}	-6.80^{b}
$0.62	$0.0397	3.39^{A}	2.74^{A}	0.78^{B}	-4.74^{A}	7.28^{B}	4.37^{C}	1.88	2.73	1.74^{a}	2.87^{b}
$0.62	$0.0441	2.34^{A}	1.71^{A}	-0.38^{B}	-5.93^{A}	6.23^{B}	2.83^{C}	0.79	1.65	0.62^{a}	1.82^{b}
$0.62	$0.0485	1.29^{A}	0.67^{A}	-1.54^{B}	-6.05^{A}	5.18^{B}	1.30^{C}	-0.29	0.58	-0.49^{a}	0.77^{b}
$0.79	$0.0397	10.50^{A}	9.77^{AB}	7.90^{B}	-1.22^{A}	15.69^{B}	13.69^{C}	8.85	9.93	8.76^{a}	10.02^{b}
$0.79	$0.0441	9.44^{A}	8.73^{A}	6.75^{B}	-1.87^{A}	14.63^{B}	12.16^{C}	7.76	8.85	7.64^{a}	8.97^{b}
$0.79	$0.0485	8.39^{A}	7.69^{A}	5.59^{B}	-2.52^{A}	13.58^{B}	10.62^{C}	6.68	7.77	6.53^{a}	7.92^{b}

1. Means having different superscripts within the same treatment classification differ significantly at $P < 0.05$ (a, b, c) and $P < 0.01$ (A, B, C)

differences between returns from pigs killed at 68 and 91 kg became greater as carcass price increased.

Returns per pig are shown in isoquant form in figure 5 for overall, breed and sex classification under conditions of average carcass price and medium feed cost. The regression equations used to produce the isoquants are given in the Appendix table 3.

It was pointed out in section II that the grading system was designed to encourage production of carcasses ranging between 57 to 82 kg, that is, of pigs slaughtered between approximately 78 to 109 kg liveweight, respectively. The overall isoquants show that the break-even point occurred near a slaughter weight of 78 kg when feeding level was 3.2 per cent and the break-even slaughter weight decreased slightly as the feeding level increased. At the higher slaughter weights, the isoquant for the break-even slaughter weight was located near 118 kg at the low feeding levels and rose slightly to about 120 kg as feeding level increased. On both sides of the area enclosed by the $5 isoquants the slaughter weight change required to move from the $5 to the break-even isoquants was larger than the change required to move from the $0 to the -$5 isoquant. The maximum return per pig within the limits of the area investigated was estimated to be $7.52, located at a slaughter weight of 96.7 kg and at a feeding level of 4.07 per cent.

The isoquants showing the separate breed group plots indicated that the YL breed group could not return $5.00 per pig if taken much below the 3.5 per cent feeding level while the YLY breed group could return $5 per pig below the 3.2 per cent feeding level. The plots suggest that the YL breed group was more sensitive to changes in feed

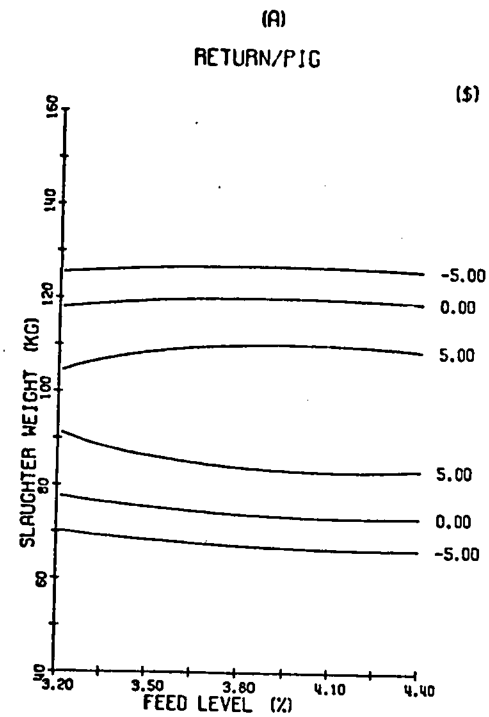
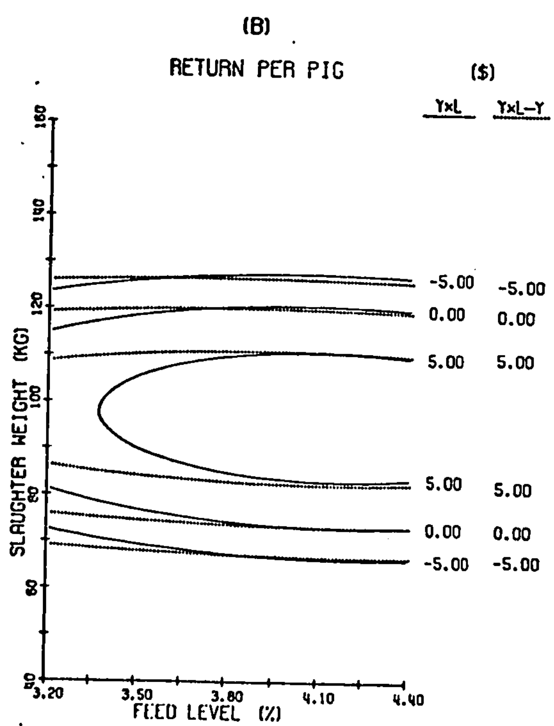
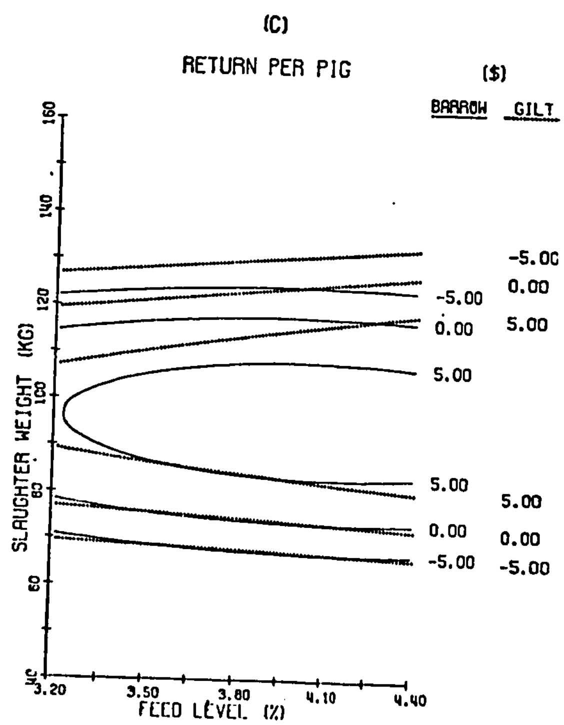


Figure 5. Isoquants for return per pig ($) showing the combinations of feed level and slaughter weight estimated to produce returns of -5, 0 and 5 dollars. Isoquants are shown for the overall experiment (a), for the YL and YLY breed groups (b), and for barrows and gilts (c).

Plot	R^2	S.E.
Overall	0.812	2.47
YL	0.836	2.33
YLY	0.836	2.50
Barrows	0.852	2.27
Gilts	0.818	2.55





level at low levels of feeding than the YLY breed group but this difference disappeared at higher levels of feeding. The maximum returns for the two breed groups were very similar. The YL breed group had a maximum return of $7.57 estimated to be at a feeding level of 4.15 per cent and a slaughter weight of 96.8 kg while the maximum for the YLY pigs was slightly higher at $7.93 and was located at a 4.05 per cent feeding level and at a slaughter weight of 96.5 kg.

The sex plots for returns per pig showed that there was little difference between sexes at the lower slaughter weights. However, at higher slaughter weights gilts were more responsive than barrows to increased feeding level. Also the slaughter weights at which gilts yielded a break-even return approximated the weights at which barrows returned a loss of $5 per pig. It appeared that a barrow required to be fed at 4.40 per cent to yield a $5 return while gilts could be fed at 3.20 per cent and still yield the same return. The maximum return for gilts was estimated to be $9.86 at 4.40 per cent feeding level and 99.3 kg slaughter weight while the maximum return for barrows was estimated to be lower at $7.38 and was located at the 4.10 per cent feeding level and at 95.5 kg slaughter weight. The maximum points illustrate that gilts can be fed at higher levels than barrows, be slaughtered at heavier weights and return more profit than barrows. There was a wider range in slaughter weights within which high returns were forthcoming for gilts than for barrows. This means that producers could be more flexible in choosing slaughter weights for gilts than for barrows. Such sex differences highlight the validity of the suggestion that weaner pigs be grouped according to sex at auction markets so that buyers could exercise their higher preference for gilts over male pigs.

Returns to management per pen space per year are shown by slaughter weight, level of feeding, breed and sex in Table 24.

As expected from the returns per pig produced, all returns were negative at the low carcass price. Losses were little affected by feeding level but were strongly influenced by slaughter weight ($P < 0.01$). At this low carcass price pigs from the YL breed group produced a greater loss than pigs from the YLY breed group ($P < 0.05$).

In Table 23 it was shown that on a per pig basis, those fed at the 3.2 per cent feeding level lost more money than those fed at higher levels. However, expressed on a per pen space per year basis the slower production of pigs fed at 3.2 per cent feeding level meant that fewer could be processed in a pen space in a year, thus reducing their capacity to influence returns per pen space per year. The result was that there was no significant difference between feeding levels in return per pen space per year at the low carcass price.

As expected, combinations of feed prices with the medium carcass price which produced negative returns per pig also produced negative returns per pen space per year.

At the high carcass price the differences due to the effect of feed level on return per pig were magnified when expressed on the basis of return per pen space per year. While there were no significant differences between the 4.2 and 3.7 per cent feeding levels in return per pig, the greater throughput possible with the 4.2 per cent feeding level enabled higher returns per year on the 4.2 per cent level than on the 3.7 per cent level ($P < 0.05$ and 0.01). The low throughput possible on the 3.2 per cent feeding level magnified the

Table 24. Means of returns to management ($) per pen space per year at three carcass values and three feed prices by feed level, slaughter weight, breed and sex.

Carcass value per kg	Feed cost per kg	Feed level			Slaughter weight			Breed		Sex	
		4.2	3.7	3.2	68	91	114	YL	YLY	B	G
$0.44	$0.0397	-16.49	-15.97	-16.87	-33.08[A][1]	-3.67[B]	-12.59[C]	-17.47[a]	-15.42[b]	-17.63[a]	-15.26[b]
$0.44	$0.0441	-20.11	-19.06	-19.47	-35.67[A]	-6.77[B]	-16.20[C]	-20.62[a]	-18.47[b]	-20.78[a]	-18.31[b]
$0.44	$0.0485	-23.73	-22.14	-22.08	-38.26[A]	-9.87[B]	-19.82[C]	-23.77[a]	-21.52[b]	-23.93[a]	-21.37[b]
$0.62	$0.0397	9.59[A]	6.36[A]	0.06[B]	-17.95[A]	23.13[B]	10.83[C]	4.33	6.34	3.62[a]	7.06[b]
$0.62	$0.0441	5.97[A]	3.28[A]	-2.54[B]	-20.54[A]	20.03[B]	7.21[C]	1.18	3.29	0.46[a]	4.00[b]
$0.62	$0.0485	2.34[A]	0.19[A]	-5.14[B]	-23.13[A]	16.94[B]	3.59[C]	-1.97	0.23	-2.68[a]	0.95[b]
$0.79	$0.0397	34.22[A]	27.45[B]	16.06[C]	-3.66[A]	48.44[B]	32.94[C]	24.92	26.89	23.68[a]	28.13[b]
$0.79	$0.0441	30.60[aA]	24.37[bA]	13.45[cB]	-6.26[A]	45.35[B]	29.32[C]	21.77	23.84	20.53[a]	25.08[b]
$0.79	$0.0485	26.98[aA]	21.29[bA]	10.85[cB]	-8.85[A]	42.25[B]	25.70[C]	18.62	20.78	17.38[a]	22.02[b]

1. Means having different superscripts within the same treatment classification differ significantly at $P < 0.05$ (a, b, c) and $P < 0.01$ (A, B, C)

differences between this level and the higher levels on return per pig.

A significant interaction ($P < 0.005$) occurred in the effects of feeding levels and slaughter weights on returns per pen space per year and is discussed later (Table 27). Briefly, there was little effect of feeding level on the substantial losses incurred in marketing pigs at 68 kg liveweight, but returns received by slaughtering at 91 and 114 kg decreased as the level of feeding decreased.

Returns per pen space per year are shown in isoquant form in figure 6 for overall, breed and sex classifications under conditions of average carcass price and medium feed cost. The regression equations used to produce the plots are in the Appendix table 3. Again, the influence of the grading system is apparent with the break-even isoquant at the lower range of slaughter weights located at approximately 78 kg slaughter weight while in the higher weights it is located between 115 and 120 kg, increasing slightly as feeding level increased. These limits are very similar to those delineated by the break-even isoquants for returns per pig produced. Actually, all plots of return per pen space per year are virtually carbon copies of the plots for return per pig with the isoquants for returns per pen space per year being about 3 times the value of those for returns per pig. Overall, the maximum return per pen space per year was estimated to be $24.43 at a feeding level of 4.15 and a slaughter weight of 97.2 kg; this point being very similar to the location of the maximum return per pig estimated in figure 5.

The isoquants for the separate breed groups suggest that the YL pigs were unable to return $15 per pen space per year when fed at levels near 3.2 per cent. Again, breed differences tended to

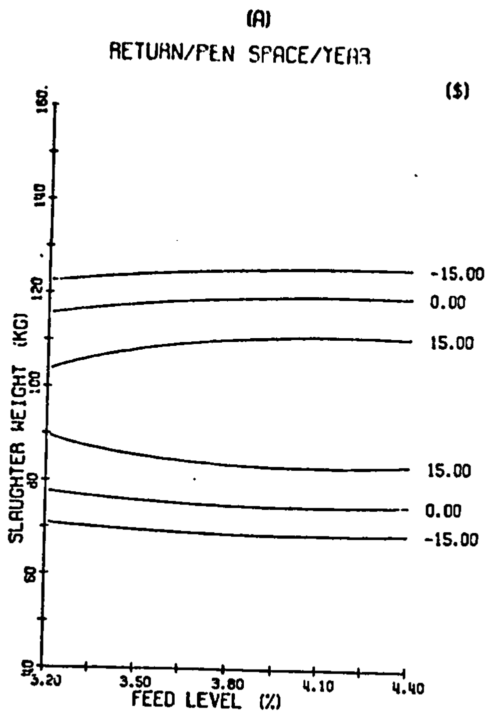
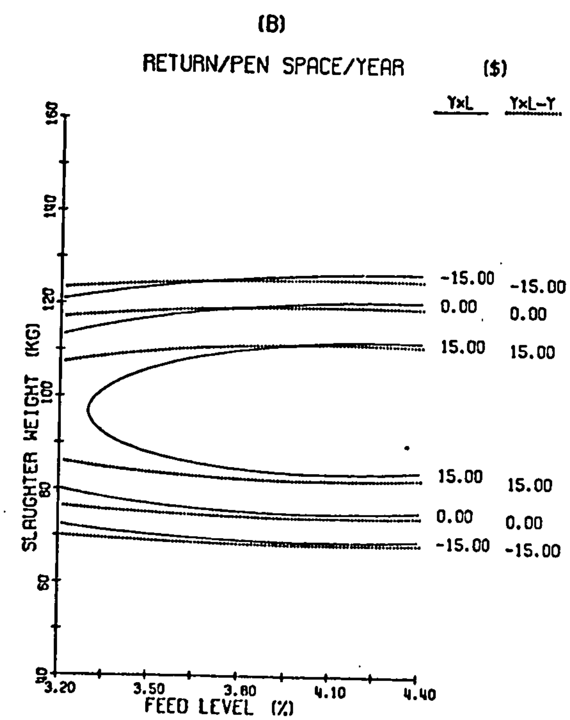
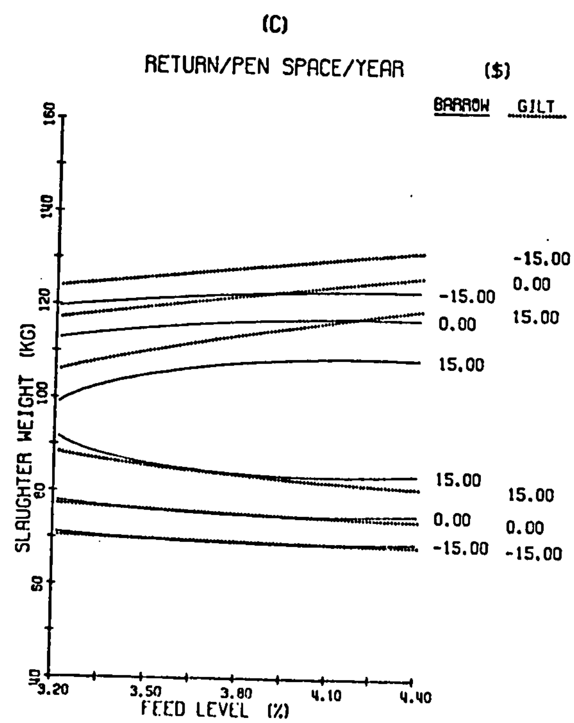


Figure 6. Isoquants for return per pen space per year ($) showing the combinations of feed level and slaughter weight estimated to produce returns of -15, 0 and 15 dollars per year. Isoquants are shown for the overall experiment (a), for the YL and YLY breed groups (b), and for barrows and gilts (c).

Plot	R^2	S.E.
Overall	0.833	7.92
YL	0.849	7.67
YLY	0.842	8.25
Barrows	0.869	7.18
Gilts	0.838	8.25





disappear as the level of feeding increased. The maximum returns of the two breed groups were very similar. The YL breed group was estimated to have a maximum return per pen space per year of $24.61 at a 4.21 per cent feeding level and at a slaughter weight of 97.7 kg while the maximum estimated for the YLY breed group was $25.40 at a feeding level of 4.10 per cent and a slaughter weight of 96.6 kg.

Comments similar to those made about the return per pig isoquants are applicable to the plots for returns per pen space per year of barrows and gilts. The superior performance of gilts in return per pig was more clearly demonstrated and the maximum point for gilts was estimated to be $32.11 at a 4.40 per cent feeding level and 100 kg slaughter weight while the maximum for barrows was estimated to be substantially lower at $23.41 at a feeding level of 4.20 per cent and a slaughter weight of 96.1 kg. Again, there was a wider range in slaughter weights for gilts than barrows within which the area of high profits was located.

The overall plot obtained for the cross-validated responses (figure 7) was prepared by applying coefficients for the YL breed group to the data for the YLY breed group and vice versa. The regression equation used to prepare the plots is given in Appendix table 3. The cross-validated plot was almost a carbon copy of that obtained using the overall prediction equation and shown in figure 6. The maximum point was estimated to be $25.74 at a feeding level of 4.20 and a slaughter weight of 97.2 kg. While such a result was very similar to the result obtained using the overall prediction equation it is considered that predictions such as these should be tested more widely before general acceptance is warranted. In testing equations

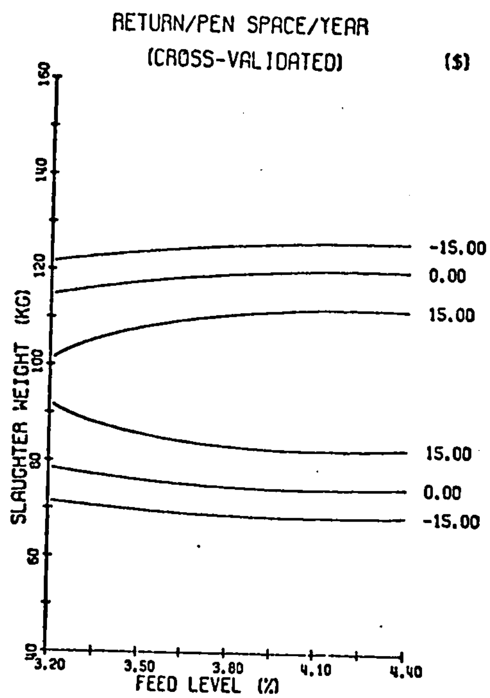


Figure 7. Isoquants for cross-validated return per pen space per year ($) showing the combinations of feed level and slaughter weight estimated to produce returns of -15, 0 and 15 dollars per year.

Plot	R^2	S.E.
Overall	0.983	2.34

for predicting performance developed in one set of pigs, Dent, English and Raeburn (1970) found that liveweight gains of other pigs on test diets did not reach the level predicted.

(2) Muscle content method of determining carcass value

Carcass value, return per pig and return per pen space per year are shown in Table 25 for conditions of medium feed cost and with muscle valued at the price paid per kg of muscle in pigs slaughtered at 91 kg when the bid price was the average for Alberta during 1970. For convenience in making comparisons, the return per pig and return per pen space per year at average carcass bid price and medium feed cost shown in Table 24 are repeated in Table 25, together with computed carcass value, value per kg of muscle and cost of production per kg of muscle using the grading system as a basis of payment.

When carcass were valued according to the grading system there was little effect due to feeding level but value increased with slaughter weight ($P < 0.01$), and YLY carcasses were more valuable than those from the YL breed group ($P < 0.05$). Figure 8 shows the combinations of feed level and slaughter weight estimated to produce carcasses valued at \$28, \$38 and \$48. The maximum carcass value computed was \$49.82 and was estimated to occur at a feeding level of 2.39 per cent and at a slaughter weight of 109 kg. The isoquants reflect the influence of the grading system in that carcass values are symmetrically distributed about a central maximum value occurring at about 110 kg and approximately parallel to the feeding level axis. Although the maximum value computed falls outside the range of feeding levels examined it does show that the surface between the isoquants for \$48

Table 25. Comparison of returns to management when carcasses were valued by either the grade index method or by the muscle content basis.

Variable		Feed level			Slaughter weight			Breed		Sex	
		4.2	3.7	3.2	68	91	114	YL	YLY	B	G
Grade index basis											
Carcass value	$	40.45	40.23	40.80	27.25[A][1]	45.34[B]	48.89[C]	40.08[a]	40.91[b]	40.26	40.73
Value/kg muscle	$	1.34[a]	1.32[ab]	1.28[b]	1.17[A]	1.47[B]	1.31[C]	1.33	1.30	1.34[A]	1.29[B]
Cost/kg muscle	$	1.28	1.29	1.33	1.40[A]	1.27[B]	1.23[B]	1.33[a]	1.27[b]	1.32[A]	1.25[B]
Return/pig	$	2.34[A]	1.71[A]	-0.38[B]	-5.93[A]	6.23[B]	2.83[C]	0.79	1.65	0.62[a]	1.82[b]
Return/pen/year	$	5.97[A]	3.28[A]	-2.54[B]	-20.54[A]	20.03[B]	7.21[C]	1.18	3.29	0.46[a]	4.00[b]
Muscle content basis											
Carcass value	$	44.15[A]	44.48[A]	46.44[B]	34.44[A]	45.42[B]	55.21[C]	44.02[A]	46.02[B]	43.83[A]	46.21[B]
Return/pig	$	6.01	5.91	5.19	1.74[A]	6.30[B]	9.06[C]	4.69[A]	6.71[B]	4.16[A]	7.25[B]
Return/pen/year	$	21.13[aA]	16.98[aAB]	11.36[bB]	8.22[A]	19.88[B]	21.37[B]	14.16[a]	18.82[b]	11.25[A]	21.73[B]

1. Means having different superscripts within the same treatment classification differ significantly at $P < 0.05$ (a,b,c) and $P < 0.01$ (A,B,C).

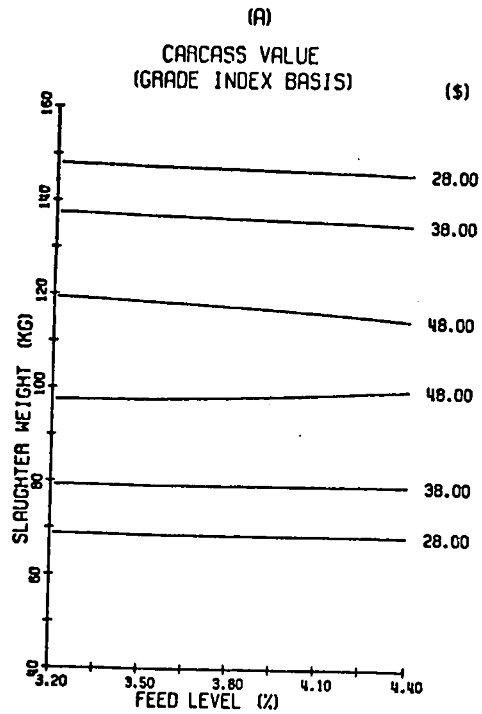
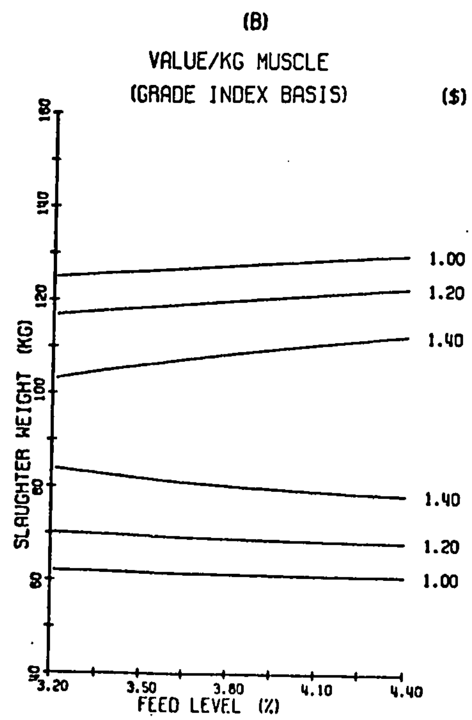
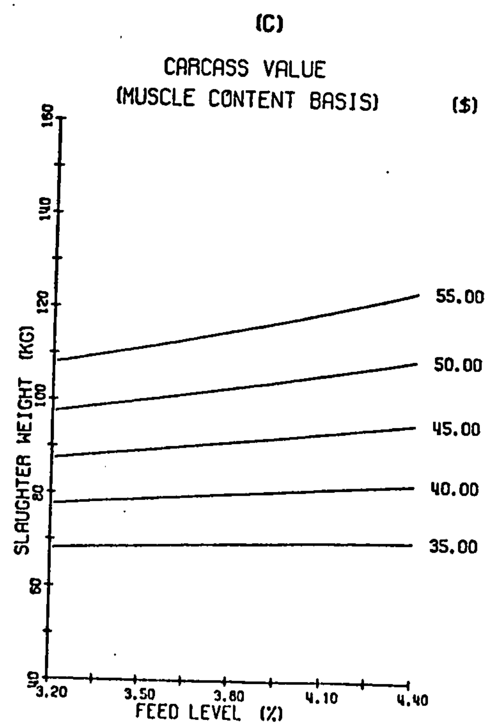


Figure 8. Isoquants for carcass value variables showing the combinations of feed level and slaughter weight estimated to produce the values ($) shown on the plots. Isoquants are shown for carcass value (grade index basis) (a), for value per kg of muscle (grade index basis) (b), and for carcass value (muscle content basis) (c).

Plot	R^2	S.E.
(a)	0.969	1.78
(b)	0.792	0.07
(c)	0.932	2.44





does not rise much higher than 48 dollars. The increase from \$28 to \$38 occurs within a smaller increase or decrease in slaughter weight than does the increase from \$38 to 48 dollars.

When carcasses are valued according to the grading system the price paid per kg of muscle decreased as feeding level decreased with higher prices paid for muscle from pigs fed at 4.2 per cent than for muscle from pigs fed at 3.2 per cent ($P < 0.05$). Since feeding level had little effect on carcass value and pigs fed at the 3.2 per cent level had more muscle than those fed at higher levels (Table 18), carcasses from pigs fed the 3.2 per cent level were paid at a lower rate per kg muscle than those fed at the 4.2 per cent level. Pigs slaughtered at the 91 kg weight were paid at the highest rate per kg muscle while those killed at 114 kg were paid more per kg muscle than those killed at 68 kg ($P < 0.01$). Barrows contained less muscle than gilts (Table 18) but since there was little sex effect on carcass value, the price paid per kg muscle in barrows exceeded that paid for muscle in gilts ($P < 0.01$). The prices paid per kg muscle are shown in figure 8. The maximum value of \$1.53 per kg occurred at the 4.40 per cent level of feeding and at a slaughter weight of 95.4 kg. Again the isoquants were symmetrical about a central high value which was approximately parallel to the feeding level axis. The distances between the \$1.00 and \$1.20 isoquants was less than that between the \$1.20 and \$1.40 isoquants.

The cost of production was not significantly affected by feeding level although there was a trend for cost to rise as feed level decreased. The cost of production per kg of muscle declined markedly from the 68 kg slaughter weight to the 91 kg weight ($P < 0.01$) and tended to decline from there to 114 kg, although not significantly. While the carcass grading system used has an important bearing on the location of the most economically efficient slaughter weight, there is a lack of agreement by British workers on this subject. Bellis and Taylor (1961) calculated that cost per unit weight of lean meat produced decreased from a slaughter weight of 41 kg through to slaughter at 100 kg and changed little from then on to a high slaughter weight of 136 kg, while Braude, Townsend and Harrington (1963) concluded that slaughter at 91 kg was more economical than at 118 kg. The results from the present study tend to support both British studies in that the costs of production per kg of muscle tended to decrease with increasing slaughter weight but the returns per pen space per year were greatest at the 91 kg slaughter weight.

There was a significant interaction ($P < 0.05$) among sex and slaughter weight on cost of muscle marketed (Table 26). While barrows were consistently higher in cost of muscle production at each slaughter weight than were gilts, the cost of production per kg of muscle consistently decreased as slaughter weight increased in gilts but in barrows there was an initial decrease to 91 kg with little change to a slaughter weight of 114 kg.

When priced according to muscle content, carcass values were higher among the main effects classifications than when valued by the grading system, except, by definition, at the 91 kg slaughter weight. As expected, the higher muscle content of pigs fed at the 3.2 per cent feeding level (Table 18) resulted in their receiving a higher carcass value than those from pigs fed at higher levels ($P < 0.01$). The value of carcasses from pigs killed at 68 and 114 kg were higher than those

Table 26. Interactions among main effects on economic variables.

(a) Interaction ($P < 0.05$) of slaughter weight and sex on cost ($) per kg of muscle marketed.

Sex	Slaughter weight 68	91	114
B	1.49	1.29	1.28
G	1.31	1.25	1.19

(b) Interaction ($P < 0.05$) of slaughter weight and sex on return per pen space per year ($), using carcass muscle content as the basis of settlement.

Sex	Slaughter weight 68	91	114
B	-0.45	17.64	16.57
G	16.89	22.13	26.18

paid under the grading system method and the increases with increasing slaughter weight were more uniform. As expected, also, the breed and sex differences in muscle content (Table 18) were reflected in price paid per carcass ($P < 0.01$). The isoquants for carcass values of 35 through to 55 dollars are shown in figure 8. The isoquants are not symmetrical as was the case with the grading system values and carcass value increases steadily as slaughter weight increases. As the level of feeding increased, pigs had to be taken to a heavier slaughter weight in order to maintain a given carcass value and this trend became more pronounced as slaughter weight increased. The maximum carcass value within the area studied was $57.76 and was estimated to occur at a feeding level of 3.2 per cent and a slaughter weight of 114 kg.

Returns per pig were not significantly affected by feeding level but were higher than when carcasses were valued by the grading system. While the return per pig when valued by the grading system was negative at the 68 kg slaughter weight, it was positive when muscle content was used as the basis for valuation and return per pig was highest at the 114 kg slaughter weight ($P < 0.01$). Returns from the YLY breed group and gilts surpassed those yielded by the YL breed group and barrows respectively ($P < 0.01$). Returns per pen space per year were generally higher than those obtained when carcasses were valued by the grade index system. While pigs killed at 114 kg produced the highest return per pig, the reduced throughput per year possible at this slaughter weight resulted in it not being superior to the 91 kg slaughter weight in returns per pen space per year.

Using carcass muscle content as the basis of valuation, there was an interaction ($P < 0.05$) of slaughter weight and sex on return per pen space per year (Table 26). Barrows were less profitable than gilts but the difference was much more pronounced at the 68 kg slaughter weight when barrows gave a negative return per pen space per year.

This study demonstrated the effect that a grading system can have on the location of the area within which it is profitable to produce pigs. At present it appears that the most profitable area is in a region which has a sharp central peak around the 91 kg slaughter weight. The adoption of a system based on muscle content would give a broader region of slaughter weight within which producers could operate according to the constraints imposed by their individual enterprises. How the system might be altered to value carcasses according to muscle content is the subject of another area of this discussion.

(ii) Use of prediction equations to compute carcass value and return per pen space per year

Interactions among feeding levels and slaughter weights on carcass value and return per pen space per year are shown in Table 27, together with carcass values and returns computed using regression equations developed in section II. The trends present in the interactions among feed levels and slaughter weights on carcass value computed using actual performance records also occur in the carcass values computed using regression equations for predicting carcass weight and grade index. Both methods suggest that as slaughter weight increased, carcass value increased and feeding level had little effect on carcass value. Except in one case, regression estimates were below actual carcass values and three of the nine estimates were within $\pm$ one

Table 27. Interactions among feeding levels and slaughter weights on carcass value and returns per pen space per year computed from individual performance records, together with those derived by use of regression equations.

(a) Carcass value ($)

	Actual performance			Regression estimates		
	Slaughter weight			Slaughter weight		
Feed level	68	91	114	68	91	114
4.2	27.47	44.99	48.90	26.32	44.30	47.84
3.7	27.21	45.11	48.38	26.54	44.70	48.38
3.2	27.07	45.94	49.40	26.59	45.03	48.67

S.E. x = 0.56

(b) Returns per pen space per year ($).

	Actual performance (P 〈 0.005)			Regression estimates		
	Slaughter weight			Slaughter weight		
Feed level	68	91	114	68	91	114
4.2	-19.77	27.79	9.88	-26.46	21.40	8.19
3.7	-20.58	23.54	6.87	-22.80	18.18	6.17
3.2	-21.27	8.77	4.87	-23.24	10.73	3.03

S.E. x = 2.14

standard error of the corresponding value computed from actual performance records.

A significant ($P < 0.005$) interaction occurred in the effects of feeding levels and slaughter weights on returns per pen space per year. While there was little effect of feeding level on the substantial losses incurred in marketing pigs at 68 kg liveweight, returns received by slaughtering at 91 and 114 kg decreased as the level of feeding decreased. The regression estimates were generally lower than those computed using actual performance records and four of the nine estimates were within $\pm$ one standard error of estimate of the values derived from the actual records. Despite the differences in magnitude, the same decision about the best combination of feeding level and slaughter weight would be reached by inspection of both tables. However, the sometimes large differences between regression estimates and those derived from actual values underlines the need for caution in interpretation of estimated values, especially when the number of variables in a model increases.

It is believed that the use of models describing the operation of pig production units will become an important feature in future pig production research. Such models will help, amongst other things, locate areas in pig production most likely to benefit from research. However, the use of models is not without problems and Alexander (1969) had this to say about the use of models in a business context.-

"Models incorporate many variables that are really estimates of such things as the future GNP, product acceptance or the likelihood of contracts being renewed. Thus when the results emerge from a computer they amount to precisely formulated and deceptively precise guesses stitched together into compounded doubtfulness. Many managers have found themselves unable to peer through the haze of jargon and formulas to discern clearly the frailties of the basic estimates and assumptions".

The results of the present study indicated that within the experimental material from which they were derived, the use of four regression equations incorporated into a model for determining return per pen space per year gave results leading to similar interpretations to those arrived at by examination of the actual data. However, further studies are needed in this area involving validation of predictions such as those developed for return per pen space per year on other breed groups of pigs and on other levels of feeding.

(iii) Examination of the carcass valuation schedule

Table 28 shows the carcass value computed for the midpoint of each carcass weight, backfat depth classification in the grading system schedule using the average bid price paid in Alberta during 1970.

The regression equations developed for predicting weight of muscle and lean (muscle plus intermuscular fat) were:

$$\text{Total muscle} = 9.11 - 0.18574(\text{total backfat}) + 0.4830(\text{carcass weight})$$
$$R^2 = 0.945, \text{ S.E.} = 1.46 \text{ kg}$$

$$\text{Total lean} = 6.7218 - 0.1768(\text{total backfat}) + 0.5656(\text{carcass weight})$$
$$R^2 = 0.969, \text{ S.E.} = 1.32 \text{ kg}$$

Using these equations, predicted muscle and lean weights were computed at the midpoints of each backfat and carcass weight range classification of the grading system schedule. Tables 29 and 30 show

Table 28. Price paid per carcass within each cell of the hog carcass valuation schedule when carcasses are valued at $0.62 per kg of hot carcass weight of grade index 100.

Carcass weight (kg)[1]	48.52	57.59	61.00	65.63	70.06	74.60	79.36	85.26	92.16[2]
Backfat (mm)									
48.3	26.41[3]	37.83	41.69	45.09	49.09	52.27	55.45	48.54	48.95
52.1	26.41	37.11	40.83	44.68	48.21	52.27	55.45	48.54	48.95
57.2	26.41	36.75	40.06	43.86	47.78	51.34	54.46	48.54	48.95
62.2	26.41	36.03	39.30	43.04	46.90	50.87	53.96	48.54	48.95
67.3	26.41	35.31	38.92	42.22	46.02	49.94	52.97	48.54	48.95
72.4	26.41	34.95	38.16	41.81	45.15	49.00	51.98	48.54	48.95
77.5	26.41	34.23	37.39	40.99	44.71	48.07	50.99	48.54	48.95
82.6	26.41	33.15	37.01	40.17	43.83	47.60	50.50	48.54	48.95
87.6	26.41	31.71	36.25	39.76	42.95	46.67	49.50	48.54	48.95
92.7	26.41	31.71	35.10	38.94	42.52	45.74	48.52	48.54	48.95
97.8	26.41	31.71	33.58	37.72	41.64	45.27	48.02	48.54	48.95
102.9	26.41	31.71	33.58	36.08	40.32	44.34	47.03	46.40	47.22
108.0	26.41	31.71	33.58	36.08	38.57	42.94	45.54	46.40	47.22
111.8	26.41	31.71	33.58	36.08	38.57	41.07	43.56	46.40	47.22

1. Values given for carcass weight and backfat are for the midpoints of the ranges given in the valuation schedule.

2. This value was obtained by adding the same increment separating the previous two midpoints to the previous midpoint.

3. Data from the current experiment fell within those cells enclosed by solid lines.

Table 29. Predicted muscle weight and predicted muscle weight expressed as per cent of hot carcass weight within each cell of the hog carcass valuation system schedule.

Predicted muscle weight (kg)

Carcass weight (kg)[1] / Backfat (mm)[1]	48.52	57.59	61.00	65.53	70.06	74.60	79.36	85.26	92.16[2]
48.3	23.58[3]	27.96	29.61	31.80	33.98	36.18	38.48	41.33	44.66
52.1	22.87	27.25	28.90	31.09	33.28	35.47	37.77	40.62	43.95
57.2	21.93	26.31	27.96	30.14	32.33	34.53	36.82	39.68	43.01
62.2	20.98	25.37	27.01	29.20	31.39	33.58	35.88	38.73	42.06
67.3	20.04	24.42	26.07	28.26	30.45	32.64	34.94	37.79	41.12
72.4	19.10	23.48	25.13	27.31	29.50	31.70	34.00	36.84	40.18
77.5	18.15	22.54	24.18	26.37	28.56	30.75	33.05	35.90	39.23
82.6	17.21	21.59	23.24	25.43	27.62	29.81	32.11	34.96	38.29
87.6	16.27	20.65	22.30	24.48	26.67	28.86	31.16	34.01	37.35
92.7	15.32	19.71	21.35	23.54	25.73	27.92	30.22	33.07	36.40
97.8	14.38	18.76	20.41	22.60	24.78	26.98	29.28	32.13	35.46
102.9	13.44	17.82	19.46	21.65	23.84	26.03	28.33	31.18	34.52
108.0	12.49	16.88	18.52	20.71	22.90	25.09	27.39	30.24	33.57
111.8	11.78	16.17	17.81	20.00	22.19	24.38	26.68	29.53	32.86

Predicted muscle weight as per cent of hot carcass weight

Carcass weight (kg)[1] / Backfat (mm)[1]	48.52	57,59	61.00	65.53	70.06	74.60	79.36	85.26	92.16[2]
48.3	48.6[3]	48.6	48.5	48.5	48.5	48.5	48.5	48.5	48.5
52.1	47.1	47.3	47.4	47.4	47.5	47.5	47.6	47.6	47.7.
57.2	45.2	45.7	45.8	46.0	46.1	46.3	46.4	46.5	46.7
62.2	43.2	44.0	44.3	44.6	44.8	45.0	45.2	45.4	45.6
67.3	41.3	42.4	42.7	43.1	43.5	43.8	44.0	44.3	44.6
72.4	39.4	40.8	41.2	41.7	42.1	42.5	42.8	43.2	43.6
77.5	37.4	39.1	39.6	40.2	40.8	41.2	41.6	42.1	42.6
82.6	35.5	37.5	38.1	38.8	39.4	40.0	40.5	41.0	41.5
87.6	33.5	35.8	36.6	37.4	38.1	38.7	39.3	39.9	40.5
92.7	31.6	34.2	35.0	35.9	36.7	37.4	38.1	38.8	39.5
97.8	29.6	32.6	33.4	34.5	35.4	36.2	36.9	37.7	38.5
102.9	27.7	30.9	31.9	33.0	34.0	34.9	35.7	36.6	37.4
108.0	25.7	29.3	30.4	31.6	32.7	33.6	34.5	35.5	36.4
111.8	24.3	28.1	29.2	30.5	31.7	32.7	33.6	34.6	35.7

1. Values given for carcass weight and backfat are for the midpoints of of the ranges given in the valuation schedule.

2. This value was obtained by adding the same increment separating the previous two midpoints.

3. Data from the current experiment fell within those cells enclosed by solid lines.

Table 30. Predicted intermuscular fat and muscle weight and predicted intermuscular fat and muscle weight expressed as per cent of hot carcass weight within each cell of the hog carcass valuation system schedule.

Predicted intermuscular fat and muscle weight (kg)

Carcass weight (kg)[1]	48.52	57.59	61.00	65.53	70.08	74.60	79.36	85.26	92.16[2]
Backfat (mm)[1]									
48.3	25.63[3]	30.76	32.69	35.25	37.81	40.38	43.07	46.41	50.13
52.1	24.96	30.09	32.02	34.58	37.14	39.71	42.40	45.74	49.64
57.2	24.06	29.19	31.12	33.68	36.24	38.81	41.50	44.84	48.74
62.2	23.16	28.29	30.22	32.78	35.34	37.91	40.60	43.94	47.84
67.3	22.26	27.39	29.32	31.88	34.45	37.02	39.71	43.04	46.95
72.4	21.37	26.50	28.42	30.99	33.55	36.12	38.81	42.15	46.05
77.5	20.47	25.60	27.53	30.09	32.65	35.22	37.91	41.25	45.15
82.6	19.57	24.70	26.63	29.19	31.75	34.32	37.01	40.35	44.25
87.6	18.67	23.80	25.73	28.29	30.85	33.42	36.11	39.45	43.35
92.7	17.77	22.90	24.83	27.39	29.96	32.52	35.22	38.55	42.46
97.8	16.88	22.00	23.93	26.50	29.06	31.63	34.32	37.66	41.56
102.9	15.98	21.11	23.04	25.60	28.16	30.73	33.42	36.76	40.66
108.0	15.08	20.21	22.14	24.70	27.26	29.83	32.52	35.86	39.76
111.8	14.40	19.54	21.46	24.03	26.59	29.16	31.85	35.18	39.09

Predicted intermuscular fat and muscle weight expressed as per cent of hot carcass weight

Carcass weight (kg)[1]	48.52	57.59	61.00	65.53	70.06	74.60	79.36	85.26	92.16[2]
Backfat (mm)[1]									
48.3	52.8[3]	53.4	53.6	53.8	54.0	54.1	54.3	54.4	54.6
52.1	51.4	52.2	52.5	52.8	53.0	53.2	53.4	53.6	53.9
57.2	49.6	50.6	51.0	51.4	51.7	52.0	52.3	52.6	52.9
62.2	47.7	49.1	49.5	50.0	50.4	50.8	51.2	51.5	51.9
67.3	45.9	47.6	48.1	48.6	49.2	49.6	50.0	50.5	50.9
72.4	44.0	46.0	46.6	47.3	47.9	48.1	48.9	49.4	50.0
77.5	42.2	44.4	45.1	45.9	46.6	47.2	47.8	48.	49.0
82.6	40.3	42.9	43.6	44.5	45.3	46.0	46.6	47.3	48.0
87.6	38.5	41.3	42.2	43.2	44.0	44.8	45.5	46.3	47.0
92.7	36.6	39.8	40.7	41.8	42.8	43.6	44.4	45.2	46.1
97.8	34.8	38.2	39.2	40.4	41.5	42.4	43.2	44.2	45.1
102.9	32.9	36.6	37.8	39.1	40.2	41.2	42.1	43.1	44.1
108.0	31.1	35.1	36.3	37.7	38.9	40.0	41.0	42.0	43.1
111.8	29.7	33.9	35.2	36.7	38.0	39:1	40.1	41.3	42.4

1. Values given for carcass weight and backfat are for the midpoints of the ranges given in the valuation schedule.

2. This value was obtained by adding the same increment separating the previous two midpoints to the previous midpoint.

3. Data from the current experiment fell within those cells enclosed by solid lines.

the predicted weights of muscle and lean respectively. The predicted weights were also expressed as percentages of the midpoint of the warm carcass weight classification for each cell of the schedule.

As expected, predicted total muscle content decreased as backfat increased within each carcass weight classification and muscle weight increased as carcass weight increased within each backfat classification. Expressed on a percentage basis, within each weight classification the per cent muscle decreased as the depth of backfat increased. Within the lowest backfat classification per cent muscle remained very stable as carcass weight increased. However, as backfat increased this stability of per cent muscle across carcass weight decreased until at the highest backfat classification per cent muscle was 24.3 in the lightest carcass classification, rising to 35.7 in the heaviest carcass classification.

A similar pattern was present in the lean and per cent lean (Table 30), except that a trend for per cent lean to increase as carcass weight increased was present at the low classification for backfat.

The prices paid per kg for estimated weight of muscle and lean are shown in Table 31. Within any fat depth classification, lowest prices were paid in carcasses of the heaviest classification; the next lowest price per kg of muscle and lean being paid for carcasses in the lightest carcass classification. However, in backfat classifications exceeding 92.7 mm the light carcasses were paid at the highest rate for muscle and lean. There was a trend over the entire table for the price paid per kg of muscle or lean to increase as backfat increased. It was found that within carcass weight classifications lower prices

Table 31. Prices paid per kg of estimated muscle weight and per kg of estimated muscle plus intermuscular fat weight within each cell of the hog carcass valuation schedule when carcass was valued at $0.62 per kg of hot carcass weight of grade index 100.

Price paid per kg of estimated muscle weight

Carcass weight (kg)[1] / Backfat (mm)[1]	48.52	57.59	61.00	65.53	70.06	74.60	79.36	85.26	92.16[2]
48.3	1.12[3]	1.35	1.40	1.42	1.44	1.44	1.44	1.17	1.10
52.1	1.16	1.36	1.41	1.44	1.45	1.47	1.47	1.20	1.11
57.2	1.20	1.40	1.43	1.46	1.48	1.49	1.48	1.22	1.14
62.2	1.26	1.42	1.46	1.47	1.49	1.52	1.50	1.25	1.16
67.3	1.32	1.45	1.49	1.49	1.51	1.53	1.52	1.28	1.19
72.4	1.38	1.49	1.52	1.53	1.53	1.55	1.53	1.32	1.22
77.5	1.46	1.52	1.55	1.55	1.56	1.56	1.54	1.35	1.25
82.6	1.53	1.54	1.59	1.58	1.59	1.60	1.57	1.39	1.28
87.6	1.62	1.54	1.63	1.62	1.61	1.62	1.59	1.43	1.31
92.7	1.72	1.61	1.64	1.65	1.65	1.64	1.60	1.47	1.34
97.8	1.84	1.69	1.64	1.67	1.68	1.68	1.64	1.51	1.38
102.9	1.96	1.78	1.73	1.67	1.69	1.70	1.66	1.49	1.37
108.0	2.11	1.88	1.81	1.74	1.68	1.71	1.66	1.53	1.41
111.8	2.24	1.96	1.88	1.80	1.74	1.68	1.63	1.56	1.44

Price paid per kg of estimated muscle plus intermuscular fat weight

Carcass weight (kg)[1] / Backfat (mm)	48.52	57.59	61.00	65.53	70.06	74.60	79.36	85.26	92.16[2]
48.3	1.03[3]	1.23	1.27	1.28	1.30	1.29	1.29	1.04	0.97
52.1	1.06	1.23	1.28	1.29	1.30	1.32	1.31	1.06	0.97
57.2	1.10	1.26	1.29	1.30	1.32	1.32	1.31	1.08	1.00
62.2	1.14	1.27	1.30	1.31	1.33	1.34	1.33	1.10	1.02
67.3	1.19	1.29	1.33	1.32	1.36	1.35	1.33	1.13	1.04
72.4	1.24	1.32	1.34	1.35	1.34	1.36	1.34	1.15	1.06
77.5	1.29	1.34	1.36	1.36	1.37	1.36	1.34	1.18	1.08
82.6	1.35	1.34	1.39	1.38	1.38	1.39	1.36	1.20	1.11
87.6	1.41	1.33	1.41	1.40	1.39	1.40	1.37	1.23	1.13
92.7	1.49	1.38	1.41	1.42	1.42	1.41	1.38	1.26	1.15
97.8	1.56	1.44	1.40	1.42	1.43	1.43	1.40	1.29	1.18
102.9	1.65	1.50	1.46	1.41	1.43	1.44	1.41	1.26	1.16
108.0	1.75	1.57	1.52	1.46	1.41	1.44	1.40	1.29	1.19
111.8	1.83	1.62	1.56	1.50	1.45	1.41	1.37	1.32	1.21

1. Values given for carcass weight and backfat are for the midpoints of the ranges given in the valuation schedule.

2. This value was obtained by adding the same increment separating the previous two midpoints to the previous midpoint.

3. Data from the current experiment fell within those cells enclosed by solid lines

were paid per kg of muscle in carcasses scoring an index of 100 or more than in carcasses scoring less than 100. There was one exception to this trend in carcass lean. Assuming that it costs about the same to process a fat carcass of a given weight as it does to process one with less backfat, the processing costs per kg of muscle or lean would increase as backfat increased. On this basis it would be expected that pigs with higher backfat measurements should be paid less per kg of muscle or lean than those with lower backfat; just the reverse of the situation outlined in Table 31.

Another way of looking at the situation is to trace the price paid per kg of muscle or lean in carcasses from different classifications but having approximately the same yield of muscle or lean. This involves a combination of values presented in Tables 29, 30 and 31 and for convenience the appropriate values have been extracted and are in Tables 32 and 33 for muscle and lean respectively.

In Table 32 it can be seen that approximately 25 kg of muscle was predicted at four combinations of carcass weight and backfat. As both carcass weight and backfat increased, the price paid per kg of muscle increased. This trend was present, but to a lesser degree, in carcasses yielding approximately 30 kg but the price had reached a peak and was declining at the heaviest carcass weight classification. For carcasses having approximately 35 kg of muscle the maximum price had shifted further towards lower backfat and lower carcass weight com binations. A similar trend was present in price paid per kg of lean (Table 33).

The previous tables have been computed using the existing indices in the tables of differentials. Use of these indices resulted in

Table 32. Combinations of carcass weights and backfat depths yielding carcasses containing approximately 25, 30 and 35 kg of predicted muscle, together with prices paid per kg of muscle.

Carcass weight (kg)	48.52	57.39	61.00	65.53	70.06	74.60	79.36	85.26	92.16
Backfat (mm)									
48.3			29.61[1] $1.40[2]						
52.1									
57.2				30.14 $1.46		34.53 $1.49			
62.2		25.37 $1.42							
67.3					30.45 $1.51		34.94 $1.52		
72.4			25.13 $1.52						
77.5									
82.6				25.43 $1.58		29.81 $1.60		34.96 $1.39	
87.6									
92.7							30.22 $1.60		
97.8					24.78 $1.68				
102.9									34.52 $1.37
108.0						25.09 $1.71		30.24 $1.53	
111.8									

1. Weight of estimated muscle (kg).

2. Price paid per kg of estimated muscle.

Table 33. Combinations of carcass weight and backfat depths yielding carcasses containing approximately 25, 30, 35 and 40 kg of predicted muscle plus intermuscular fat, together with prices paid per kg of tissue.

Carcass weight (kg)	48.52	57.59	61.00	65.53	70.06	74.60	79.36	85.26	92.16
Backfat (mm)									
48:52	25.63 $1.03			35.25 $1.28					
52.1		30.09 $1.23				39.71 $1.32			
57.2									
62.2			30.22 $1.30		35.34 $1.33		39.71 $1.33		
67.3									
72.4									
77.5		25.68 $1.34		30.09 $1.36		35.22 $1.36			
82.6								40.35 $1.20	
87.6			25.73 $1.41						
92.7					29.96 $1.42		35.22 $1.38		
97.8									
102.9				25.60 $1.41					
108.0						29.83 $1.44			39.76 $1.19
111.8								35.18 $1.32	

1. Weight of estimated muscle plus intermuscular fat (kg).

2. Price paid per kg of estimated tissue.

discrepancies in the prices paid for the muscle or lean in carcasses. Table 34 shows the existing indices together with those which would apply if muscle was valued at a constant price, regardless of the carcass weight classification or backfat depth of the carcass. Up to a backfat depth classification of 77.5 mm all carcasses would receive higher indices. For carcasses above the 87.6 mm backfat classification and weighing less than 85.26 carcass weight classification the trend would be for lower indices for carcasses as backfat depth increased. For carcasses within the 85.26 kg carcass weight classification or higher, the amended indices would be higher than the present indices over all backfat classifications, thus compensating such carcasses for their high muscle content. Similar comments are also applicable to Table 35 which is based on paying the same price over all classifications for the content of lean.

The basis for this examination has been yield of muscle or lean and this differs from the work on which the system was based since yield of cuts used in the original study included muscle, intermuscular fat, bone and some subcutaneous fat. This would account for the differences in the per cent yield in the published table of differentials and those presented for muscle and lean in this study. However, it is considered that a revision of the table of differentials incorporating some of the findings of this study would be beneficial to the Canadian hog industry. The amended indices give a wider range in indices (123 - 62 and 121 - 65 for muscle and lean respectively) than the existing table (112 - 82). A revision which resulted in such a widening of the range of indices would encourage the production of

Table 34. Actual grade indices and grade indices adjusted so that a uniform price would be paid for each kg of estimated muscle weight. Based on payment of $1.587 per kg muscle to carcass having index of 100 in cell located at 82.6 mm backfat and 70.06 kg hot carcass weight.

Carcass weight (kg)[1] / Backfat (mm)[1]	48.52[3]	57.59	61.00	65.53	70.06	74.60	79.36	85.26	92.16[2]
48.3	87 123	105 123	109 123	110 123	112 123	112 123	112 123	91 123	85 123
52.1	87 120	103 120	107 120	109 120	110 120	112 121	112 121	91 121	85 121
57.2	87 115	102 116	105 116	107 117	109 117	110 117	110 118	91 118	85 118
62.2	87 110	100 112	103 112	105 113	107 114	109 114	109 115	91 115	85 116
67.3	87 105	98 108	102 108	103 109	105 110	107 111	107 112	91 112	85 113
72.4	87 100	97 103	100 104	102 106	103 107	105 108	105 109	91 110	85 111
77.5	87 95	95 99	98 100	100 102	102 103	103 104	103 106	91 107	85 108
82.6	87 90	92 95	97 97	98 98	100 100	102 101	102 103	91 104	85 106
87.6	87 85	88 91	95 93	97 95	98 97	100 98	100 100	91 101	85 103
92.7	87 80	88 87	92 89	95 91	97 93	98 95	98 97	91 98	85 100
97.8	87 75	88 83	88 85	92 87	95 90	97 92	97 94	91 96	85 98
102.9	87 70	88 78	88 81	88 84	92 86	95 88	95 91	87 93	82 95
108.0	87 65	88 74	88 77	88 80	88 83	92 85	92 88	87 90	82 92
111.8	87 62	88 71	88 74	88 77	88 80	88 83	88 86	87 88	82 91

1. Values given for carcass weight and backfat are for the midpoints of the ranges given in the valuation schedule.

2. This value was obtained by adding the same increment separating the previous two midpoints to the previous midpoint.

3. Data from the current experiment fell within those cells enclosed by solid lines.

Table 35. Actual grade indices and grade indices adjusted so that a uniform price would be paid for each kg of estimated weight of muscle plus intermuscular fat. Based on payment of $1.380 per kg of muscle plus fat for carcass having index of 100 in cell located at 82.6 mm backfat and 70.06 kg hot carcass weight.

Carcass weight (kg)[1]	48.52	57.59	61.00	65.53	70.06	74.60	79.36	85.26	92.16[2]
Backfat (mm)[1]	[3]								
48.3	87 117	105 118	109 118	110 119	112 119	112 119	112 120	91 120	85 121
52.1	87 114	103 115	107 116	109 116	110 117	112 117	112 118	91 118	85 119
57.2	87 109	102 112	105 113	107 113	109 114	110 115	110 116	91 116	85 117
62.2	87 105	100 108	103 109	105 110	107 111	109 112	109 113	91 114	85 115
67.3	87 101	98 105	102 106	103 107	105 108	107 110	107 111	91 111	85 112
72.4	87 97	97 102	100 103	102 104	103 106	105 107	105 108	91 109	85 110
77.5	87 93	95 98	98 100	100 101	102 103	103 104	103 106	91 107	85 108
82.6	87 89	92 95	97 96	98 98	100 100	102 102	102 103	91 104	85 106
87.6	87 85	88 91	95 93	97 95	98 97	100 99	100 101	91 102	85 104
92.7	87 81	88 88	92 90	95 92	97 94	98 96	98 98	91 100	85 102
97.8	87 77	88 84	88 87	92 89	95 92	97 94	97 96	91 97	85 100
102.9	87 73	88 81	88 83	88 86	92 87	95 91	95 93	87 95	82 97
108.0	87 68	88 77	88 80	88 83	88 86	92 88	92 91	87 93	82 95
111.8	87 65	88 75	88 78	88 81	88 84	88 86	88 89	87 91	82 94

1. Values given for carcass weight and backfat are for the midpoints of the ranges given in the valuation schedule.

2. This value was obtained by adding the same increment separating the previous two midpoints to the previous midpoint.

3. Data from the current experiment fell within those cells enclosed by solid lines.

leaner carcasses by paying more for them and by paying much less for fat carcasses than current practice.

CONCLUSIONS

Prediction equations for total muscle were developed from measurements made routinely during hog carcass grading in Canada (i.e. carcass weight and backfat depths). Such equations gave results sufficiently accurate to agree broadly with those obtained by actual dissection. However, when predicted values were used in lieu of actual values in analysis of variance the percentage of estimated means falling within $\pm$ one standard error of the actual mean decreased when equations were used on carcasses which did not contribute to the data from which the prediction equation was derived. The addition of increasingly expensive predictors such as cavity fat and individual muscles to the predictors furnished by the hog valuation system resulted in improved accuracy of prediction. Thus research workers in Canada could interpret their results in terms of muscle production by use of such equations. However, it is considered that the equations were not rigorously tested in this experiment since cross-validation consisted of dividing the experiment into two breed groups, developing separate equations for those breed groups and applying these to the other half of the experiment. A more stringent test would be to apply the regression equations developed to carcasses derived from a completely different experiment and it is suggested that this should be done in future studies.

In view of the possibility of treatment effects on the relationship between a predictor and a predictant, it is considered that up-dating is an essential feature of the use of prediction equations. The prediction equations developed in this study should be considered merely as a basis, subject to continual up-dating. It is urged that future pig production studies include routine dissection of several carcasses from each treatment and that these be incorporated into an up-dated equation for use on the remaining carcasses produced on the experiment.

An exploration was made into the suggestion that predictors be measured and that inferences be made about the effects of treatments on actual muscle by examining the predictors themselves and not by estimating total muscle and making inferences on the basis of estimated muscle. It was found that in some cases similar inferences would have been made by considering either the predictor or actual muscle while in others it would have been misleading to do so. In view of this it is considered that caution should be used when interpreting results of treatment effects on indices of carcass composition.

Data were examined by use of analyses of variance followed by response surface analyses using production function prediction equations. Analyses of variance of main treatment effects and interactions on such variables as daily liveweight gain, feed conversion ratios and grade index, provided some insight into which treatments were superior for given situations. The response surface approach resulted in equations which provided opportunity for broader and more integrated interpretations. Combinations of inputs (treatments) which resulted in areas of most profitable response could be ascertained. A combination of conventional analyses of variance and the response surface approach was shown to be complementary and is recommended in pig production research.

A feeder operation was used as the basis for the economic analysis in this thesis. It is recognized that this was a simplified approach and the more complex conditions of large scale farrow to finish units should be subjected to a similar analysis. The final evaluation could be made by determining the combination of input variables which would result in higher return per unit of physical plant - perhaps returns per pen space per year. It is recommended that future hog production research incorporate an analysis of data using economic models designed to put monetary values on treatment effects. The use of the economic analysis demonstrated that gilts are considerably more profitable than male castrates. This demonstration supports the suggestion that weaner pigs be sold by sex at auction marts. It highlights the importance of research directed at sex determination. While there is discrimination against the use of boars as a source of pork it is felt that further research into the influence of sex status on performance is warranted. Such research could lead to moves to remove the discrimination against the use of boars as a source of pork.

The grading system strongly influenced the liveweight range within which slaughter achieved high returns per pen space per year. This was made apparent by valuing carcasses on a muscle content basis and demonstrating that the slaughter weight range within which high returns were achieved was widened. The revised table of differentials presented are not proposed as realistic alternatives to the existing schedule as no account was taken of the point that carcasses of heavier weights yield more muscle per unit of processing costs than do those of lighter weights. The amended differentials also ignore the influence of size of cuts on suitability for merchandising. Moreover the results from this experiment need to be treated with caution since they are based on a prediction equation derived from only 72 carcasses. However, the finding that within a carcass weight range the price paid per kg of muscle increased as the depth of backfat increased requires further investigation which perhaps could lead to an amended valuation grid. In addition, it is considered that the suggestion to widen the range in indices is worthy of further investigation as it would provide a greater incentive for the production of low backfat carcasses.

The grading system is an advanced technique which has enabled development of the sophisticated hog marketing procedures in use by the Alberta Hog Producers Marketing Board. Because of the fundamental importance of the system it is strongly recommended that it be subjected to periodic review. This study has demonstrated that the grading system may not be adequately rewarding producers who market pigs of high muscle content. Pig production research is being reported in terms of efficiency of muscle production and this and other studies have reported prediction equations for estimating total muscle. However, total muscle weight may not be a realistic measure of carcass merit. Consequently, it is urged that attention be given to the relationship between total muscle content and percent yield of retail cuts; currently the basis of the grading system.

Cross-validation is a procedure to be kept in mind when discussing regression equations be they referred to as prediction equations or production functions. Until it is known how much discrepancy there can be between research results and those which would be obtained on the commercial farm, recommendations made on the basis of experimental responses are suspect. Candler (1962) suggested that such unadjusted recommendations can only be regarded as untested hypotheses that have every chance of being inadequate. He proposed that an alternative was to issue recommendations based on responses determined under farm conditions.

The response surface methods used in this thesis require skilled staff and sophisticated computer hardware and software. Box and Draper (1969) have found that use of such accurate approaches limits the application of the technique in secondary industry. They concluded that it would be better to settle for a less sophisticated approach which could be used routinely in plant operation than to advocate an accurate method, so costly and complicated, that it would not be used routinely. Accordingly, they designed an operations research technique which could be conducted by plant foremen. They argue that operations research conducted in this manner is like natural evolution in that adjustment of the process variables to their best levels involves a process of natural selection in which unpromising combinations of the levels of the process variables are neglected in favour of promising ones.

It is considered that research aimed at adapting the type of routine operations research developed by Box and Draper (1969) to pig production is required. Such a technique could provide the fine tuning required to adapt research recommendations to commercial practice. The improvement attained in constantly moving towards the optimum conditions is not the only possible benefit. The replacement of a routine chore by a constantly altering production process with progress results constantly in view could lead to improved operator morale, a factor of some importance in the conduct of an intensive pig production unit.

There are many areas where attention is required in the adaption of the process to routine operation in a hog enterprise. Some of these areas include:

the development of a suitable record system,

definition of what constitutes a batch,

methods of providing several diets simultaneously,

whether or not to segregate sexes,

how to account for the removal of replacement breeding stock, and

the likely costs and returns.

While much work needs to be done in adapting the process to pig production it is considered that such a procedure would be beneficial in large scale production units which can apply the results to their pigs, their environment, their restriction on age at slaughter, their management and their feeds.

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Appendix I

The Response Function

The response function used to estimate each of the dependent variables in this study was the second degree polynomial

$$(1) \quad Y = A + BX_1 + CX_2 + DX_1^2 + EX_2^2 + FX_1X_2$$

where X_1 = Feed level

and X_2 = Slaughter weight.

The values of the intercept (A) and the regression coefficients (B, C, D, E, F) were derived using a multiple regression program.

The Isoquant Equation

For a constant value of Y = Y*, the isoquant function is derived from the response function by solving for X_2 in terms of X_1.

Since

$$Y^* = A + BX_1 + CX_2 + DX_1^2 + EX_2^2 + FX_1X_2$$

then

$$(E)X_2^2 + (C + FX_1)X_2 + (A + BX_1 + DX_1^2 - Y^*) = 0.$$

Using the solution of a standard form quadratic in X_2

$$(2) \quad X_2 = \frac{-(C + FX_1) \pm \sqrt{(C + FX_1)^2 - 4(E)(A + BX_1 + DX_1^2 - Y^*)}}{2E}$$

In order to do the plotting, there was defined a vector v (corresponding to feed level) with 100 elenents ranging in value from 3.212 to 4.4 in equal increments of 0.012.

From those values of v which had two solutions in equation (2) two vectors w_1 and w_2 (corresponding to slaughter weight) were generated for each isoquant. Those values of w_1 and w_2 which fell within the range of the data were plotted against the corresponding values of v.

Equations for the Solution of the Maximum Response

Two methods were employed in solving for the maximum response: A. Maximum response within the range of the data.
B. Maximum response outside the range of the data.

A. For those plots where the maximum value of the response lies within the range of the data (the boundaries of the plot), this value may be solved for directly.

On the response surface

$$Y = A + BX_1 + CX_2 + DX_1^2 + EX_2^2 + FX_1X_2$$

the maximum value of X_1 in terms of X_2 is the partial derivative (set to zero) of Y with respect to X_1.

$$\frac{\partial Y}{\partial X_1} = B + 2DX_1 + FX_2 = 0,$$

or

$$(3) \quad X_1 = \frac{-B}{2D} - \left(\frac{F}{2D}\right)X_2$$

Similarly, the maximum value of X_2 in terms of X_1 is

(4) $X_2 = \frac{-C}{2E} - \left(\frac{F}{2E}\right)X_1.$

Since the maximum response value (Y max) occurs at the intersection of (3) and (4), the X_1 coordinate ($x_1$max) of Y max is obtained by substituting the R.H.S. of (4) for X_2 in (3).

Thus

$$x_1max = \frac{-B}{2D} - \frac{F}{2D}\left(\frac{-C}{2E} - \frac{F}{2E}x_1max\right)$$

or

$$x_1max = \left(\frac{FC}{4DE} - \frac{B}{2D}\right) \div \left(1 - \frac{F^2}{4DE}\right).$$

Likewise,

$$x_2max = \left(\frac{FB}{4DE} - \frac{C}{2E}\right) \div \left(1 - \frac{F^2}{4DE}\right).$$

B. If the maximum response value lies outside the range of the data, the maximum appropriate to the data (Ydatamax) is found by solving for the largest response value along the plot boundary nearest the absolute maximum response.

For example, if Ymax has coordinates $x_1$max = 5 (%) and $x_2$max = 100 (kg), then, since the range of the data does not exceed $X_1 = 4.4$, the X_1 coordinate ($x_1$datamax) of Ydatamax is set to 4.4.

From (4)

$$x_2datamax = \frac{-C}{2E} - \left(\frac{F}{2E}\right)4.4$$

When the appropriate coordinates have been found, the value of Ymax or of Ydatamax is solved for by substituting the values of the coordinates into (1).

Appendix table 1. Parameters for regression equations relating inputs and outputs discussed in section I.

Dependent Variable	Unit	Intercept	FL_1	SW_2	FL^2	SW^2	(FL)(SW)	R^2	S.E.
Time on trial	Days								
Overall		407.74	-226.11	3.5709	27.411	$-0.683\ E^{-2}$	-0.2754	0.786	17.8
YL		579.90	-326.07	4.7836	38.216	$-0.142\ E^{-1}$	-0.2629	0.812	19.2
YLY		543.28	-282.05	2.0750	33.994	$-0.271\ E^{-2}$	-0.0431	0.854	13.9
Barrows		473.26	-262.84	3.9752	32.378	$-0.610\ E^{-2}$	-0.3801	0.795	19.5
Gilts		328.38	-179.95	3.2449	22.829	$-0.380\ E^{-2}$	-0.3618	0.851	14.4
Feed consumed	kg								
Overall		498.60	-267.20	1.1053	30.510	$0.120\ E^{-1}$	0.3211	0.896	29.4
Grade index									
Overall		111.52	3.4242	0.5131	-0.3895	$-0.503\ E^{-2}$	-0.0554	0.844	3.81
Hot carcass weight	kg								
Overall		13.154	-4.9946	0.5137	-0.1252	$-0.787\ E^{-4}$	0.0914	0.978	2.44
Total carcass muscle weight	kg								
Overall		-12.414	1.8549	0.6480	0.2772	$-0.567\ E^{-3}$	-0.0647	0.932	1.66
YL		-14.583	3.5599	0.5873	0.1333	$-0.188\ E^{-3}$	-0.0660	0.959	1.31
YLY		-17.835	3.8540	0.7076	0.0117	$-0.890\ E^{-3}$	-0.0660	0.921	1.91
Barrows		-23.701	-1.6784	1.0503	0.6466	$-0.277\ E^{-2}$	-0.0614	0.959	1.37
Gilts		29.403	-10.6580	0.1968	1.7290	$0.125\ E^{-2}$	-0.0341	0.941	1.56

(1) FL. Feed level
(2) SW. Slaughter weight

Appendix table 1 continued. Parameters for regression equations relating inputs and outputs discussed in section I.

Dependent Variable	Unit	Intercept	FL_1	SW_2	FL^2	SW^2	(FL)(SW)	R^2	S.E.
Total carcass muscle gained	kg								
Overall		-20.707	1.7844	0.6527	0.3567	-0.476 E^{-3}	-0.0716	0.926	1.71
YL		-19.479	1.6942	0.6092	0.4753	-0.833 E^{-4}	-0.0790	0.950	1.44
YLY		-19.850	0.4870	0.6872	0.4124	-0.916 E^{-3}	-0.0586	0.919	1.93
Barrows		-37.189	-0.6294	1.1239	0.6228	-0.300 E^{-2}	-0.0719	0.958	1.40
Gilts		23.555	-10.4186	0.1378	1.7529	0.166 E^{-2}	-0.0405	0.935	1.62
						E			
Total carcass fat weight	kg								
Overall		18.038	-7.4944	-0.1905	0.1689	0.866 E^{-3}	0.1102	0.856	2.96
YL		-18.527	-2.2928	0.4740	-0.3268	-0.238 E^{-2}	0.0853	0.868	2.84
YLY		71.680	-23.3850	-0.8209	1.7534	0.330 E^{-2}	0.1689	0.877	2.98
Barrows		10.368	2.9455	-0.4526	-0.8500	0.297 E^{-2}	0.0806	0.880	2.94
Gilts		11.591	-11.2860	0.1266	0.7101	-0.706 E^{-3}	0.0999	0.881	2.64
Total carcass fat gained	kg								
Overall		14.886	-7.5630	-0.1888	0.2375	0.954 E^{-3}	0.1044	0.849	3.01
YL		-18.639	-3.9039	0.4876	-0.0345	-0.227 E^{-2}	0.0744	0.864	2.83
YLY		73.908	-26.3257	-0.8390	2.1033	0.328 E^{-2}	0.1754	0.873	3.04
Barrows		2.723	3.8739	-0.3929	-0.8760	0.281 E^{-2}	0.0719	0.878	2.95
Gilts		10.466	-11.0800	0.0752	0.7315	-0.348 E^{-3}	0.0943	0.871	2.72
Total carcass bone weight	kg								
Overall		-1.318	0.9309	0.0672	-0.0994	-0.334 E^{-4}	-0.0041	0.891	0.32
YL		-2.243	0.8824	0.0942	-0.0780	-0.153 E^{-3}	-0.0062	0.848	0.39
YLY		2.674	-0.7063	0.0367	0.0600	0.600 E^{-3}	0.0026	0.954	0.22
Barrows		-0.887	-0.3777	0.1157	0.0306	0.306 E^{-3}	-0.0016	0.888	0.34
Gilts		1.467	0.5818	0.0132	-0.0532	0.226 E^{-3}	-0.0023	0.923	0.28

(1) FL. Feeding level
(2) SW. Slaughter weight

Appendix table 2. Canada hog carcass valuation system table of differentials

Backfat (mm)	Predicted yield %	Hot carcass weight (kg) 40.8[1] – 56.2	56.7 – 58.5	59.0 – 63.0	63.5 – 67.6	68.0 – 72.1	72.6 – 76.6	77.1 – 81.6	82.1 – 88.4	88.9 – +	Ridgling
- 48.3[1]	69.7	87	105	109	110	112	112	112	91	85	67
50.8 - 53.3	69.0	87	103	107	109	110	112	112	91	85	67
55.9 - 58.4	68.2	87	102	105	107	109	110	110	91	85	67
61.0 - 63.5	67.5	87	100	103	105	107	109	109	91	85	67
66.0 - 68.6	66.7	87	98	102	103	105	107	107	91	85	67
71.1 - 73.7	66.0	87	97	100	102	103	105	105	91	85	67
76.2 - 78.7	65.2	87	95	98	100	102	103	103	91	85	67
81.3 - 83.8	64.5	87	92	97	98	100	102	102	91	85	67
86.4 - 88.9	63.8	87	88	95	97	98	100	100	91	85	67
91.4 - 94.0	63.0	87	88	92	95	97	98	98	91	85	67
96.5 - 99.0	62.3	87	88	88	92	95	97	97	91	85	67
101.6 - 104.1	61.5	87	88	88	88	92	95	95	87	82	67
106.7 - 109.0	60.8	87	88	88	88	88	92	92	87	82	67
111.8 - +	60.1	87	88	88	88	88	88	88	87	82	67

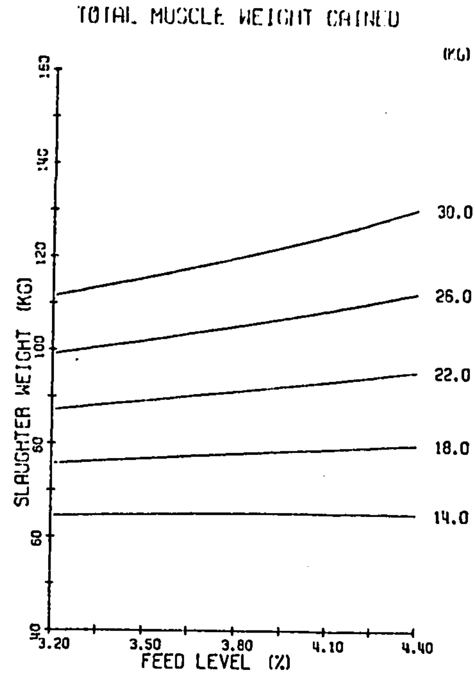
1. The published grading schedule is in pounds and inches; the values given here are the nearest metric equivalents.

Appendix table 3. Parameters for regression equations relating inputs and outputs discussed in section III.

Dependent Variable	Unit	Intercept	FL_1	SW_2	FL^2	SW^2	(FL)(SW)	R^2	S.E.
Carcass value grade index basis	$								
Overall		-122.97	4.2070	3.0740	-0.2755	$-0.1379\ E^{-1}$	$-0.2649\ E^{-1}$	0.969	1.78
Muscle value	$/kg								
Overall		-2.3951	0.0176	0.0785	-0.0100	$-0.4440\ E^{-3}$	$0.1410\ E^{-2}$	0.792	0.07
Carcass value muscle content basis	$								
Overall		-18.277	2.7194	0.9542	0.4103	$-0.8362\ E^{-3}$	$-0.9534\ E^{-1}$	0.932	2.44
Return per pig	$								
Overall		-180.17	25.190	2.8232	-2.6536	$-0.1382\ E^{-1}$	$-0.3726\ E^{-1}$	0.812	2.47
YL		-207.19	39.439	2.7471	-4.3358	$-0.1342\ E^{-1}$	$-0.3598\ E^{-1}$	0.836	2.33
YLY		-167.75	16.396	2.9538	-1.6082	$-0.1457\ E^{-1}$	$-0.3498\ E^{-1}$	0.836	2.50
Barrows		-195.94	29.138	3.0084	-3.1809	$-0.1506\ E^{-1}$	$-0.3228\ E^{-1}$	0.852	2.27
Gilts		-121.72	-1.4541	2.5594	0.2802	$-0.1345\ E^{-1}$	$0.2530\ E^{-1}$	0.818	2.55
Return per pen space per year	$								
Overall		-551.61	61.834	9.2159	-7.9606	$-0.4836\ E^{-1}$	$0.4378\ E^{-1}$	0.833	7.92
YL		-591.99	87.604	8.8421	-11.586	$-0.4743\ E^{-1}$	0.1022	0.849	7.67
YLY		-549.41	52.239	9.6805	-6.3194	$-0.5000\ E^{-1}$	$-0.4250\ E^{-2}$	0.842	8.25
Barrows		-574.69	62.701	9.7259	-8.3146	$-0.5216\ E^{-1}$	$0.7053\ E^{-1}$	0.869	7.18
Gilts		-403.23	-4.3345	8.4305	-0.8712	$-0.4711\ E^{-1}$	0.2257	0.838	8.25
Cross validated return per pen space per year	$								
Overall		-588.36	77.548	9.2925	-9.9039	$-0.4905\ E^{-1}$	$0.5714\ E^{-1}$	0.983	2.34

(1) FL. Feeding level
(2) SW. Slaughter weight

(a)

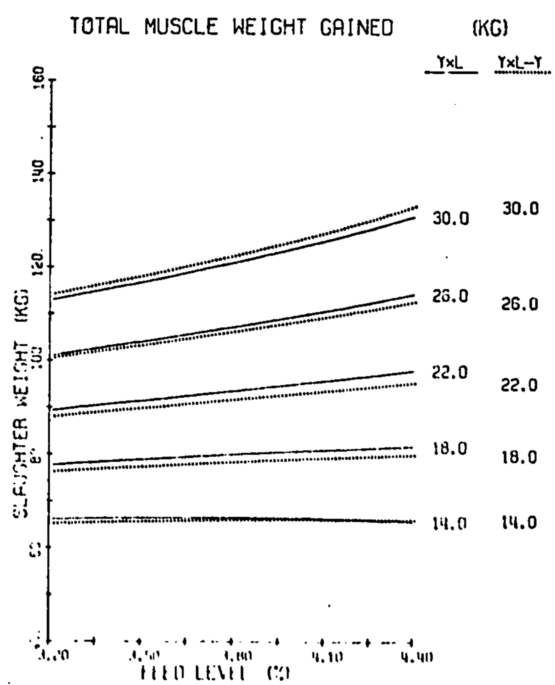


Appendix

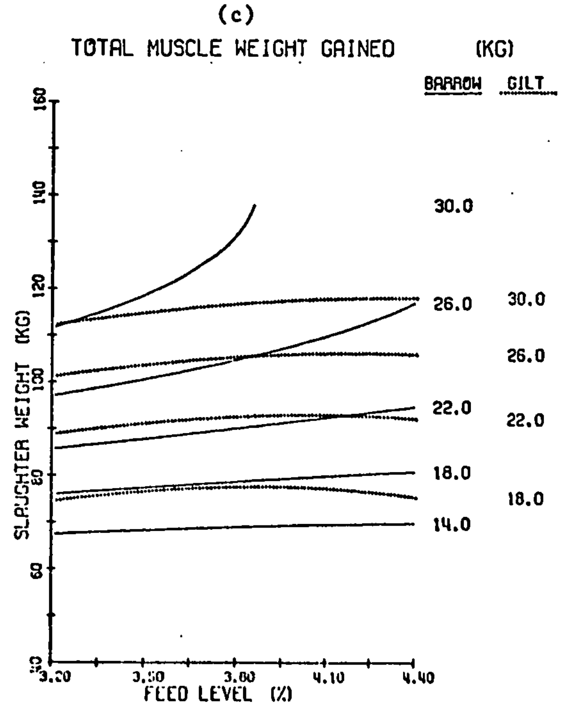
Figure 1. Isoquants for total weight of muscle gained showing the combinations of feed level and slaughter weight estimated to produce 14, 18, 22, 26 and 30 kg of total muscle weight gain in pigs. Isoquants are shown for the overall experiment (a), for the YL and YLY breed groups (b), and for barrows and gilts (c).

Plot	R^2	S.E.
Overall	0.926	1.71
YL	0.950	1.44
YLY	0.919	1.93
Barrows	0.958	1.40
Gilts	0.935	1.62

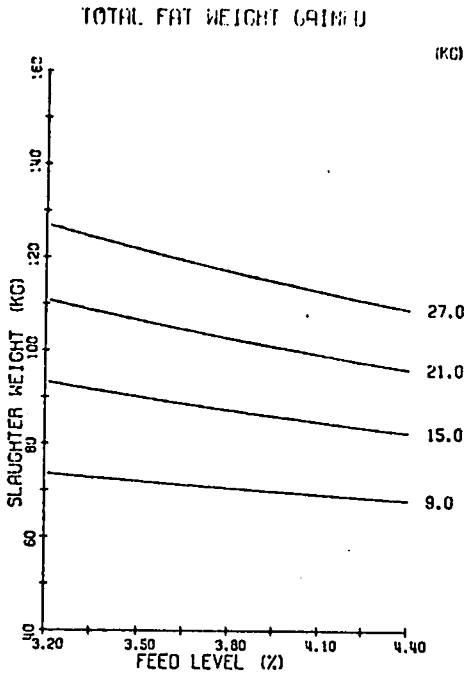
(b)



(c)



(a)

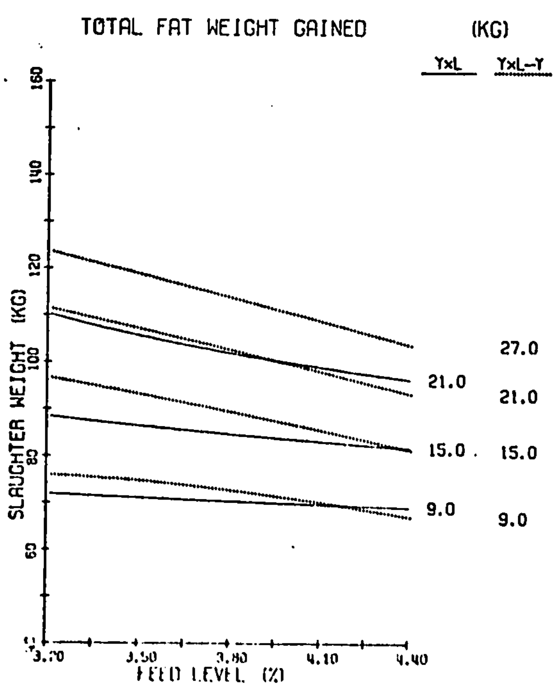


Appendix

Figure 2. Isoquants for total weight of fat gained showing the combinations of feed level and slaughter weight estimated to produce 9, 15, 21 and 27 kg of total fat gain in pigs. Isoquants are shown for the overall experiment (a), for the YL and YLY breed groups (b), and for barrows and gilts (c).

Plot	R^2	S.E.
Overall	0.849	3.01
YL	0.864	2.83
YLY	0.873	3.04
Barrows	0.878	2.95
Gilts	0.871	2.72

(b)



(c)