THE EFFECTS OF LIMIT-FEEDING ON TWO BREEDS OF BEEF CATTLE FED TO A COMMON BACKFAT LEVEL FOR SLAUGHTER

A Thesis
Submitted to the Faculty
of
Graduate Studies
The University of Manitoba

(36)

by

Robert G. McNabb

In Partial Fulfilment of the
Requirements for the Degree
of
Master of Science
Department of Animal Science

July 24, 1995

ISBN 0-612-13364-8

Name ______________________

Dissertation Abstracts International is arranged by broad, general subject categories. Please select the one subject which most nearly describes the content of your dissertation. Enter the corresponding four-digit code in the spaces provided.

Biological Sciences — SUBJECT TERM

0475 — SUBJECT CODE

U·M·I

Subject Categories

THE HUMANITIES AND SOCIAL SCIENCES

COMMUNICATIONS AND THE ARTS
Architecture 0729
Art History 0377
Cinema 0900
Dance 0378
Fine Arts 0357
Information Science 0723
Journalism 0391
Library Science 0399
Mass Communications 0708
Music 0413
Speech Communication 0459
Theater 0465

EDUCATION
General 0515
Administration 0514
Adult and Continuing 0516
Agricultural 0517
Art 0273
Bilingual and Multicultural 0282
Business 0688
Community College 0275
Curriculum and Instruction 0727
Early Childhood 0518
Elementary 0524
Finance 0277
Guidance and Counseling 0519
Health 0680
Higher 0745
History of 0520
Home Economics 0278
Industrial 0521
Language and Literature 0279
Mathematics 0280
Music 0522
Philosophy of 0998
Physical 0523
Psychology 0525
Reading 0535
Religious 0527
Sciences 0714
Secondary 0533
Social Sciences 0534
Sociology of 0340
Special 0529
Teacher Training 0530
Technology 0710
Tests and Measurements 0288
Vocational 0747

LANGUAGE, LITERATURE AND LINGUISTICS
Language
- General 0679
- Ancient 0289
- Linguistics 0290
- Modern 0291

Literature
- General 0401
- Classical 0294
- Comparative 0295
- Medieval 0297
- Modern 0298
- African 0316
- American 0591
- Asian 0305
- Canadian (English) 0352
- Canadian (French) 0355
- English 0593
- Germanic 0311
- Latin American 0312
- Middle Eastern 0315
- Romance 0313
- Slavic and East European 0314

PHILOSOPHY, RELIGION AND THEOLOGY
Philosophy 0422
Religion
- General 0318
- Biblical Studies 0321
- Clergy 0319
- History of 0320
- Philosophy of 0322

Theology 0469

SOCIAL SCIENCES
American Studies 0323
Anthropology
- Archaeology 0324
- Cultural 0326
- Physical 0327

Business Administration
- General 0310
- Accounting 0272
- Banking 0770
- Management 0454
- Marketing 0338

Canadian Studies 0385
Economics
- General 0501
- Agricultural 0503
- Commerce-Business 0505
- Finance 0508
- History 0509
- Labor 0510
- Theory 0511

Folklore 0358
Geography 0366
Gerontology 0351
History
- General 0578
- Ancient 0579
- Medieval 0581
- Modern 0582
- Black 0328
- African 0331
- Asia, Australia and Oceania 0332
- Canadian 0334
- European 0335
- Latin American 0336
- Middle Eastern 0333
- United States 0337

History of Science 0585
Law 0398
Political Science
- General 0615
- International Law and Relations 0616
- Public Administration 0617

Recreation 0814
Social Work 0452
Sociology
- General 0626
- Criminology and Penology 0627
- Demography 0938
- Ethnic and Racial Studies 0631
- Individual and Family Studies 0628
- Industrial and Labor Relations 0629
- Public and Social Welfare 0630
- Social Structure and Development 0700
- Theory and Methods 0344

Transportation 0709
Urban and Regional Planning 0999
Women's Studies 0453

THE SCIENCES AND ENGINEERING

BIOLOGICAL SCIENCES
Agriculture
- General 0473
- Agronomy 0285
- Animal Culture and Nutrition 0475
- Animal Pathology 0476
- Food Science and Technology 0359
- Forestry and Wildlife 0478
- Plant Culture 0479
- Plant Pathology 0480
- Plant Physiology 0817
- Range Management 0777
- Wood Technology 0746

Biology
- General 0306
- Anatomy 0287
- Biostatistics 0308
- Botany 0309
- Cell 0379
- Ecology 0329
- Entomology 0353
- Genetics 0369
- Limnology 0793
- Microbiology 0410
- Molecular 0307
- Neuroscience 0317
- Oceanography 0416
- Physiology 0433
- Radiation 0821
- Veterinary Science 0778
- Zoology 0472

Biophysics
- General 0786
- Medical 0760

EARTH SCIENCES
Biogeochemistry 0425
Geochemistry 0996
Geodesy 0370
Geology 0372
Geophysics 0373
Hydrology 0388
Mineralogy 0411
Paleobotany 0345
Paleoecology 0426
Paleontology 0418
Paleozoology 0985
Palynology 0427
Physical Geography 0368
Physical Oceanography 0415

HEALTH AND ENVIRONMENTAL SCIENCES
Environmental Sciences 0768
Health Sciences
- General 0566
- Audiology 0300
- Chemotherapy 0992
- Dentistry 0567
- Education 0350
- Hospital Management 0769
- Human Development 0758
- Immunology 0982
- Medicine and Surgery 0564
- Mental Health 0347
- Nursing 0569
- Nutrition 0570
- Obstetrics and Gynecology 0380
- Occupational Health and Therapy 0354
- Ophthalmology 0381
- Pathology 0571
- Pharmacology 0419
- Pharmacy 0572
- Physical Therapy 0382
- Public Health 0573
- Radiology 0574
- Recreation 0575
- Speech Pathology 0460
- Toxicology 0383

Home Economics 0386

PHYSICAL SCIENCES
Pure Sciences

Chemistry
- General 0485
- Agricultural 0749
- Analytical 0486
- Biochemistry 0487
- Inorganic 0488
- Nuclear 0738
- Organic 0490
- Pharmaceutical 0491
- Physical 0494
- Polymer 0495
- Radiation 0754

Mathematics 0405
Physics
- General 0605
- Acoustics 0986
- Astronomy and Astrophysics 0606
- Atmospheric Science 0608
- Atomic 0748
- Electronics and Electricity 0607
- Elementary Particles and High Energy 0798
- Fluid and Plasma 0759
- Molecular 0609
- Nuclear 0610
- Optics 0752
- Radiation 0756
- Solid State 0611

Statistics 0463

Applied Sciences

Applied Mechanics 0346
Computer Science 0984

Engineering
- General 0537
- Aerospace 0538
- Agricultural 0539
- Automotive 0540
- Biomedical 0541
- Chemical 0542
- Civil 0543
- Electronics and Electrical 0544
- Heat and Thermodynamics 0348
- Hydraulic 0545
- Industrial 0546
- Marine 0547
- Materials Science 0794
- Mechanical 0548
- Metallurgy 0743
- Mining 0551
- Nuclear 0552
- Packaging 0549
- Petroleum 0765
- Sanitary and Municipal 0554
- System Science 0790

Geotechnology 0428
Operations Research 0796
Plastics Technology 0795
Textile Technology 0994

PSYCHOLOGY
General 0621
Behavioral 0384
Clinical 0622
Developmental 0620
Experimental 0623
Industrial 0624
Personality 0625
Physiological 0989
Psychobiology 0349
Psychometrics 0632
Social 0451

Nom ______________________________

Dissertation Abstracts International est organisé en catégories de sujets. Veuillez s.v.p. choisir le sujet qui décrit le mieux votre thèse et inscrivez le code numérique approprié dans l'espace réservé ci-dessous.

______________________________ SUJET

☐☐☐☐ CODE DE SUJET

U·M·I

Catégories par sujets

HUMANITÉS ET SCIENCES SOCIALES

COMMUNICATIONS ET LES ARTS

Architecture 0729
Beaux-arts 0357
Bibliothéconomie 0399
Cinéma 0900
Communication verbale 0459
Communications 0708
Danse 0378
Histoire de l'art 0377
Journalisme 0391
Musique 0413
Sciences de l'information 0723
Théâtre 0465

ÉDUCATION

Généralités 515
Administration 0514
Art 0273
Collèges communautaires 0275
Commerce 0688
Économie domestique 0278
Éducation permanente 0516
Éducation préscolaire 0518
Éducation sanitaire 0680
Enseignement agricole 0517
Enseignement bilingue et multiculturel 0282
Enseignement industriel 0521
Enseignement primaire. 0524
Enseignement professionnel 0747
Enseignement religieux 0527
Enseignement secondaire 0533
Enseignement spécial 0529
Enseignement supérieur 0745
Évaluation 0288
Finances 0277
Formation des enseignants 0530
Histoire de l'éducation 0520
Langues et littérature 0279
Lecture 0535
Mathématiques 0280
Musique 0522
Orientation et consultation 0519
Philosophie de l'éducation 0998
Physique 0523
Programmes d'études et enseignement 0727
Psychologie 0525
Sciences 0714
Sciences sociales 0534
Sociologie de l'éducation 0340
Technologie 0710

LANGUE, LITTÉRATURE ET LINGUISTIQUE

Langues
- Généralités 0679
- Anciennes 0289
- Linguistique 0290
- Modernes 0291

Littérature
- Généralités 0401
- Anciennes 0294
- Comparée 0295
- Mediévale 0297
- Moderne 0298
- Africaine 0316
- Américaine 0591
- Anglaise 0593
- Asiatique 0305
- Canadienne (Anglaise) 0352
- Canadienne (Française) 0355
- Germanique 0311
- Latino-américaine 0312
- Moyen-orientale 0315
- Romane 0313
- Slave et est-européenne 0314

PHILOSOPHIE, RELIGION ET THÉOLOGIE

Philosophie 0422
Religion
- Généralités 0318
- Clergé 0319
- Études bibliques 0321
- Histoire des religions 0320
- Philosophie de la religion 0322

Théologie 0469

SCIENCES SOCIALES

Anthropologie
- Archéologie 0324
- Culturelle 0326
- Physique 0327

Droit 0398
Économie
- Généralités 0501
- Commerce-Affaires 0505
- Économie agricole 0503
- Économie du travail 0510
- Finances 0508
- Histoire 0509
- Théorie 0511

Études américaines 0323
Études canadiennes 0385
Études féministes 0453
Folklore 0358
Géographie 0366
Gérontologie 0351
Gestion des affaires
- Généralités 0310
- Administration 0454
- Banques 0770
- Comptabilité 0272
- Marketing 0338

Histoire
- Histoire générale 0578
- Ancienne 0579
- Médiévale 0581
- Moderne 0582
- Histoire des noirs 0328
- Africaine 0331
- Canadienne 0334
- États-Unis 0337
- Européenne 0335
- Moyen-orientale 0333
- Latino-américaine 0336
- Asie, Australie et Océanie 0332

Histoire des sciences 0585
Loisirs 0814
Planification urbaine et régionale 0999
Science politique
- Généralités 0615
- Administration publique 0617
- Droit et relations internationales 0616

Sociologie
- Généralités 0626
- Aide et bien-àtre social 0630
- Criminologie et établissements pénitentiaires 0627
- Démographie 0938
- Études de l' individu et de la famille 0628
- Études des relations interethniques et des relations raciales 0631
- Structure et développement social 0700
- Théorie et méthodes 0344
- Travail et relations industrielles 0629

Transports 0709
Travail social 0452

SCIENCES ET INGÉNIERIE

SCIENCES BIOLOGIQUES

Agriculture
- Généralités 0473
- Agronomie. 0285
- Alimentation et technologie alimentaire 0359
- Culture 0479
- Élevage et alimentation 0475
- Exploitation des péturages 0777
- Pathologie animale 0476
- Pathologie végétale 0480
- Physiologie végétale 0817
- Sylviculture et faune 0478
- Technologie du bois 0746

Biologie
- Généralités 0306
- Anatomie 0287
- Biologie (Statistiques) 0308
- Biologie moléculaire 0307
- Botanique 0309
- Cellule 0379
- Écologie 0329
- Entomologie 0353
- Génétique 0369
- Limnologie 0793
- Microbiologie 0410
- Neurologie 0317
- Océanographie 0416
- Physiologie 0433
- Radiation 0821
- Science vétérinaire 0778
- Zoologie 0472

Biophysique
- Généralités 0786
- Medicale 0760

SCIENCES DE LA TERRE

Biogéochimie 0425
Géochimie 0996
Géodésie 0370
Géographie physique 0368
Géologie 0372
Géophysique 0373
Hydrologie 0388
Minéralogie 0411
Océanographie physique 0415
Paléobotanique 0345
Paléoécologie 0426
Paléontologie 0418
Paléozoologie 0985
Palynologie 0427

SCIENCES DE LA SANTÉ ET DE L'ENVIRONNEMENT

Économie domestique 0386
Sciences de l'environnement 0768
Sciences de la santé
- Généralités 0566
- Administration des hipitaux 0769
- Alimentation et nutrition 0570
- Audiologie 0300
- Chimiothérapie 0992
- Dentisterie 0567
- Développement humain 0758
- Enseignement 0350
- Immunologie 0982
- Loisirs 0575
- Médecine du travail et thérapie 0354
- Médecine et chirurgie 0564
- Obstétrique et gynécologie 0380
- Ophtalmologie 0381
- Orthophonie 0460
- Pathologie 0571
- Pharmacie 0572
- Pharmacologie 0419
- Physiothérapie 0382
- Radiologie 0574
- Santé mentale 0347
- Santé publique 0573
- Soins infirmiers 0569
- Toxicologie 0383

SCIENCES PHYSIQUES

Sciences Pures

Chimie
- Genéralités 0485
- Biochimie 487
- Chimie agricole 0749
- Chimie analytique 0486
- Chimie minérale 0488
- Chimie nucléaire 0738
- Chimie organique 0490
- Chimie pharmaceutique 0491
- Physique 0494
- PolymÇres 0495
- Radiation 0754

Mathématiques 0405
Physique
- Généralités 0605
- Acoustique 0986
- Astronomie et astrophysique 0606
- Electronique et électricité 0607
- Fluides et plasma 0759
- Météorologie 0608
- Optique 0752
- Particules (Physique nucléaire) 0798
- Physique atomique 0748
- Physique de l'état solide 0611
- Physique moléculaire 0609
- Physique nucléoire 0610
- Radiation 0756

Statistiques 0463

Sciences Appliqués Et Technologie

Informatique 0984
Ingénierie
- Généralités 0537
- Agricole 0539
- Automobile 0540
- Biomédicale 0541
- Chaleur et ther modynamique 0348
- Conditionnement (Emballage) 0549
- Génie aérospatial 0538
- Génie chimique 0542
- Génie civil 0543
- Génie électronique et électrique 0544
- Génie industriel 0546
- Génie mécanique 0548
- Génie nucléaire 0552
- Ingénierie des systömes 0790
- Mécanique navale 0547
- Métallurgie 0743
- Science des matériaux 0794
- Technique du pétrole 0765
- Technique minière 0551
- Techniques sanitaires et municipales 0554
- Technologie hydraulique 0545

Mécanique appliquée 0346
Géotechnologie 0428
Matières plastiques (Technologie) 0795
Recherche opérationnelle 0796
Textiles et tissus (Technologie) 0794

PSYCHOLOGIE

Généralités 0621
Personnalité 0625
Psychobiologie 0349
Psychologie clinique 0622
Psychologie du comportement 0384
Psychologie du développement 0620
Psychologie expérimentale 0623
Psychologie industrielle 0624
Psychologie physiologique 0989
Psychologie sociale 0451
Psychométrie 0632

THE EFFECTS OF LIMIT-FEEDING ON TWO BREEDS OF BEEF CATTLE FED TO A COMMON BACKFAT LEVEL FOR SLAUGHTER

BY

ROBERT G. MCNABB

A Thesis submitted to the Faculty of Graduate Studies of the University of Manitoba in partial fulfillment of the requirements of the degree of

MASTER OF SCIENCE

ACKNOWLEDGEMENTS

I wish to express my gratitude to my advisors, Dr. T. Devlin in the beginning, and Dr. G. Crow in the completion phase of this study. Counsel from the advisory committee, Drs. G. Crow, T. Devlin, R. Richmond and R. Smith and the examining committee, Drs. A. Kennedy, G. Crow, R. Smith and D. Veira was very much appreciated.

I owe a special thanks to Lorne Dawadiuk and the staff at the Glenlea Research Station for the valuable assistance they provided to me during the trials. I would like to express my appreciation to the staff of Manitoba Agriculture who provided support and encouragement throughout the endeavour.

I wish to dedicate this paper to my family, whose support and faith was unwavering and very much appreciated.

ABSTRACT

Backgrounding feeder cattle by limiting energy concentration intake during an initial period in the finishing phase is an important management system alternative for Manitoba cattle producers. The objective of this study was to examine the effects on performance and carcass attributes by limiting energy concentration intakes on two breeds of beef cattle. Two trials were conducted over two years with Angus steers and Simmental-cross steers fed two levels of energy concentration (High Energy - HE; Low Energy - LE) for 84d during the growth period. LE steers were adjusted to an ad libitum feeding regime equivalent to the energy concentration intakes of the HE steers to the end of the trial period. Feed intake and animal weight data were collected to determine if the LE steers would exhibit compensatory growth during the final finishing phase. Ultrasound measurements of the live animal backfat thickness were monitored to determine the market readiness of all steers. Carcass data was collected and analyzed to determine if the compensatory growth exhibited by the LE steers had an effect on carcass traits when compared to HE steers at a common backfat measurement. The LE steers in both years of the trial exhibited growth performance improvement. Digestible energy (DE) intake and feed efficiency, measured by DE intake/gain was enhanced after feed intake adjustments for the LE steers to an ad libitum feeding regime. There were no significant detrimental effects on the carcass traits of LE steers compared to HE steers slaughtered at a common backfat measurement. The ultrasound measurements of the live animals were accurate in predicting the market readiness of these feedlot steers. The use of limit feeding for backgrounding and ultrasound technology in a beef production system may have practical and economic implications for beef producers.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDIX TABLES

ABBREVIATIONS

AAFC	Agriculture and Agrifood Canada
d	day
DE	Digestible Energy
DEWT	Digestible Energy Intake relative to weight
FEM	Feed efficiency mean
GBF	Graded Backfat
HE	High Energy
kg	kilogram
LE	Low Energy
LP	Lean Percentage
MB	Marbling
Mcal	Mega calories
REA	Rib-eye Area
SWT	Sale Weight
TDay	Trial Day
TDN	Total Digestible Nutrients
UBF	Ultrasound Backfat
WCW	Warm Carcass Weight
Wt.	Weight
Y1	Year 1
Y2	Year 2

INTRODUCTION

Today's competitive beef industry requires producers to continually assess alternative production systems which will be resource efficient and sustainable, provide economic return and produce the products demanded by the market, domestic and global. Manitoba's beef cattle industry, in particular, relies on a number of production systems and markets, which are mainly at a significant distance from the farm. Backgrounding feeders, where cattle are grown from weaning (250 - 280 kg) to a weight of 340 - 385 kg and then finished or transported to another site is recognized as a feasible alternative system to the traditional systems of selling weaned calves or placing cattle on full feed at 250 kg. Backgrounding is primarily accomplished with forage-based rations, but may include grain if the economics are viable. Backgrounding limits or controls the potential genetic expression for growth of cattle, and the effect this restricted growth may have on the animals performance during the final growth phase and in producing an acceptable market product requires further study.

Backgrounding or limit-feeding cattle will often create the potential for compensatory growth during the finishing phase of production. Compensatory growth is the phenomenon manifested in animals, previously limited in feed or nutrient intake, to realize enhanced growth rates when given free access to good quality feed. There is little current information in the literature on the effect limit-feeding followed by compensatory growth has on the ultimate product of the production system, the carcass. While a significant number of studies have been undertaken on the matter, results vary, as do the conclusions identifying the precise mechanisms which contribute to compensatory growth (O'Donovan, 1984).

Moran and Holmes (1978) stated that compensatory gain can be defined as having occurred if: 1) following a period of undernutrition when the animal's growth rate has been retarded; 2) it is realimentated on an ad libitum ration and 3) it grows at a rate which is faster than that for a continuously fed animal of comparable chronological age.

In more recent studies, the debate on the cause and effect of compensatory growth has continued. Limiting total feed intake during a specific period in the growth phase has been examined by many workers, but their results have led to inconsistent conclusions as to the mechanisms of compensatory growth (Park et al., 1987, Wright and Russel, 1987, Hicks et al., 1990, Yamabayamba and Price, 1991). Many workers have concentrated on the study of specific nutrient components of the diet to explain the cause and effect of compensatory growth. Energy intake and utilization has been the focus of other studies (Meyer et al., 1965, Drori et al., 1974, Byers, 1982, Thomson et al., 1982, Merchan et al., 1987, Old and Garrett, 1987, Keane et al., 1990, Carsten et al., 1991, McKinnon et al., 1993). Other research has examined the role of protein intake during a feed restriction phase and the subsequent effect on compensatory growth (Bohman and Torell, 1956, Fox et al., 1972, Byers, 1982, Abdalla et al., 1988, Anderson et al., 1988, Madar et al., 1989, Drouillard et al., 1991, Sindt et al., 1993). Some workers have differentiated the cause and effect of compensatory growth on the basis of breed type (Smith et al., 1977, Jones et al., 1994) and feeder frame size (Oltjen, 1986, Tatum et al., 1986, Oltjen and Garrett, 1988), relative to the ability to fatten at specific weight and finish endpoints.

Numerous studies have examined the effect of compensatory growth on the ultimate product of commercial beef cattle production, the carcass. Carcass composition (Tatum et al., 1988; Oltjen and Garrett, 1988; Wright and Russel, 1991; Coleman et al., 1993, Murphy and Loerch, 1994) has been studied to quantitate the effect of compensatory growth on the constituents of the carcass. Other researchers have examined the effect on the more practical basis of carcass yield and quality to demonstrate the commercial application of compensatory growth manipulation in the feedlot (Hicks et al., 1990; Keane et al., 1990; Bruce et al., 1991; Yambayamba and Price, 1991; Kabbali et al., 1992).

A technology which may provide assistance to producers in monitoring the growth performance of cattle is the use of ultrasound to predict the level of subcutaneous backfat in live feeder cattle and determine the endpoint of feeding for a feeder or slaughter market. Houghton and Turlington (1992) reviewed the literature describing and evaluating the application of ultrasound for feeding and finishing animals. Specific studies have been conducted to evaluate the technology for accuracy and use in commercial production (Houghton, 1988; Perkins et al., 1992; Robinson et al., 1992; Smith et al., 1992; Herring et al., 1994).

The objective of the present study was to determine the effect of a low level of feed intake during the initial feedlot finishing phase on growth patterns and feed efficiencies of two breeds of beef cattle representing two frame sizes, and the subsequent effect of any evident compensatory growth on the carcass trait components of yield and quality when the steers are slaughtered at a constant level of subcutaneous backfat.

A secondary objective was to determine the accuracy of ultrasound measurement of the live animal subcutaneous backfat in predicting the graded backfat measurement of the carcass.

Both objectives may have practical implications for commercial feedlot production for determining feeding system management for some types of feeder cattle and predicting market readiness with the desired finish for slaughter.

LITERATURE REVIEW

COMPENSATORY GROWTH

Bohman (1955) reported that consistently each summer, animals in a hay maturity study that had been restricted (in feed intake) during the winter gained more rapidly than the control animals. This was thought to have been influenced by age, severity of winter growth restriction, and quantity of feed available during the summer.

Wilson and Osbourne (1960) in a comprehensive review of the subject to that date, identified six major factors which contribute to compensatory growth in animals. They were: increase in body tissue, increase in gut fill, lower maintenance requirements, more efficient food utilization, altered energy value and increase in appetite.

Effect by Limiting Feed Intake

The normal growth pattern of animals allowed unrestricted access to feed follows an often cited sigmoidal curve (Park, 1982). This has been studied extensively in many species, including beef cattle. This typical pattern of growth is far from a constant, however, and the natural environment as well the management practices in cattle production systems can create a variety of alternative growth patterns. Restricting feed or nutrient intake is one such system.

Degrees of restriction of feed may range from inanition (a partial or total lack of all nutrients) to only minor reductions from ad libitum (unrestricted access) feeding (O'Donovan, 1984). In his review of previous studies, O'Donovan (1984) distinguished between two causes of reduced growth which lead to the same end result. These are (a) the intake of sub-optimum amounts of good quality feed and (b) free access to feed limiting in one or more essential nutrients. The result in both cases, during realimentation, is well documented as compensatory growth. Park et al. (1987) noted that different opinions are expressed in the literature with regard to compensatory and growth responses because of the differences in the duration, timing, level, and combination of dietary nutrients imposed in the various experiments.

Animals expressing compensatory growth have been shown to exhibit greater feed intake and a significantly higher daily gain than conventionally-fed (ad libitum) animals of a similar age during a similar period (Koch, 1982; Park et al., 1987). Lofgreen and Kiesling (1985), in an experiment with receiving rations and stressed feeder calves, concluded that the increased feed intake during the finishing period accounted for the compensatory gains achieved during the growing-finishing period. Coleman and Evans (1986) showed similar results with steers of varying ages, but concluded that restricted animals rarely compensate totally and usually require more time for the total production scheme, thus increasing maintenance costs, and questionable practical applications. The question also remains if the animals ate more because they grew more, or grew more because they ate more.

Common to a number of studies is the concept that the results in live weight are the same for beef cattle of the same age fed different planes of nutrition (Lopez Saubidet and Verde, 1976; Lofgreen and Kiesling, 1985; Wright and Russel, 1987). On the other hand, in studies where feed intake was limited, animals undergoing the resulting compensatory growth exhibited a trend ($P > .05$) towards improved gains and live weight (Lofgreen et al., 1987). This had been demonstrated earlier by Fox et al.(1976) who showed that the relative increases in gains by steers undergoing compensatory growth over control steers varied with ration and length of feeding period. Steers undergoing compensatory growth were shown by Fox et al. (1976) to gain significantly ($P < .01$) faster and to require significantly ($P < .01$) less feed per kilogram of gain during the full feeding period than did the controls. Saubidet and Lopez (1976) offered the theory that limited feed intake prior to compensatory growth provided for lower maintenance requirements in the feed restricted animals at the beginning of realimentation period.

Hicks et al. (1990) offered a number of possible explanations for the cause and effect of restricted feeding resulting in improved feed efficiency. These include: reduced maintenance requirements, altered behaviour or energy expenditures, increased diet digestibility, and reduced feed wastage from spillage and spoilage. Hicks et al. (1990) showed that the efficiency of feed use, on a live weight basis, tended to be improved ($P = .11$) with limit feeding. Yambayamba and Price (1991) demonstrated that heifers initially restricted in feed for 4 months had a greater growth rate ($P < .05$) than heifers restricted in feed for only 2 months.

Protein Intake and Utilization During Compensatory Growth

Numerous studies have examined the relationship of limited feed intake, the subsequent increase in feed intake and efficiency and whether protein and energy utilization are factors responsible for the results (O'Donovan, 1984). Restricted protein in the post-weaning growth phase has been shown to result in the requirement of more days on feed to reach a final body fat endpoint despite the compensatory growth effect (Abdalla et al., 1988).

Bohman and Torell (1956) illustrated that animals fed a supplemental protein source gained significantly more during the winter than unsupplemented animals. The unsupplemented animals, however, which displayed a comparative retarded growth, compensated during the following summer and were as heavy at the end of trial as the supplemented group.

Fox et al. (1972) showed that weight gains made by compensating steers were higher in the body protein constituents and lower in fat (energy) body constituents than controls during the first part of the full feeding period, but higher in fat and lower in protein than controls during the last part of the full feeding period. The conclusion made by Fox et al. (1976) was that an increase in efficiency of protein utilization was evident in compensating steers so that by the time a weight endpoint, similar to controls was reached, both groups were similar in efficiency. Byers (1982) reported that the rate of protein growth decreased with increasing body weight, which indicated effects of age and relative maturity on protein deposition. Also, rates of protein growth increase very little at rates of gain in excess of 1.0 kg d^{-1}, which documents the existence of a biological limit for daily protein growth.

Turgeon et al. (1986) concurred with these results in their study with sheep, when they found that compensatory growth in lambs can occur in either of the two stages of growth and finishing; a greater proportion of protein gain was made early in the finishing phase.

In a study on the effect of dietary crude protein level on the growth rate of beef bulls, Anderson et al. (1988) found that limiting crude protein intake below NRC (1984) recommended levels for a sustained period resulted in decreased finish on the animals. Abdalla et al. (1988) showed that the degree of protein restriction altered the amount of compensatory gain; those animals that gained less during low-protein feeding gained faster during recovery and that efficiency of gain (gain/feed) always was higher for the compensating groups, than for the ad libitum fed animals.

Drouillard et al. (1991) compared the effects of metabolizable protein and energy restrictions on subsequent compensatory growth. Their findings, in slight support of the aforementioned, were that compensatory growth was influenced by differences in duration and severity of nutrient deprivation, but to a lesser extent for protein-restricted steers than for energy-restricted steers. Mader et al. (1989) showed that steers placed on high-energy finishing diets immediately after an extended period of nutritional restriction will respond to levels of protein higher than recommended, supporting the theory of energy-protein utilization interaction found by other workers (Fox et al., 1972; Abdalla et al., 1988).

In an evaluation of beef production systems, Sindt et al. (1993) reported that a higher level of metabolizable protein in the finishing diet may be required to maximize the feed efficiency if the calves are expressing compensatory growth. From these studies, we can generally agree that during the period of compensation, protein content of the diet is an important constituent. However, in creating the disposition of animals for compensatory growth, limited protein intake may not be as significant a factor as restricted energy intake.

Energy Intake and Utilization During Compensatory Growth

Various growth rates resulting from the consumption of different types and quantities of feed are important for the economical production of beef cattle (O'Donovan, 1984), since it results in the development of different production systems, based on sustainable resources. A number of studies on the correlation of energy intake, energy utilization and compensatory growth have been undertaken (Meyer et al., 1965; Fox et al., 1972; Drori et al., 1974; Rompala et al., 1985; Turgeon et al., 1986; Old and Garret, 1987).

The majority of studies have reported that energy intake and utilization are increased during compensatory growth. Meyer et al. (1965) showed that the efficiency of energy utilization (daily gain divided by daily digestible energy intake) was greater for the steers previously fed a low energy intake and subsequently fattened and exhibiting compensatory growth. Fox et al. (1972) found similar results in that compensatory steers in their experiment had higher daily gains and feed efficiency than controls during the full feeding period and went further to conclude that the increased efficiency of energy and protein utilization during the full feeding period was evident during the compensatory growth response. Fox et al. (1972) also found a trend for net energy used for maintenance, gain and efficiency of metabolizable energy utilization to be higher for steers exhibiting compensatory growth, which were supported by later studies (Byers, 1982; Thomson et al., 1982; Carsten et al., 1991; Drouillard et al. 1991).

Thomson et al. (1982) reported that in an experiment with lambs and steers which were mildly restricted in nutrition, during the recovery phase, realimented steers gained significantly more than control animals from a similar metabolizable energy intake and required less ME kg^{-1} daily live weight gain. This led Thomson et al. (1982) to conclude that indirect evidence suggests an improved utilization of metabolizable energy for protein deposition, at least at the beginning of realimentation for animals which have undergone feed restriction.

The majority of studies indicate that increases in energy intake do occur during compensatory growth and that this is accompanied by increased efficiencies of utilization. This may be due to the reduced maintenance requirements at the beginning of realimentation, and into the compensatory growth period.

Effect on Animal Genotype

The genetic differences in the capacity to exhibit compensatory growth under the same feeding regimes has been well documented (O'Donovan, 1984). Genetic differences among individual animals and breeds which differ in age and liveweight at maturity are likely, in part, responsible for the variable responses between experiments in both performance and carcass yields and composition (O'Donovan, 1984).

Some studies have examined the genetic differences by studying cattle of different frame size (Smith et al., 1977; Tatum et al., 1986; Oltjen and Garrett, 1988). Although not distinctly different in approach, other workers have examined compensatory growth with animals varying in maturity at specific liveweight endpoints (Rompala et al., 1985; Old and Garrett, 1987; Keane et al., 1990; McKinnon et al., 1993). Rompala et al. (1985) reported that cattle of a large frame genotype fed lower energy diets may not finish at a reasonable liveweight or within an economical length of time. They concluded that the dietary energy intake would be primarily used for maintenance and lean growth, particularly during a compensatory growth phase. This is supported by the work of Tatum et al. (1986) who reported that larger genotypes tend to be younger at a given weight (because of their faster growth rate), less mature (because of their slower maturing rates and younger ages) and leaner (because of their tendency to fatten at relatively higher weights).

Oltjen et al. (1986) utilized a computer model to study beef cattle growth and composition under the same production system. Their research, while supporting previous findings, also concluded that at a given body weight for animals fed different quantities of diets of high energy concentration, the fat composition of steers increases as total energy intake increases across cattle genotypes. Further, Oltjen et al. (1986) found that fatter animal genotypes fed a high energy diet, ad libitum, remain fatter throughout subsequent growth. Old and Garrett (1987) compared two breeds of different maturity size and found that large, late-maturing animals used feed energy less efficiently for gain than the smaller, early-maturing animals. As well, ad libitum fed steers used feed energy less efficiently for gain than steers at lower intakes for both types.

In would appear that although beef cattle differing in specific genetic makeup will perform at varying rates during compensatory growth, the resulting effects of the compensatory growth on the growth characteristics are similar enough to allow for the same production system to be utilized, regardless of genetic differences.

EFFECT OF COMPENSATORY GROWTH ON CARCASS TRAITS

The effect on the ultimate product of beef cattle production, the carcass, is of utmost importance in evaluating the benefits compensatory growth may have. In his review of the subject, O'Donovan (1984) found that, in general, one or more periods of (feed) restriction during post-natal life has no, or only minor, effects on meat quality. Tudor et al. (1980) concluded that restrictions (feed) early in post-natal life may result in slight changes in carcass and body composition in intensively-finished cattle, but make no difference in pasture-fed cattle at the same weight constant. The effect of a severe restriction in growth in early post-natal life on the development of individual muscle and bones disappears by slaughter (380-400 kg). Others have also demonstrated little or no effect on carcass composition subsequent to a compensatory growth phase (Hancock et al., 1987; Old and Garrett, 1987; Keane et al., 1990; Carsten et al., 1991; Wright and Russel, 1991; Yambayamba and Price, 1991). However, there is not complete agreement on this issue. Numerous studies have shown an increase in carcass yields (lean meat) following compensatory growth (Morgan, 1972; Hironaka and Kozub, 1973; Sully and Morgan, 1982). Kabbali et al (1992) demonstrated that lambs undergoing compensatory growth had improved feed efficiency and resulted in leaner carcasses than controls at the same weight. This is supported by cattle studies which achieved similar results, ie. leaner carcasses for compensatory animals (Smith et al., 1977; Madar et al., 1989; Coleman et al., 1993).

In a study that concluded that improvement of partial efficiency of feed utilization and feeding capacity were responsible for compensatory growth, Meyer et al. (1965) reported that fat content, backfat thickness, marbling score and rib-eye area were enhanced due to compensatory growth when animals were slaughtered at a common weight. Hancock et al. (1987) reported that steers grown on a forage system with low palatability forages and then finished in a feedlot compensated in rib-eye area, marbling and quality grade as days in the feedlot increased, when compared to conventional feedlot steers. Old and Garrett (1987) achieved similar results and reported that although steers consuming the lowest level of feed made gains containing a lower level of percentage of fat and a higher percentage of protein than steers at higher intakes, body composition within a breed was not altered by the level of energy intake when animals, within breeds, were slaughtered at similar weight endpoints. This is further supported by Bartle et al. (1994).

In comparing breed types differing in maturity crossed with a common control breed, Keane et al. (1990) found that there was no significant interactions between breed type and dietary metabolizable energy concentration for carcass composition traits on a weight constant basis. They concluded that the effects of diet on carcass composition were similar for the three breed types.

Carsten et al. (1991) suggested that the change in composition of empty-body tissue during compensatory growth was dependent on the stage of maturity at which growth is restricted and(or) the severity of the growth restriction. The experiment by Carsten et al. (1991) showed no significant difference in the economically-important carcass components between normal growth and compensatory-growth steers, but did show differences in non-carcass components (bone, gut-fill) when the data was adjusted to common weights. In support of this, Wright and Russel (1991) demonstrated a two-phase growth process, whereby during the first phase of growth, feed-restricted cattle initially showed enhanced proportions of protein and water in the empty body-weight gain and a reduced proportion of fat. A second phase of growth resulted when fat deposition increased and protein and water deposition decreased. The net result of the findings of Wright and Russel (1991) were that the body composition of feed-restricted cattle eventually reached that of unrestricted cattle.

Although some carcass traits may be enhanced by the effect of compensatory growth during the finishing stages, there appears to be significant evidence that at a constant live-weight endpoint for cattle with similar genetic potential for growth and development, the economically important carcass traits, such as lean percentage and subcutaneous fat, are not adversely affected by compensatory growth.

PREDICTING GROWTH ENDPOINT FOR SLAUGHTER

The evaluation of alternative production systems in the beef cattle industry is ultimately at the time of slaughter. A fair assessment of the success or short-coming of the system is made usually on the basis of weight, age, or time on feed, as determined by experienced operators. We have seen that with the potential variation of carcass trait results, even within a breed or genotype, a method that could provide a more accurate assessment of market readiness at a single predetermined endpoint would be invaluable to the industry. Ultrasound technology is an unobtrusive method which may have practical applications in a commercial production system.

Principles of Ultrasonics

Ultrasonics are simply defined by the root words ultra, meaning high, and sonic, meaning sound (Ruel, 1989). Sound is measured in terms of frequency, therefore, ultrasonics is high frequency sound.

Sound frequencies will travel through materials differing in densities at different rates. These materials differing in densities will also absorb or attenuate sound waves differently. It is this combination of acoustic velocity (rate of speed) and acoustic impedance (attenuation) which gives materials their main characteristics relative to the transmission of sound.

It is the fact that ultrasound travels through different live tissues at varied rates which provides us with the use of the technology for predicting the depth and size of those tissues. For example, ultrasound will travel through fat at a rate of 1,480 m sec^{-1} and through muscle at 1,620 m sec^{-1}. It is this difference that can be measured and analyzed to predict the backfat thickness of live animals.

Use of Ultrasound Measurements of Live Animal

All sectors in the beef cattle industry are recognizing the significance of value-based marketing and primary producers, in particular, are becoming more aware and concerned about carcass traits. The dilemma faced by cattle producers is the lack of accurate methods for measuring carcass value prior to slaughter (Houghton and Turlington, 1992). Ultrasound technology has offered a means of determining fat thickness and muscle development in live animals.

In a review of the application of ultrasound for feeding and finishing animals, Houghton and Turlington (1992) cite a 1950 article by J.J. Wild who stated that the ultrasound technique is nondestructive and humane and provides a means of quantifying muscle and fatty tissues in live animals. From this, we recognize that the concept and technology has been accessible for close to fifty years.

One of the first display formats or modes of ultrasonic imaging was the amplitude mode (A-mode) which is a one-dimensional display of returning echo amplitude and distance. This mode consists of vertical peaks along the horizontal axis. The height of the peak corresponds to the amplitude of the echo (Rantanen and Ewing, 1981).

The more current equipment used is the real-time linear array ultrasound units. Actual images of the internal body structures are scanned by a transducer which transmits the display to a monitor. A video recording is taken of the images which is then measured and analyzed.

A number of recent studies have been undertaken to evaluate the accuracy of prediction using ultrasound, based on the backfat and rib-eye area (Perkins et al., 1992; Smith et al., 1992), the personnel applying the technique (Robinson et al., 1992) and combinations of equipment, personnel and interpretation of the findings (Herring et al, 1994). All have demonstrated a significant degree of variation due to these factors among the results (Houghton and Turlington, 1992).

In two experiments, Smith et al.(1992) measured the subcutaneous fat thickness and longissimus muscle area between the 12th and 13th ribs of four hundred and fifty-two yearling steers using real-time linear array ultrasound equipment. Ultrasound predictions were compared to corresponding carcass measurements to determine accuracy of ultrasound measures. Similar results were achieved in both experiments. The extremes for each trait proved most difficult to predict; fat thickness was underestimated on fatter cattle and muscle area was under-predicted on more heavily muscled steers. Smith et al.(1992) concluded that ultrasound measures of fat thickness are precise and accurate in determining carcass fat thickness, but muscle area estimates are inconsistent and warrant further investigation.

Perkins et al.(1992) reached similar conclusions after measuring yearling crossbred feedlot steers (n=495) and heifers (n=151). In contrast, however, Perkins et al.(1992) found the accuracy of ultrasound-predicted muscle measurements to be acceptable (within 6.5 cm^2 53% of the time), while Smith et al.(1992) found the accuracy of the predicted estimates of muscle measurements to be unacceptable (within 6.45 cm^2 53% of the time).

Robinson et al.(1992) concluded that ultrasound measurement was an accurate method of predicting the two carcass traits. This research concentrated more on the technician variance and led to the conclusion that the development and maintenance of technique is critical to ensure meaningful and consistent results.

Herring et al.(1994) summarized the current knowledge and understanding of the ultrasound technology, as it applies to animal science, by concluding that ultrasound is a valid means of measuring carcass traits in live animals if appropriate personnel and equipment are selected.

Application to Commercial Production

Of primary importance to cattle feedlot managers is the ability to identify and market groups of cattle that will consistently produce carcasses of similar weight with acceptable yield and quality grades (Houghton, 1988). Accurate measurements of subcutaneous fat, muscle, and marbling in the live animal would allow more accurate marketing practices (Houghton and Turlington, 1992). Many studies have been undertaken to evaluate the practical application of ultrasound to predict carcass traits in live animals in the feedlot setting (Houghton, 1988; Smith et al., 1988; Perry et al., 1990; Smith et al., 1992; Herring et al., 1994).

Houghton (1988) postulated that the ability to identify and market groups of cattle that will consistently produce carcasses of similar weight with acceptable yield and quality grades can be accomplished using one, or a combination of the following methods: 1) improve the uniformity of pens by sorting cattle into the feedlot based on body composition and frame size (biological type); 2) determine a compositional endpoint at which a set of cattle should be slaughtered and identify and market individuals or groups of cattle as they reach that point; or 3) identify breeding cattle with the genetics to consistently produce progeny with acceptable yield and quality grades at a specified weight and/or age. These methods are supported by the previously mentioned studies.

Houghton (1988) presented a caveat to the use of the technology in that the use of ultrasound in practical breeding and feedlot programs could suffer due to inaccurate measurements and data collection. The following key considerations were offered: 1) The continued validation of ultrasonic measurements for backfat and loin eye area in beef cattle is necessary; 2) The accuracy of ultrasound measurements is highly related to operator technique. Cattlemen should be sure that trained, "certified" technicians are used if they decide to incorporate ultrasound into their programs; 3) Cost, durability and practicality of the equipment needs to be considered; 4) A reliable data base needs to be developed that monitors muscle growth and fat deposition in various biological types of cattle under different management systems; 5) Adjustment factors need to be developed for loin eye area and backfat so that animals can be compared at a constant age and/or weight.

MATERIALS AND METHODS

Objectives:

The objective of the present study was to determine the effect of a low level of feed intake during the initial feedlot finishing phase on growth patterns and feed efficiencies of two breeds of beef cattle representing two frame sizes, and the subsequent effect of any evident compensatory growth on the carcass trait components of yield and quality when the steers are slaughtered at a constant level of subcutaneous backfat.

A secondary objective was to determine the accuracy of ultrasound measurement of the live animal subcutaneous backfat in predicting the graded backfat measurement of the carcass.

Experimental Animals

Steers from two consecutive calf crops from the University of Manitoba beef cattle herd were fed in two trials. In year 1 (Y1), fourteen Simmental-cross steers and ten Black Angus steers (n1 = 24) were paired on the basis of breed, birthdate, and a 200-day adjusted weaning weight using the Federal/Provincial Records of Performance system for adjusted weaning weights. The average age of all steers at the start of test was 236d. Average age at the end of the growth phase was 444d. The pairs were randomly assigned to pens in a semi-enclosed shelter at the Glenlea Research Station.

In year 2 (Y2), eleven Simmental-cross steers (one steer was badly injured at the mid-way point of the trial, and sent for slaughter early) and twelve Red Angus steers (n2 = 23) were paired by breed, birthdate, and the 200-day adjusted weaning weight. The average age of all steers at the start of test was 239d. Average age at the end of Y2 growing phase was 422d. The pairs were randomly assigned to pens in the same semi-enclosed shelter used in Y1.

Feeding Regime

In Y1, breed pairs were randomly assigned to one of two groups, both fed a ration based on corn silage. Feed intake was limited for half of the breed pairs to achieve a low-energy concentration (LE) intake level, 91% of NRC requirements, and a high-energy concentration (HE) intake of 100% of NRC requirements for large-frame steer calves and medium-frame yearling steers respectively). In Y2, the same feed intake and energy concentration values were randomly assigned using a mixed grain based diet. In both years, all steers in both groups were provided with 3 - 5 kg d^{-1} of medium quality hay for roughage. The ration ingredient chemical composition for each year of the trial is summarized in Table 1.

TABLE 1. Ration ingredient chemical composition for Year 1 (1989) and Year 2 (1990).[1]

	Year 1 (1989)				Year 2 (1990)			
Feed Component	Dry Matter	Crude Protein (CP %)	TDN (%)	DE[2] (Mcal kg^{-1})	Dry Matter	Crude Protein	TDN	DE[2] (Mcal kg^{-1})
Corn Silage	36.2	12.1	65.3	2.96				
Grain Mix	89.8	10.9	83.0	3.70	89.4	14.6	78.6	3.88
Hay	92.0	17.9	59.0		93.0	18.2	61.8	

[1] CP and TDN are expressed as percentages on a Dry Matter analysis basis

[2] DE = Digestible Energy (Mcal kg^{-1}) expressed on a Dry Matter analysis basis

In both years of the trial, the level of feed intake was adjusted for the LE steers at 84d to bring them up to the equivalent levels of energy concentration as the HE steers. Growth and feed intake were observed for 196d in Y1 and 140d in Y2. All steers in both years were finished to a common backfat end point, which was beyond the growth and feed intake observation periods, within the respective years of the trial.

Subcutaneous backfat measures were monitored by a Manitoba Agriculture livestock technician, Certified in Ultrasound technology, from 112d to end of trial, as required, with the use of a Krautkramer, A-mode ultrasound device, which measured the backfat thickness by the differentiation of sound frequency velocity and attenuation of the fat tissue and muscle tissue. Animals were shipped for slaughter when a backfat measurement showed at least 5 mm of backfat. All steers in both years of the trial were transported to the Burns packing plant in Winnipeg for slaughter.

Data Collection

Steers in years 1 and 2 were weighed every 28 days, when practical (shorter intervals were observed near completion of each year's growth trial), to monitor the rate of gain. Feed was weighed daily for each pen and a weekly feed-bunk weighback was made to determine feed intake by pen. Weights and feed intake data were summarized for each pen of 2 steers.

In Y1, the performance data was summarized for the period extending from 14d to 180d, the time during which all animals were present and contributing feed intake data. In Y2, the performance data was summarized for the period extending from 28d to 140d, for the same reason.

The day after slaughter, all carcasses were graded by an Agriculture and Agri-food Canada Grader, with the Blue-tag system of grade reports, which lists warm carcass weight, an averaged backfat measure (3 points on the carcass between the 12th - 13th rib), the grade backfat, the quality grade assigned for each carcass, rib-eye area, percent lean (cutability) and marbling score. A sample report is appended (Appendix Table 5).

Statistical Analysis

Significant effects for each growth period were determined for weight, gain during each 28d period, digestible energy (DE) intake, digestible energy intake relative to gain for each 28d period (feed efficiency), and digestible energy intake relative to daily weight (DEWT) [DEWT = Digestible Energy Intake mean / Average Weight mean by Trial Day] by analysis of variance using the General Linear Modelling (GLM) procedure in the Statistical Analysis System (SAS Institute Inc., 1988). Factors included in the model were breed, ration, pen and trial day. Pen(Breed*Ration) was used as the error term to test breed and ration effects. Since this was a repeated measure design, the impact of breed and ration over time was also assessed.

For the carcass data, significant effects for saleweight, ultrasound backfat measurements and the carcass traits of graded backfat, rib-eye area, lean percentage, marbling score, and warm carcass weight were determined by analysis of variance using the General Linear Models (GLM) procedure in the Statistical Analysis System (SAS Institute Inc., 1988). Factors included in the model were breed, ration, sale weight, warm carcass weight, ultrasound backfat, grade backfat, rib-eye area, percent lean (cutability) and marbling score.

RESULTS AND DISCUSSION

The summary of analysis of variance (ANOVA) for treatment effects on performance (growth, feed intake and feed efficiencies) in Year 1 (1989) is illustrated in Table 2. Table 3 illustrates the ANOVA summary for Year 2 (1990). In Y1, the interaction of Ration*Trial Day (TDay) showed a significant effect ($P < .01$) on Digestible Energy (DE) Intake, DE Intake relative to weight (DEWT), and weight (Wt); an effect ($P < .05$) on gain; and no significant effect ($P > 0.05$) on DE Intake relative to gain (Feed Efficiency-FEM). In Y2, the interaction of Ration*Tday showed a significant effect ($P < .01$) on DE Intake, DE Intake relative to gain, and DE Intake relative to weight; no significant effect ($P > 0.1$) on weight or gain. In Y1, ration showed a significant effect ($P < .01$) on DE Intake and DEWT, with no significant effect ($P > 0.1$) on weight, gain or FEM. In Y2, ration had an effect ($P < .05$) on DE Intake and weight, a trend effect ($P < 0.1$) on FEM and DEWT, and no significant effect ($P > 0.1$) on gain. Trial Day (TDay) showed a significant effect ($P < .01$) on all growth characteristics in Y1 and Y2. Breed only demonstrated a significant effect ($P < .01$) on DEWT in Y1.

TABLE 2. Year 1 (1989): Summary of analysis of variance (ANOVA) for treatment effects on steer performance (growth, feed intake and feed efficiencies) from 14d to 180d during the growing/finishing period.

		Characteristic				
				Digestible Energy DE		
Source of Variation	df	Wt	Gain	Intake	FEM[1]	DEWT[2]
Breed	1	ns	ns	ns	ns	**
Ration	1	ns	ns	**	ns	**
Breed*Ration	1	ns	ns	ns	ns	ns
Pen(Breed*Ration)	11	-	-	-	-	-
TDay	7	**	**	**	**	**
Breed*TDay	7	ns	ns	ns	<0.1	<0.1
Ration*TDay	7	**	*	**	<0.1	**
Breed*Ration*TDay	7	ns	ns	ns	ns	ns
Error		65.80	49.69	2328.84	72.58	0.0186

** P < .01 * P < .05 ns - not significant P > 0.05

[1] DE Intake relative to Gain

[2] DE Intake relative to Weight

TABLE 3. Year 2 (1990): Summary of analysis of variance (ANOVA) for treatment effects on steer performance (growth, feed intake and feed efficiencies) from 28d to 140d during the growing/finishing period.

		Characteristic				
				Digestible Energy DE		
Source of Variation	df	Wt	Gain	Intake	FEM[3]	DEWT[4]
Breed	1	ns	ns	ns	ns	ns
Ration	1	*	ns	*	<0.1	<0.1
Breed*Ration	1	ns	ns	ns	ns	ns
Pen(Breed*Ration)	8	-	-	-	-	-
TDay	4	**	**	**	**	**
Breed*TDay	4	ns	ns	ns	ns	ns
Ration*TDay	4	ns	ns	**	**	**
Breed*Ration*TDay	4	ns	ns	ns	ns	ns
Error		61.36	52.04	4254.99	15.07	0.0155

** P < .01 * P < .05 ns - not significant P > 0.05

[3] DE Intake relative to Gain

[4] DE Intake relative to Weight

Examining the treatment effects in detail, patterns of growth and energy intake are shown in Figures 1 - 4 (Appendix Table 3 and 4). Figure 1 illustrates the effect of the interaction of TDay and ration energy concetration levels, High Energy (HE) vs Low Energy (LE) for DE Intake, weight and gain in year 1. Figure 2 illustrates the TDay*Ration effects on the same characteristics in year 2, but only the DE Intake (Figure 2a) showed a significant effect ($P<.01$). The interesting observation is the relationship between each growth characteristic and the levels of energy intake. In Y1, DE Intake and gain take a downward adjustment after 84d, which is the period of realimentation for the LE steers. While the weight differences remain relatively constant, the DE Intake for the LE steers adjusts to a point nearing the HE steers at the end of the trial. More interesting is the observation that the LE steers, following realimentation, appear to show greater gains than the HE steers, although the significance of the differences for the exclusive period after 84d has not been tested. This observation, with a greater degree of significance, was reported in the reviewed literature (O'Donovan, 1984; Rompala at al., 1985; Old and Garrett, 1987) and forms the basis of the hypothesis of this work. While the TDay*Ration effect on weight and gain were not significant ($P>0.1$) in Y2, the patterns of growth (gain) illustrated by Figure 2c depict the hypothesis that upon realimentation after a period of feed intake restriction, steers that are limit-fed for even a brief period during the finishing phase and subsequently exhibiting compensatory growth, may perform as well as steers fed on a steady plane of intake. The DE

Intake illustrated in Figure 2a demonstrates that after 84d, when the ration availability for the LE steers was adjusted, the intake increased at a more significant rate then the HE steers ($P < .01$). Concurrently, the gains realized by the LE steers, as shown in Figure 2c appear to be at an increasing rate, eventually surpassing the gains of the HE steers, although again, the significance during this specific period was not tested. This is, however, supported by the work of Meyer et al. (1965), Fox et al. (1972), Byers (1982) and Drouillard et al. (1991).

Figures 3 and 4 illustrate the mean effect of the interaction of TDay and ration energy concentration levels (HE vs LE) on the DE Intake relative to gain (feed efficiency) and DE Intake relative to daily weight in year 1 and 2 respectively. In Y1 (Figure 3a) the HE steers appear to exhibit an improvement in feed efficiency (DE Intake/gain) between 42d and 112d, illustrated by the downward slope of the graph , more so than the LE steers. The treatment groups demonstrated an expected difference in DEWT (DE Intake/weight) until they intersected at 140d, after the LE steers were completely realimented. This is supported by the work reviewed by O'Donovan (1984). The results illustrated in Figure 4 for Y2 of the effect of the interaction of TDay and ration energy levels (HE vs LE) are statistically significant, and the graph illustrates the difference between the two levels of intake. Here again, the most significant observation is the adjustment after 84d when the LE steers were realimented and begin to exhibit a similar growth pattern to the HE steers in the first part of the trial (pre-84d).

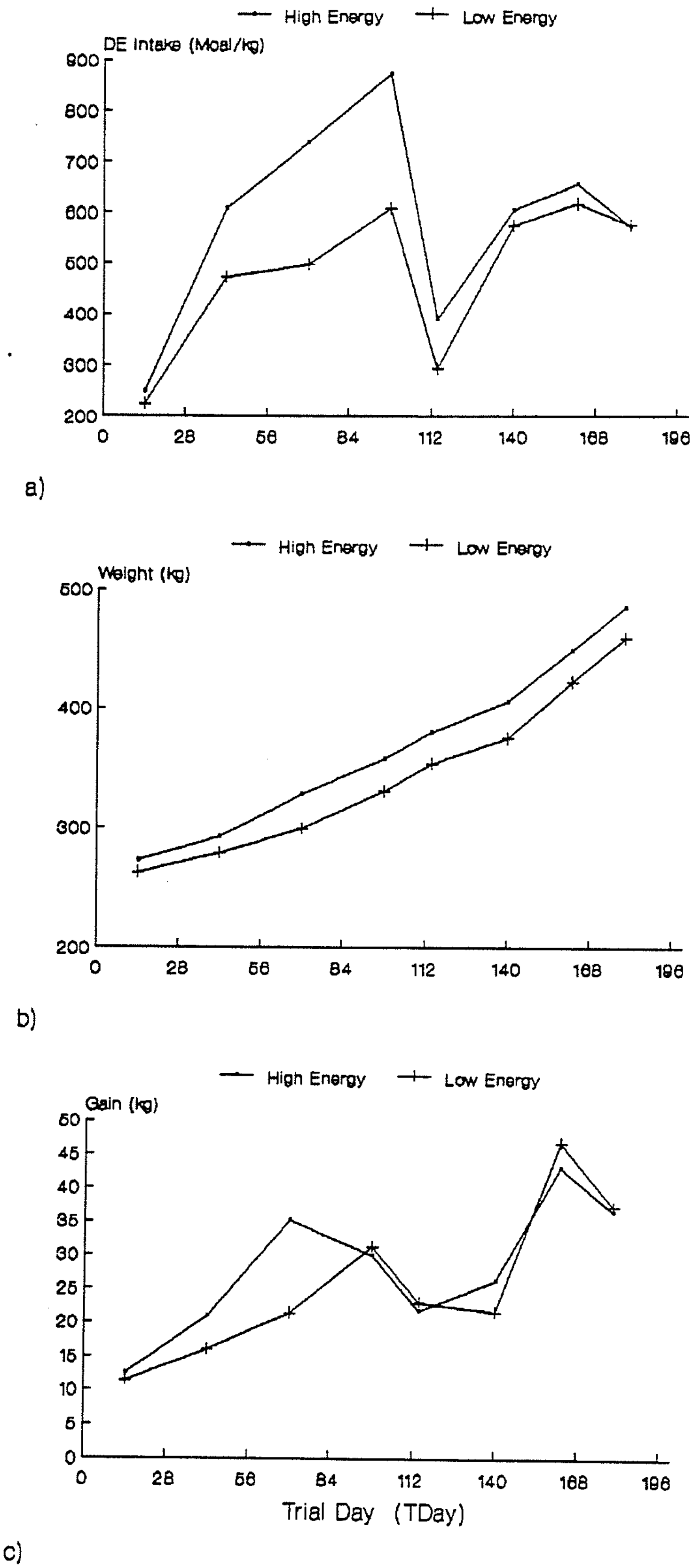


Figure 1. Average across breeds, Trial year 1 (1989): Effect of the interaction of trial day (TDay) and ration energy level (High - HE vs Low - LE) on a) Digestible Energy (DE) intake (Mcal $period^{-1}$) (HE - $P<.01$, SEM=17.62; LE - $P<.01$, SEM=18.43); b) Weight (kg) (HE - $P<.01$, SEM=2.96; LE - $P<.01$, SEM=3.10) and c) Gain (kg) (HE - $P<.05$, SEM=2.57; LE - $P<.05$, SEM=2.69).

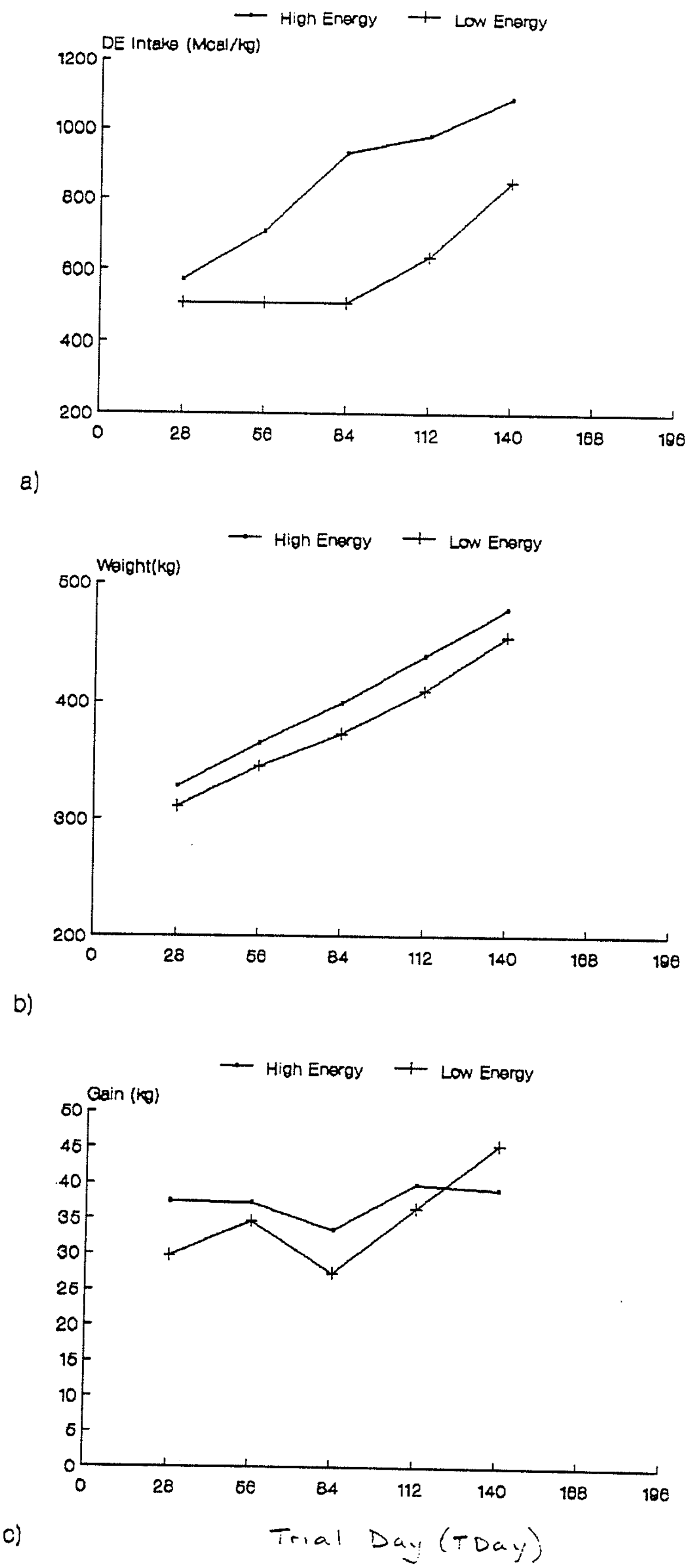
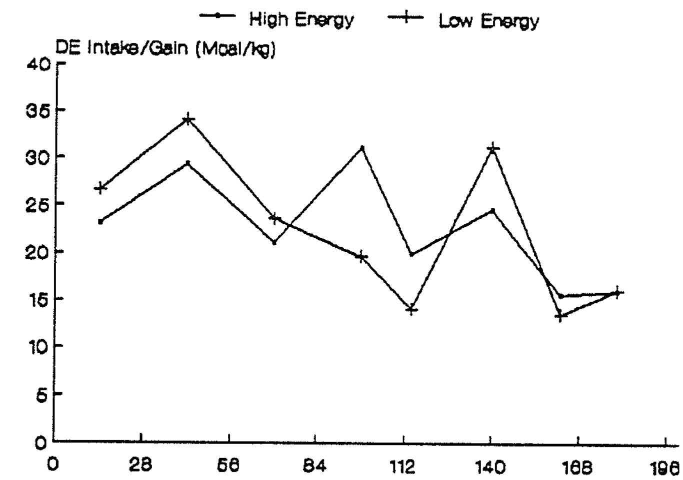
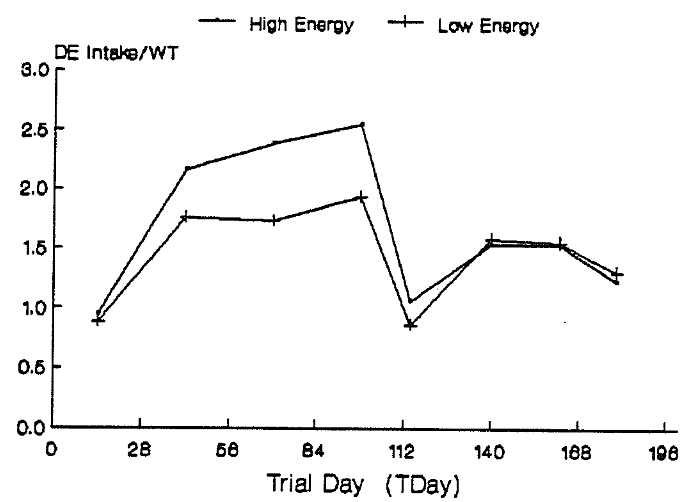


Figure 2. Average across breeds, Trial year 2 (1990): Effect of the interaction of trial day (TDay) and ration energy level (High - HE vs Low - LE) on a) Digestible Energy (DE) intake (Mcal period^{-1}) (HE - P<.01, SEM=26.63; LE - P<.01, SEM=26.63); b) Weight (kg) (HE - P>.1, SEM=3.20; LE - P>.1, SEM=3.20) and c) Gain (kg) (HE - P>.1, SEM=2.95; LE - P>.1, SEM=2.95).

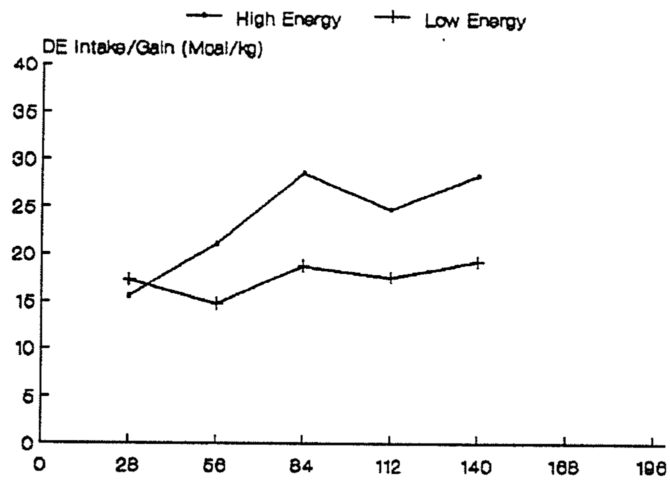


a)

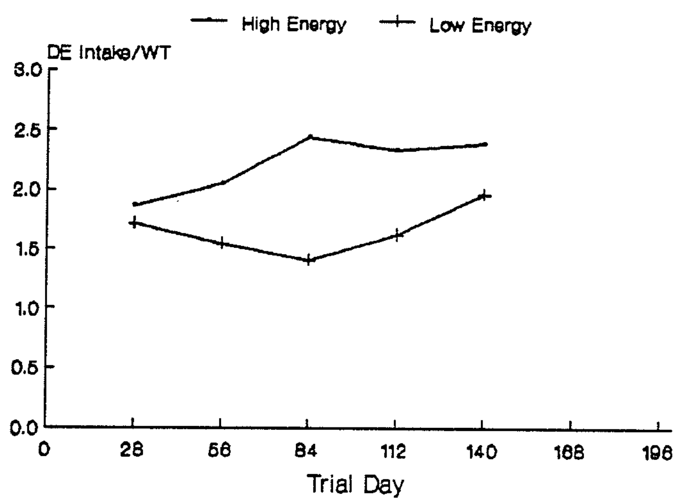


b)

Figure 3. Average across breeds, Trial year 1 (1989): Effect of the interaction of trial day (TDay) and ration energy level (High - HE vs Low - LE) on a) Digestible Energy (DE) intake (Mcal period^{-1}) relative to gain (kg) (feed efficiency) (HE -P<.01, SEM=3.11; LE - P<.01, SEM=3.25) and b) DE intake (Mcal period^{-1}) relative to daily weight (kg) (HE - P<.01, SEM=0.05; LE - P<.01, SEM=0.05).



a)



b)

Figure 4. Average across breeds, Trial year 2 (1990): Effect of the interaction of trial day (TDay) and ration energy level (High - HE vs Low - LE) on a) Digestible Energy (DE) intake (Mcal $period^{-1}$) relative to gain (kg) (feed efficiency) (HE - $P<.01$, SEM=1.58; LE - $P<.01$, SEM=1.58) and b) DE intake (Mcal $period^{-1}$) relative to daily weight (kg) (HE - $P<.01$, SEM=0.05; LE - $P<.01$, SEM=0.05).

Table 4. illustrates the ration effect on the growth characteristics of all steers in years 1 and 2 of the trial. The digestible energy intake (DE Intake) was significantly different ($P<.01$) for the high energy (HE) and low energy (LE) levels in year 1. This may be attributed to the ration composition in Y1, the silage/grain combination. The DE Intake difference between rations in Y2 was not as significant ($P<.05$). It should also be noted that the standard error term in Y2 is relatively higher than in Y1, suggesting that the data period, which was shorter in Y2, or the population of animals used in Y2 required a higher difference for the treatment effects to be significant. The grain-only ration in Y2 could explain the difference in observations between years, consistent with Wilson and Osbourn (1960) who reported that one of the factors contributing to compensatory growth following limited feed intake was the nature (composition) of the restricted diet, but contrary to Byers (1982), who suggested that the level of nutrition effects are more related to energy intake and growth rates than to specific feedstuffs included in the diets.

The effect of ration on weight for all steers was insignificant ($P>.1$) in year 1, but showed a difference ($P<.05$) in year 2 (Table 4). This may suggest that once compensatory growth is realized after realimentation, the end weight result is equalized, over a similar period in time, as suggested by Wilson and Osbourn (1960), Tudor et al. (1980) and Thomson et al. (1982).

Ration had no effect ($P>0.1$) on gain for all steers, in both years of the trial (Table 4). The ration effect on digestible energy intake relative to gain (feed efficiency) was insignificant in both year 1 (P>.1) and year 2 (P>.05). This observation agrees with the findings of Meissner et al. (1995) who postulated that there is a poor relationship between feed intake and feed efficiency. The effect of ration on digestible energy intake relative to daily weight was significantly different (P<.01) in year 1, but not in year 2, although the higher standard error mean in Y2 should be noted as discussed earlier (Table 4).

There was a significant effect (P<.01) of trial day (TDay) on all growth characteristics in both years of the trial (Appendix Table 1 and 2) . The interesting observations, as in the TDay*Ration effect, are the relationships between each characteristic within years and compared across years. Figure 5 illustrates the average for all steers in Y1 and the effect of TDay on a) DE Intake, b) weight and c) gain. While weight shows the expected progression over time (Figure 5b), the DE Intake exhibits a dramatic drop after 84d (Figure 5a). Correspondingly, gain also drops for a period after 84d (Figure 5c). This coincides with the realimentation of the low energy fed steers in Y1. The results illustrated in Figure 6 are the average of all steers in Y2 for the same effect of TDay on the growth characteristics. These results do not show the same decline in DE Intake, although there is a slight adjustment prior to 84d (Figure 6a). Despite Byers (1982) contention, the difference in the two years would suggest that the adjustment from a silage-based ration to a grain-based ration in Y1 may have caused an effect on DE Intake and gain which was not observed in Y2 where the ration was grain-based throughout the trial.

TABLE 4. Years 1 and 2 (1989 & 1990): Effect of ration intake level on steer performance (growth, feed intake and feed efficiencies) for all steers from 14d to 180d (Y1) and 28d to 140d (Y2) during the growing/finishing period.

	Year 1 (1989)				Year 2 (1990)			
Growth Characteristic	HE[1]	SEM	LE[2]	SEM	HE	SEM	LE	SEM
DE Intake (Mcal)[3]	585.75[a]	18.55	482.43[a]	19.40	855.34[b]	73.45	600.16[b]	73.45
Weight (kg)	371.32[d]	10.37	347.72[d]	10.85	401.92[b]	5.26	379.00[b]	5.26
Gain (kg)	28.23[d]	0.84	26.07[d]	0.88	37.48[d]	1.50	34.76[d]	1.50
DE Intake/Gain ($Mcal\ kg^{-1}$)	22.60[d]	0.76	22.39[d]	0.80	23.65[c]	2.11	17.49[c]	2.11
DEWT ($Mcal\ kg^{-1}$)[4]	1.67[a]	0.03	1.45[a]	0.03	2.21[c]	0.20	1.65[c]	0.20

[a, b, c, d] Indicate the degree of significance in comparing average performance of steers for the two rations within each year.

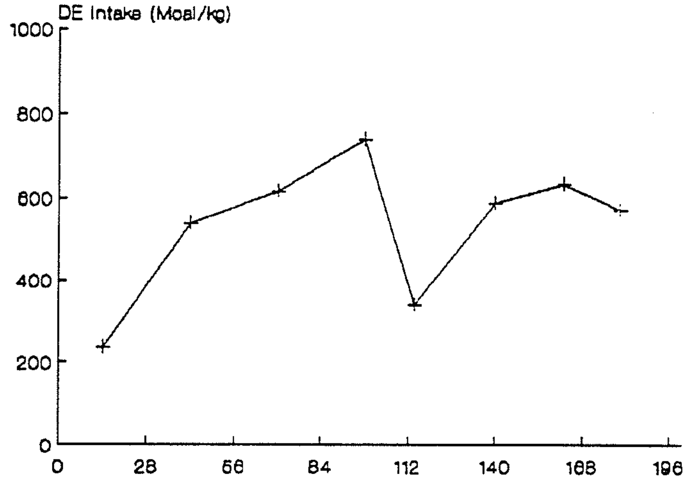
[a] $P < .01$; [b] $P < .05$; [c] $P < 0.1$ [d] $P > 0.1$

[1] HE = High Energy concentration Intake: TDN = 100% NRC

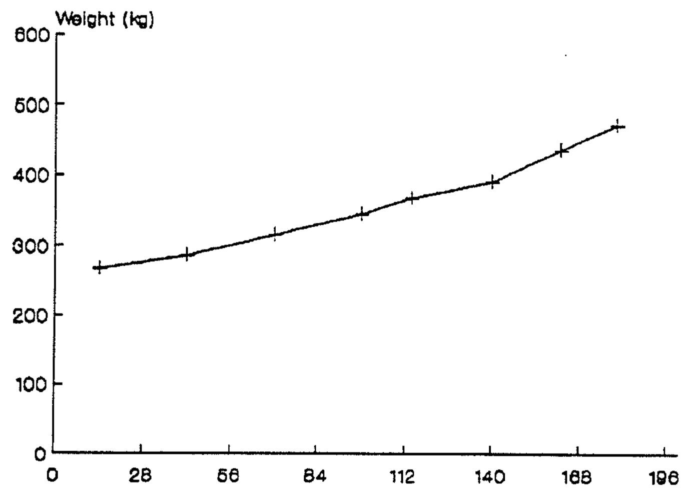
[2] LE = Low Energy concentration Intake: TDN = 91% NRC

[3] DE Intake is expressed as Mcal $period^{-1}$ for the data analysis intervals

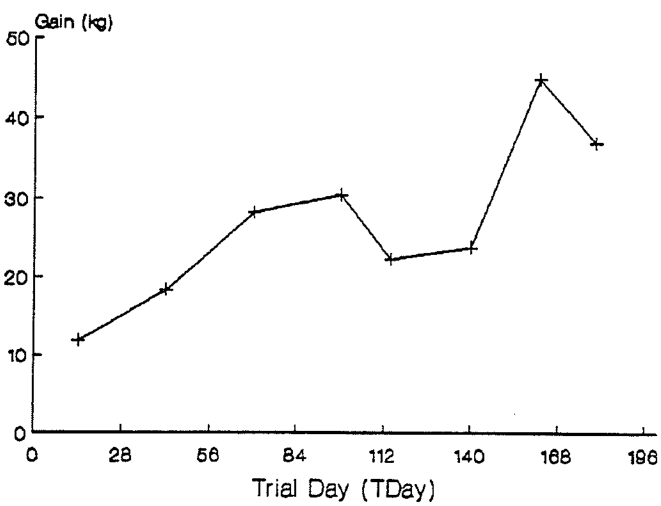
[4] DEWT = Digestible Energy Intake relative to daily weight
= Mcal $period^{-1}$ mean / weight mean by TDay



a)



b)



c)

Figure 5. Average for all steers, Trial year 1 (1989): Effect of trial day (TDay) on a) Digestible Energy (DE) intake (Mcal period^{-1}) ($P<.01$, SEM=12.75); b) Weight (kg) ($P<.01$, SEM=2.14); c) Gain (kg) ($P<.01$, SEM=1.86).

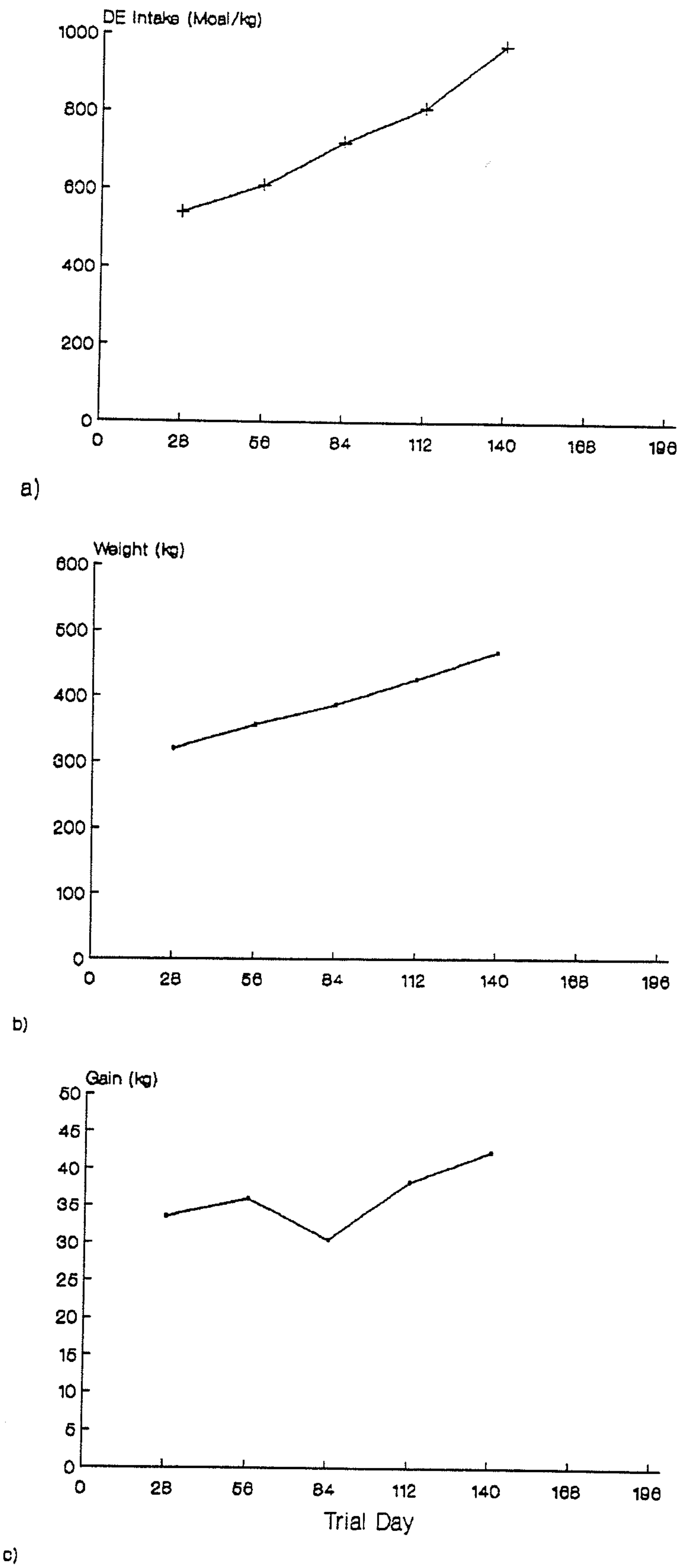


Figure 6. Average for all steers, Trial year 2 (1990): Effect of trial day (TDay) on a) Digestible Energy (DE) intake (Mcal period^{-1}) ($P<.01$, SEM=18.83); b) Weight (kg) ($P<.01$, SEM=2.26); c) Gain (kg) ($P<.01$, SEM=2.08).

Figures 7 and 8 illustrate the effect of TDay on DE Intake relative to gain and DE Intake relative to daily weight for all steers in year 1 and year 2 respectively. The graphic patterns are so distinctly different between years that it is difficult to demonstrate a comparison or contrast. The results shown in Y1 (Figure 7) are consistent with Ledger and Sayers (1977) who concluded that there is a progressive increase in the efficiency of energy utilization for the production of edible meat, although attention is drawn to the need to differentiate between the live-weight maintenance needs of fast and slow growing animals. The results for Y2 (Figure 8), which illustrates an average effect of increasing energy intake requirements, are more consistent with Meissner et al. (1995) who suggested that higher feed intake increases gain for both fast- and slow-growing steers and it improves the feed conversion ratio for slow-growing steers, but not for fast-growing steers. Meissner (1995) suggested that feed efficiency and feed intake are poorly correlated.

During the growing phase of the trials, the only growth characteristic which showed an effect ($P<.01$) of breed was the digestible energy intake relative to daily weight (DEWT) in Y1, illustrated by Table 5.

TABLE 5. Year 1 (1989): Effect of Breed on Digestible Energy Intake relative to Daily Weight (DEWT) ($P < .01$)

Breed	DEWT[a]	SEM
Angus	1.65	0.03
Simmental	1.47	0.03

[a] Mcal kg^{-1}

These results suggest that smaller framed, early-maturing steers, as represented by the Angus breed, will utilize a higher level of digestible energy per body weight unit than large frame, late-maturing steers, as represented by the Simmental breed. This is consistent with the findings by Tatum et al. (1986) and Old and Garrett (1987). This also concurs with Meissner et al. (1995) who reported that higher feed intake increased average daily gain (ADG) for both slow- and fast-growing steers, and that it improved the feed conversion ratio for slow-growing steers but not for fast-growing steers. Trial year 2 (1990) showed no significant difference between breeds ($P > .05$), which suggests that ration composition (silage/grain-Y1 vs grain-Y2) has an effect on this growth characteristic (DEWT), which is contrary to the findings of Byers (1982) who reported that diet composition was irrelevant.

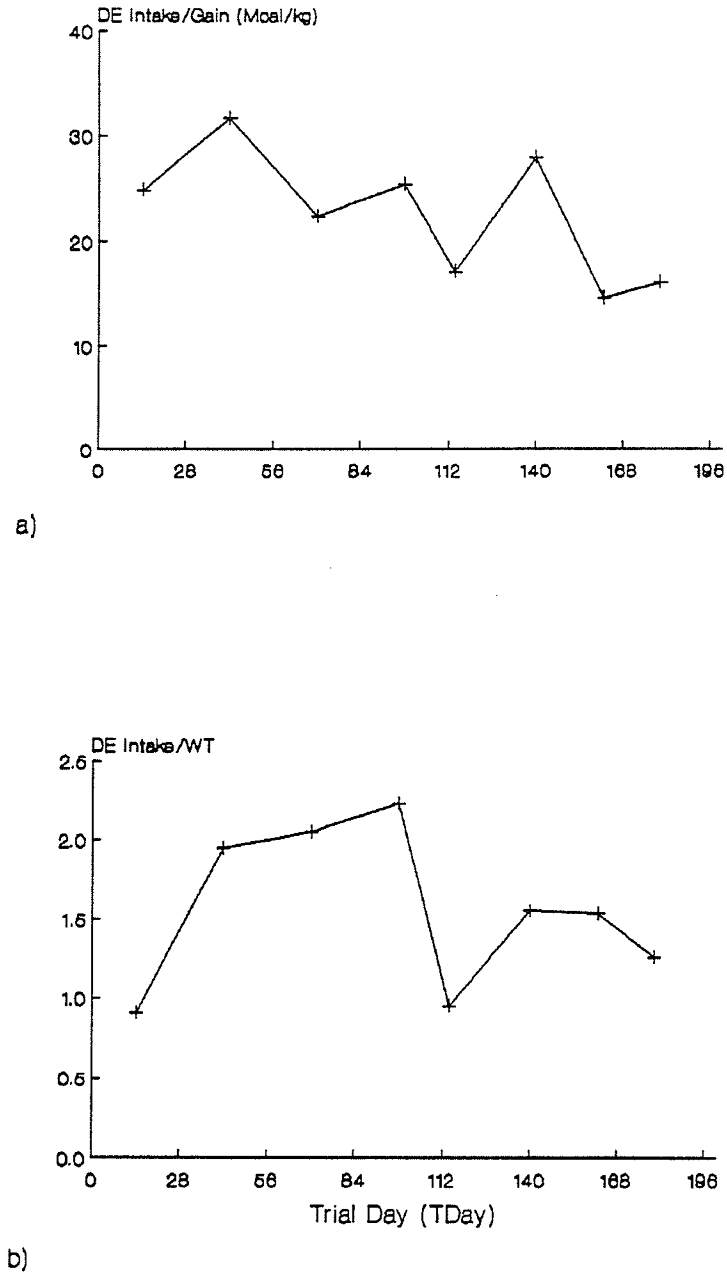


Figure 7. Average for all steers, Trial year 1 (1989): Effect of trial day (TDay) on a) Digestible Energy (DE) intake (Mcal period^{-1}) relative to gain (kg) (feed efficiency) ($P<.01$, SEM=2.25); b) Digestible Energy intake (Mcal period^{-1}) relative to daily weight (kg) ($P<.01$, SEM=0.04).

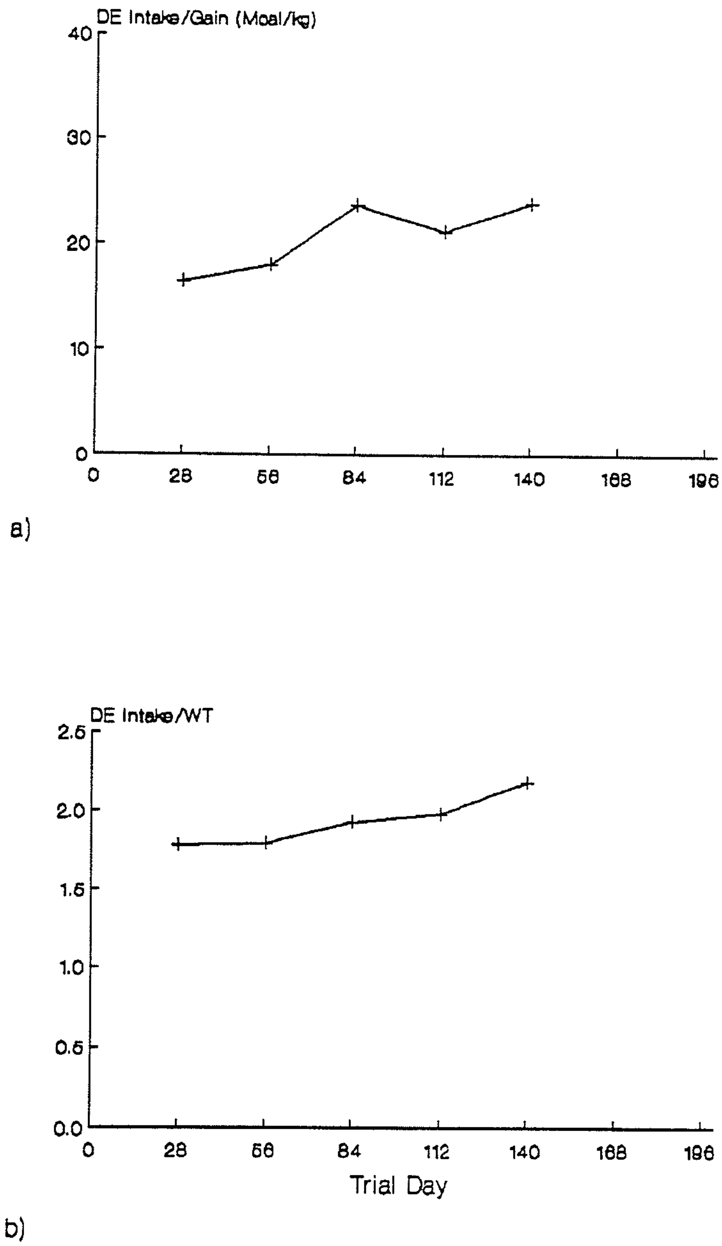


Figure 8. Average for all steers, Trial year 2 (1990): Effect of trial day (TDay) on a) Digestible Energy (DE) intake (Mcal $period^{-1}$) relative to gain (kg) (feed efficiency) ($P<.01$, SEM=1.12); b) Digestible Energy intake (Mcal $period^{-1}$) relative to daily weight (kg) ($P<.01$, SEM=0.04).

Tables 6 and 7 summarize the ANOVA for treatment effects on carcass traits for Y1 and Y2, respectively. Ration had a significant effect ($P<.01$) on marbling (MB) and warm carcass weight (WCW) and an effect ($P<.05$) on sale weight (SWT) in Y1 (Table 6). In Y2, ration had an effect ($P<.05$) on WCW and SWT (Table 7). Breed had a significant effect ($P<.01$) on all of the carcass traits, with the exception of MB in Y1 (Table 6). In Y2, the breed effect was significant ($P<.01$) on all carcass traits except MB and SWT, where no effect ($P>.05$) was observed (Table 7). The interaction of Breed*Ration had an effect ($P<.05$) on Lean Percentage (LP) in Y1, but no effect ($P>.05$) on the other carcass traits in Y1 and no effect ($P>.05$) on any carcass traits in Y2.

Table 8 summarizes the effect of ration on carcass traits for all steers in both years 1 and 2 of the trial. The ration effect on ultrasound predicted measurements of backfat was not significant ($P>0.1$) in either year. Similarly, the graded backfat measurement (actual) difference was insignificant ($P>0.1$) in year 1, although there was a significant difference ($P<.01$) observed in year 2, where the HE steers had a graded backfat measurement of 5.65 mm vs 4.42 mm for the LE steers. This is in keeping with Coleman et al. (1993) who observed that there should be no significant effect on carcass characteristics at the same age. The difference between the observations for Y1 and Y2 may be attributed to the sample population of animals comprising each year's trial, although each breed represented came from similar genetic backgrounds in both years. Effects of the environment (weather) on feed intake depression and realimentation may also explain some of the differences.

TABLE 6. Year 1 (1989): Summary of analysis of variance (ANOVA) for treatment effects on carcass attributes for all steers from 14d to 180d during the growing/finishing phase.

		Characteristic						
				AAFC Graded				
Source of Variance	df	SWT	UBF	GBF	REA	LP	MB	WCW
Breed	1	**	**	**	**	**	ns	**
Ration	1	*	ns	ns	ns	ns	**	**
Breed * Ration	1	ns	ns	ns	ns	*	ns	ns
Error		3996.55	0.9564	1.5771	88.5396	5.0211	0.3896	1188.62

Terms: ** P < .01 * P < .05 ns P > .05

SWT - Sale Weight
UBF - Ultrasound Backfat
GBF - Graded Backfat
REA - Rib-eye Area
LP - Lean Percentage
MB - Marbling Score
WCW - Warm Carcass Weight
AAFC - Agriculture & AgriFood Canada

TABLE 7. Year 2 (1990): Summary of analysis of variance (ANOVA) for treatment effects on carcass attributes for all steers from 28d to 140d during the growing/finishing phase.

		Characteristic						
				AAFC Graded				
Source of Variance	df	SWT	UBF	GBF	REA	LP	MB	WCW
Breed	1	ns	**	**	**	**	ns	**
Ration	1	*	ns	<.1	<.1	ns	ns	*
Breed * Ration	1	ns	ns	ns	ns	ns	ns	ns
Error		5295.70	0.7561	2.4807	64.5877	4.8047	3.7351	1510.02

Terms: ** P < .01 * P < .05 ns P > .05

SWT - Sale Weight
UBF - Ultrasound Backfat
GBF - Graded Backfat
REA - Rib-eye Area
LP - Lean Percentage
MB - Marbling Score
WCW - Warm Carcass Weight
AAFC - Agriculture & AgriFood Canada

TABLE 8. Years 1 and 2 (1989 & 1990): Effect of ration intake level on carcass attributes as reported by the Agriculture and Agri-Food Canada Blue-Tag grading system, all steers.

	Year 1 (1989)				Year 2 (1990)			
	High Energy[1]		Low Energy[2]		High Energy		Low Energy	
Carcass Trait	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM
Age at Sale (days)	472		473		500		511	
Ult. Backfat (mm)	5.14[c]	0.26	4.67[c]	0.28	4.22[c]	0.26	3.83[c]	0.25
Grd. Backfat (mm)	5.43[c]	0.38	5.50[c]	0.36	5.65[c]	0.48	4.42[c]	0.45
Rib-eye Area (cm^2)	72.94[c]	2.88	67.25[c]	2.72	76.92[c]	2.43	70.67[c]	2.32
Lean Percentage (%)	59.02[c]	0.69	59.52[c]	0.65	61.18[c]	0.66	61.11[c]	0.63
Warm Car. Wt. (lb)	618.73[a]	9.83	560.67[a]	9.95	606.85[b]	11.77	572.58[b]	11.21
Marbling Score	7.94[a]	0.19	8.75[a]	0.18	7.60[c]	0.59	7.25[c]	0.56
Sale Weight (lb)	1110.63[b]	19.14	1049.13[b]	20.40	1124.23[b]	22.03	1060.42[b]	21.00

[a,b,c,d] Indicate the degree of significance in comparing average performance of steers for the two rations within each year.

[a] $P < .01$; [b] $P < .05$; [c] $P > 0.05$

[1] High Energy = High Energy concentration Intake: TDN = 78.5% (100% NRC)

[2] Low Energy = Low Energy concentration Intake: TDN = 93.0% (91% NRC)

The ration effect on rib-eye area was not significantly different ($P>0.05$) in either Y1 or Y2, which is supported by the observations of Hironka and Kozub (1993).

The difference in ration effect on lean percentage or meat yield was insignificant ($P>0.05$) for both years of the trial. This is somewhat contrary to the observations of Hironaka and Kozub (1973) who reported that restricted steers had a lower dressing percentage (yield) and tended to have less backfat per unit of carcass weight than the full fed steers, but all had the same area of rib-eye.

The HE steers in Y1 had a significantly ($P<.01$) higher warm carcass weight than the LE steers, with a less significant ($P<0.05$) difference observed in Y2. This correlates to the sale weight differences and may be more a function of the animal types in each year than a ration effect.

The marbling score was significantly different ($P<.01$) in Y1, but not in Y2 ($P>0.1$). More interesting was the observation that the LE steers in Y1 had a higher marbling score than those of HE steers, which may indicate that steers undergoing compensatory gain and then realimented may overcompensate with fat deposition if the energy intake exceeds requirements. This is supported by the work of Byers (1982). In Y1, the sale weight was slightly but significantly ($P<.05$) higher for the HE steers compared to the LE steers (1110.63 kg vs 1049.13 kg). The difference in Y2 was similar ($P<0.1$). This supports the observation that after realimentation, endpoint weights for steers undergoing compensatory growth should not be greatly different than full fed animals on the same ration (Old and Garrett, 1987).

Table 9 summarizes the effect of breed on carcass traits for Y1 and Y2. There were significant differences ($P<.01$) between breeds for all carcass traits, with the exception of sale weight in Y2, which demonstrated an effect ($P<.05$), and the marbling score which was not significant ($P>0.1$) for breed in either year. This is consistent with the observations of Old and Garrett (1987), Oltjen and Garrett (1988) and McKinnon et al. (1993) who reported significant differences on carcass traits for cattle differing in body size and maturity despite compensatory growth effects.

The only difference ($P<.05$) observed for the interaction of breed and ration effect on carcass traits was on lean percentage (yield) in Y1, as illustrated by Table 10. The Angus steers which were initially limited in energy intake (LE) and exhibited compensatory growth after realimentation, exhibited a higher lean percentage carcass than the HE Angus steers. This is contrary to Byers (1982) and suggests that upon realimentation, smaller late-maturing steers undergoing compensatory growth may utilize energy intake for protein deposition to a greater extent than non-compensating steers of the same breed. This is sustained by the observations of Foot and Tulloh (1977) and Old and Garrett (1987).

TABLE 9. Years 1 and 2 (1989 & 1990): Effect of breed on carcass attributes as reported by Agriculture and Agri-Food Canada Blue-Tag grading system, all steers.

	Year 1 (1989)				Year 2 (1990)			
	Angus		Simmental		Angus		Simmental	
Carcass Trait	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM
Age at Sale (days)	471		481		508		504	
Ult. Backfat (mm)	5.75[a]	0.28	4.06[a]	0.26	4.67[a]	0.25	3.38[a]	0.26
Grd. Backfat (mm)	6.42[a]	0.41	4.52[a]	0.34	6.00[a]	0.45	4.07[a]	0.48
Rib-eye Area (cm^2)	62.04[a]	3.03	78.15[a]	2.54	65.83[a]	2.32	81.75[a]	2.43
Lean Percentage (%)	56.79[a]	0.72	61.74[a]	0.61	59.09[a]	0.63	63.21[a]	0.66
Warm Car. Wt. (lb)	562.93[a]	10.44	616.46[a]	9.31	562.17[a]	11.22	617.27[a]	11.77
Marbling Score	8.21[c]	0.20	8.48[c]	0.17	7.17[c]	0.56	7.68[c]	0.59
Sale Weight (lb)	1031.33[a]	18.25	1128.43[a]	21.20	1076.92[a]	21.00	1107.73[a]	22.03

[a] $P < .01$ [b] $P < 0.05$ [c] $P > .05$

TABLE 10. Year 1 (1989): Effect of the Breed * Ration interaction on carcass lean percentage for steers initially provided two levels of feed intake[1].

	Angus		Simmental	
	High	Low	High	Low
Lean Percentage	56.35	58.24	62.69	60.79
SE	1.1204	0.9148	0.7922	0.9148

[1] $P < .05$

There was no significant ($P > .05$) effect of the interaction of breed and ration for the other carcass traits in either year.

CONCLUSIONS

Growth and performance improvements were exhibited by steers of both breeds in both years of these trials. Steers fed the low intake ration for the initial period of 84d and then realimented to an ad libitum feeding regime equivalent in energy concentration intake to the high intake steers compensated in performance during the finishing phase of the growth trial, ending with a total feedlot performance similar to the steers receiving feed ad libitum throughout the trials. However, the significance of the performance improvement during the specific period following the ration adjustment was not tested exclusively. Therefore, whether or not we can conclude that true compensatory growth took place after ration intake adjustments is difficult.

The economically important carcass traits of backfat thickness, lean percentage and rib-eye area, which contribute to the quality and yield grade of the carcass, were not adversely affected by the initial limit-fed regime, or the subsequent improvement in performance exhibited by the steers when fed to a common subcutaneous backfat endpoint. In addition, it was observed that the marbling score, which is a singular factor in the quality grade for carcasses, was enhanced by the presumed compensatory phenomena in year 1 of the trial.

The use of ultrasound technology for predicting the measurements of live animal backfat thickness was demonstrated to be an accurate, practical tool in evaluating the market readiness of finished feedlot steers. Of course, the equipment used in this study is somewhat antiquated to that which is available and used in today's industry, both in finishing cattle and in selecting breeding animals with the desired genetic potential for backfat and rib-eye area development.

We observe the results of the practice of limit feeding and subsequent compensatory growth when feeder cattle are backgrounded on a forage-based ration to achieve a weight gain of approximately 200 to 250 kg. In effect, these animals have been limited in their genetic potential for growth by limiting energy concentration intake. When these animals are shipped to a feedlot for finishing, where a high level of energy concentration intake is provided, compensatory growth is exhibited, resulting in an economic benefit for the feedlot operator. Given the proper economic and market conditions, backgrounding beef cattle could offer the producer a valuable choice of alternative production systems within their own operation. Caution must be observed, however, always considering input costs relative to the market costs of both feeder cattle and feed inputs.

REFERENCES

Abdalla, H.O., Fox, D.G. and Thonney, M.L. 1988. Compensatory gain by holstein calves after underfeeding protein. J. Anim. Sci. 66: 2687-2695.

Anderson, P.T., Bergen, W.G., Merkel, R.A. and Hawkins, D.R. 1988. The effects of dietary crude protein level on rate, efficiency and composition of gain of growing beef bulls. J. Anim. Sci. 66: 1990-1996.

Bartle, S.J., Preston, R.L. and Miller, M.F. 1994. Dietary energy source and density: Effects of roughage source, roughage equivalent, allow level, and steer type on feedlot performance and carcass characteristics. J. Anim. Sci. 72: 1943-1953.

Bohman, V.R. 1955. Compensatory growth of beef cattle: The effect of hay maturity. J. Anim. Sci. 14: 249-255.

Bohman, V.R. and Torell, C. 1956. Compensatory growth of beef cattle: The effect of protein supplements. J. Anim. Sci. 15: 1089-1096.

Bruce, H.L., Ball, R.O. and Mowat, D.N. 1991. Effects of compensatory growth on protein metabolism and meat tenderness of beef steers. Can. J. Anim. Sci. 71: 659-668.

Byers, C.E. 1982. Nutritional factors affecting growth of muscle and adipose tissue in ruminants. Fed. Proc. 41: 2562-2566.

Carstens, G.E., Johnson, D.E., Ellenberger, M.A. and Tatum, J.D. 1991. Physical and chemical components of the empty body during compensatory growth in beef steers. J. Anim. Sci. 69: 3251-3264

Coleman, S.W. and Evans, B.C. 1986. Effect of nutrition, age and size on compensatory growth in two breeds of steers. J. Anim. Sci. 63: 1968-1982.

Coleman, S.W., Evans, B.C. and Guenther, J.J. 1993. Body and carcass composition of Angus and Charolais steers as affected by age and nutrition. J. Anim. Sci. 71: 86-95.

Drori, D., Levy, D., Folman, Y. and Holzer, Z. 1974. Compensatory growth of intensively raised bull calves II. The effect of feed energy concentration. J. Anim. Sci. 38: 654-661.

Drouillard, J.S., Ferrell, C.L., Klopfenstein, T.J. and Britton, R.A. 1991. Compensatory growth following metabolizable protein or energy restrictions in beef steers. J. Anim. Sci. 69: 811-818.

Foot, J.Z. and Tulloh, N.M. 1977. Effects of two paths of live-weight change on the efficiency of feed use on body composition of Angus steers. J. Agric. Sci. (Camb.) 88: 135-142

Fox, D.G., Johnson, R.R., Preston, R.L., Dockerty, T.R. and Klosterman, E.W. 1972. Protein and energy utilization during compensatory growth in beef cattle. J. Anim. Sci. 34: 310-318.

Fox, D.G., Dockerty, T.R., Johnson, R.R. and Preston, R.L. 1976. Relationship of empty body weight to carcass weight in beef cattle. J. Anim. Sci. 43: 566-568.

Hancock, D.L., Williams, J.E., Hedrick, H.B., Beaver, E.E., Larrick, D.K., Ellersieck, M.R., Garner, G.B., Morrow, R.E., Paterson, J.A. and Gerrish, J.R. 1987. Performance, body composition and carcass characteristics of finishing steers as influenced by previous forage systems. J. Anim. Sci. 65: 1381-1391.

Herring, W.O., Miller, D.C., Bertrand, J.K. and Benyshek, L.L. 1994. Evaluation of machine, technician, and interpreter effects on ultrasonic measures of backfat and longissimus muscle area in beef cattle. J. Anim. Sci. 72: 2216-2226.

Hicks, R.B., Owens, F.N., Gill, D.R., Martin, J.J. and Strasia, C.A. 1990. Effects of controlled feed intake on performance and carcass characteristics of feedlot steers and heifers. J. Anim. Sci. 68: 233-244.

Hironaka, R. and Kozub, G.C. 1973. Compensatory growth of beef cattle restricted at two energy levels for two periods. Can. J. Anim. Sci. 53: 709-715.

Houghton, P.L. 1988. Application of ultrasound in commercial feedlots and beef breeding programs. pp 89-99. Beef Improvement Federation Proc., Albuquerque, NM.

Houghton, P.L. and Turlington, L.M. 1992. Application of ultrasound for feeding and finishing animals: A review. J. Anim. Sci. 70: 930-941.

Jones, S.D.M., Thorlakson, B. and Robertson, W.M. 1994. The effect of breed type on beef carcass characteristics and Canadian carcass grade. Can. J. Anim. Sci. 74: 149-151.

Kabbali, A., Johnson, W.L., Johnson, D.W., Goodrich, R.D. and Allen, C.E. 1992. Effects of compensatory growth on some body components weights and on carcass and noncarcass composition of growing lambs. J. Anim. Sci. 70: 2852-2858.

Keane, M.G., More O'Ferrall, G.J., Connolly, J. and Allan, P. 1990. Carcass composition of serially slaughtered Friesian, Hereford X Friesian and Charolais X Friesian steers finished on two dietary energy levels. Anim. Prod. 50: 231-243.

Koch, A. 1982. A kinetic model for growth as a function of time and nutritional status. Growth 46: 74-87

Ledger, H.P. and Sayers, A.R. 1977. The utilization of dietary energy by steers during periods of restricted food intake and subsequent realimentation. 1. The effect of time on the maintenance requirements of steers held at constant live weights. J. Agric. Sci. (Camb.) 88: 11-26.

Lofgreen, G.P. and Kiesling, H.E. 1985. Effects of receiving and growing diets on compensatory gains of stressed calves. J. Anim. Sci. 61: 320-328.

Lofgreen, G.P., Hubbert, M.E. and Branine, M.E. 1987. Feeding restriction influence on feedlot performance. J. Anim. Sci. 65 (Suppl.): 430 (Abstr.)

Lopez Saubidet, C. and Verde, L.S. 1976. Relationship between live weight, age and dry-matter intake for beef cattle after different levels of food restriction. Anim. Prod. 22: 61-69.

McKinnon, J.J., Cohen, R.D.H., Jones, S.D.M., Laarveld, B. and Christensen, D.A. 1993. The effects of dietary energy and crude protein concentration on growth and serum insulin-like growth factor-I levels of cattle that differ in mature body size. Can. J. Anim. Sci. 73: 303-313.

Mader, T.L., Turgeon,Jr., O.A., Klopfenstein, T.J., Brink, D.R. and Oltjen, R.R. 1989. Effects of previous nutrition, feedlot regimen and protein level on feedlot performance of beef cattle. J. Anim. Sci. 67: 318-328.

Meissner, H.H., Smuts, M. and Coertze, R.J. 1995. Characteristics and efficiency of fast-growing feedlot steers fed different dietary energy concentrations. J. Anim. Sci. 73: 931-936.

Merchen, N.R., Darden, D.E., Berger, L.L., Fahey,Jr., G.C., Titgemeyer, E.C. and Fernando, R.L. 1987. Effects of dietary energy level and supplemental protein source on performance of growing steers and nutrient digestibility and nitrogen balance in lambs. J. Anim. Sci. 65: 658-668.

Meyer, J.H., Hull, J.L., Weitkamp, W.H. and Bonilla, S. 1965. Compensatory growth responses of fattening steers following various low energy intake regimes on hay or irrigated pasture. J. Anim. Sci. 24: 29-37.

Moran, J.B. and Holmes, W. 1978. The application of compensatory growth in grass/cereal beef production systems in the United Kingdom. World Preview of Animal Production 14(2): 65-73

Morgan, J.H.L. 1972. Effect of plane of nutrition in early life on subsequent live-weight gain, carcass and muscle characteristics and eating quality of meat in cattle. J.Agric. Sci. (Camb.) 78: 417-423.

Murphy, T.A. and Loerch, S.c. 1994. Effects of restricted feeding of growing steers on performance, carcass characteristics and composition. J. Anim. Sci. 72: 2497-2507.

NRC. 1984. Nutrient Requirements of Beef Cattle (6th Ed.) National Academy Press, Washington, DC.

O'Donovan, P.B. 1984. Compensatory gain in cattle and sheep. Nut. Abs. and Rev. Series B. 54: 389-410

Old, C.A. and Garrett, W.N. 1987. Effects of energy intake on energetic efficiency and body composition of beef steers differing in size at maturity. J. Anim. Sci. 65: 1371-1380.

Oltjen, J.W., Bywater, A.C. and Baldwin, R.L. 1986. Evaluation of a model of beef cattle growth and composition.J. Anim. Sci. 62: 98-108.

Oltjen, J.W. and Garrett, W.N. 1988. Effects of body weight, frame size and rate of gain on the composition of gain of beef steers. J. Anim. Sci. 66: 1732-1738.

Park, J.R. 1982. A Theory of Feeding and Growth of Animals. Springer-Verlag, New York, N.Y.

Park, C.S., Erickson, G.M., Choi, Y.J. and Marx, G.D. 1987. Effect of compensatory growth on regulation of growth and lactation: Response of dairy heifers to a stair-step growth pattern. J. Anim. Sci. 64: 1751-1758.

Perkins, T.L., Green, R.D. and Hamlin, K.E. 1992. Evaluation of ultrasonic estimates of carcass fat thickness and longissimus muscle area in beef cattle. J. Anim. Sci. 70: 1002-1010.

Perry, T.C., Ainslie, S.J., Traxler, M.J., Fox, D.G. and Stouffer, J.R. 1990. Use of real-time and attenuation ultrasonic measurements to determine backfat thickness, ribeye area, carcass marbling and yield grade in live cattle. J.Anim. Sci. 68 (Suppl.1): 120 (Abstr.).

Rantanen, N.W. and Ewing, R.L. 1981. Principles of ultrasound application in animals. Vet. Radiol. 22: 196

Robinson, D.L., McDonald, C.A., Hammond, K. and Turner, J.W. 1992. Live animal measurement of carcass traits by ultrasound: Assessment and accuracy of sonographers.J. Anim. Sci. 70: 1667-1676.

Rompala, R.E., Jones, S.D.M., Buchanan-Smith, J.G. and Bayley, H.S. 1985. Feedlot performance and composition of gain in late-maturing steers exhibiting normal and compensatory growth. J. Anim. Sci. 61: 637-646.

Ruel, J. 1989. National Ultrasonics Standards Manual. Agriculture Canada, Ottawa.

Sindt, M.H., Stock, R.A., Klopfenstein, T.J. and Vieselmeyer. 1993. Protein sources for finishing calves as affected by management systems. J. Anim. Sci. 71:740-752.

Smith, M.T., Oltjen, J.W., Dolezal, H.G., Gill, D.R. and Behrens, B.D. 1988. Evaluation of ultrasound for prediction of carcass fat thickness and ribeye area in feedlot steers. Oklahoma Agri. Exp. Sta., Anim. Sci. Res. Rep. MP-127: 291

Smith, G.M., Crouse, J.D., Mandigo, R.W. and Neer, K.L. 1977. Influence of feeding regime and biological type on growth, composition and palatability of steers. J. Anim. Sci. 45: 236-253

Smith, M.T., Oltken, J.W., Dolezal, H.G., Gill, D.R. and Behrens, B.D. 1992. Evaluation of ultrasound for prediction of carcass fat thickness and longissimus muscle area in feedlot steers. J. Anim. Sci. 70: 29-37.

Statistical Analysis System Institute, Inc. 1988. SAS users guide. SAS Institute Inc. Cary, N.C.

Sully, R.J. and Morgan, J.H.L. 1982. The influence of feeding level and type of feed on the carcasses of steers. Australian J. Agri. Res. 33: 721-729.

Tatum, J.D., Dolezal, H.G., Williams,Jr., F.L., Bowling, R.A. and Taylor, R.E. 1986. Effects of feeder-cattle frame size and muscle thickness on subsequent growth and carcass development. II. Absolute growth and associated changes in carcass composition. J.Anim. Sci. 62: 121-131.

Tatum, J.D., Klein, B.J., Williams,Jr., F.L. and Bowling, R.A. 1988. Influence of diet on growth rate and carcass composition of steers differing in frame size and muscle thickness. J. Anim. Sci. 66: 1942-1954.

Thomson, E.F., Bickel, H. and Schurch, A. 1982. Growth performance and metabolic changes in lambs and steers after mild nutritional restriction. J.Agric. Sci. (Camb.) 98: 183-194.

Tudor, G.D., Utting, D.W. and O'Rourke, P.K. 1980. The effect of pre- and post-natal nutrition on the growth of beef cattle. III. The effect of severe restriction in early post-natal life on the development of the body components and chemical composition. Aust. J. Agric. Res. 31: 191-204

Turgeon,Jr., O.A., Brink, D.R., Bartle, S.J., Klopfenstein, T.J. and Ferrell, C.L. 1986. Effects of growth rate and compensatory growth on body composition in lambs. J. Anim. Sci. 63: 770-780.

Wilson, P.N. and Osbourn, D.F. 1960. Compensatory growth after undernutrition in mammals and birds. Biol. Rev. 35: 324-363

Wright, I.A. and Russel, A.J.F. 1987. The effects of genotype and post-weaning nutrition on compensatory growth in cattle reared as singles or twins. Anim. Prod. 45: 423-432.

Wright, I.A. and Russel, A.J.F. 1991. Changes in the body composition of beef cattle during compensatory growth. Anim. Prod. 52: 105-113.

Yambayamba, E. and Price, M.A. 1991. Growth performance and carcass composition in beef heifers undergoing catch-up (compensatory) growth. Can. J. Anim. Sci. 71: 1021-1029

Yambayamba, E. and Price, M.A. 1991. Fibre-type proportions and diameters in the longissimus muscle of beef heifers undergoing catch-up (compensatory) growth. Can. J. Anim. Sci. 71: 1031-1035.

APPENDIX

Appendix TABLE 1. Year 1 (1989): Effect of Trial Day (TDay) on Weight, Gain, Digestible Energy (DE) Intake, DE Intake relative to Gain (Feed Efficiency) and DE Intake relative to Weight (DEWT) ($P < .01$).

TDay	Weight[1]	Gain[2]	Digestible Energy (DE) Intake[3]	DE/Gain[4]	DEWT[5]
14	267.17	11.88	236.49	24.81	0.908
42	285.55	18.38	539.59	31.76	1.954
70	313.81	28.25	616.87	22.31	2.053
98	344.35	30.54	739.68	25.39	2.237
114	366.69	22.34	340.92	17.04	0.956
140	390.58	23.89	589.17	27.90	1.558
162	435.54	44.96	636.35	14.60	1.542
180	472.49	36.94	573.67	16.06	1.263
SE	2.143	1.862	12.749	2.250	0.036

[1] kg

[2] kg $period^{-1}$

[3] Mcal

[4] Mcal kg^{-1}

[5] Mcal kg^{-1}

Appendix TABLE 2. Year 2 (1990): Effect of Trial Day (Tday) on Weight, Gain; Digestible Energy (DE) Intake, DE Intake relative to Gain (Feed Efficiency, DE Intake relative to Weight (DEWT) ($P<.01$)

Tday	Weight[1]	Gain[2]	Digestible Energy		
			Intake[3]	DE/Gain[4]	DEWT[5]
28	319.63	33.55	539.56	16.38	1.78
56	355.58	35.95	606.76	17.95	1.79
84	386.05	30.47	717.51	23.65	1.93
112	424.34	38.29	805.95	21.09	1.98
140	466.69	42.35	968.98	23.77	2.18
SE	2.2612	2.0824	18.8304	1.1206	0.0360

[1] kg

[2] kg $period^{-1}$

[3] Mcal

[4] Mcal kg^{-1}

[5] Mcal kg^{-1}

Appendix TABLE 3. Year 1 (1989): Effect of the interaction of Ration * TDay on Digestible Energy (DE)Intake, Weight, Gain,DE Intake relative to gain (FEM), and DE Intake relative to daily weight (DEWT) for steers of both breeds from 14d to 180d.

High Energy					
Tday	DE Intake[1]	Weight[2]	Gain[a3]	FEM[b4]	DEWT[b5]
14	249.00	272.00	12.40	23.01	0.939
42	606.69	292.80	20.80	29.39	2.154
70	736.84	328.02	35.21	21.08	2.382
98	872.25	357.92	29.90	31.16	2.546
114	389.22	379.62	21.70	19.94	1.054
140	604.04	405.80	26.17	24.55	1.538
162	655.66	448.94	43.14	15.60	1.533
180	572.31	485.48	36.54	16.04	1.224
SE	17.6213	2.9621	2.5742	3.1109	0.0498

Low Energy					
Tday	DE Intake	Weight	Gain[a]	FEM[b]	DEWT[b]
14	223.97	262.34	11.37	26.61	0.878
42	472.48	278.30	15.96	34.16	1.754
70	496.90	299.59	21.29	23.65	1.724
98	607.12	330.77	31.18	19.63	1.929
114	292.63	353.75	22.98	14.15	0.857
140	574.30	375.37	21.61	31.26	1.579
162	617.05	422.14	46.77	13.61	1.550
180	575.02	459.49	37.36	16.09	1.302
SE	18.4288	3.0978	2.6921	3.2535	0.0521

$P < 0.01$, except [a] $P < .05$ [b] $P < 0.1$

---

[1] Mcal

[2] kg

[3] kg period^{-1}

[4] Mcal kg^{-1}

[5] Mcal kg^{-1}

Appendix TABLE 4. Year 2 (1990): Effect of the interaction of Ration * TDay on DE Intake, Weight, Gain, DE Intake relative to gain (FEM), and DE Intake relative to daily weight (DEWT) for steers of both breeds from 28d to 140d.

High						Low					
TDay	DE Intake[1]	Weight[a2]	Gain[a3]	FEM[4]	DEWT[5]	Tday	DE Intake	Weight[a]	Gain[a]	FEM	DEWT
28	572.86	328.14	37.35	15.52	1.86	28	506.26	311.13	29.75	17.23	1.71
56	707.56	365.37	37.23	21.08	2.05	56	505.96	345.79	34.66	14.82	1.54
84	929.65	398.94	33.57	28.61	2.44	84	505.36	373.14	27.37	18.69	1.41
112	977.27	438.93	39.99	24.71	2.34	112	634.64	409.75	36.59	17.48	1.62
140	1089.37	478.20	39.27	28.31	2.39	140	848.59	455.18	45.44	19.23	1.96
SE	26.6302	3.1978	2.9450	1.5848	0.0509	SE	26.6302	3.1978	2.9450	1.5848	0.0509

P <.01, except, [a] P >0.1

[1] Mcal

[2] kg

[3] kg $period^{-1}$

[4] Mcal kg^{-1}

[5] Mcal kg^{-1}

Appendix TABLE 5. Example of Agriculture and AgriFood Canada Blue-Tag Beef Carcass Appraisal Report for 10 steers slaughtered at Burns Meats in Winnipeg June 13, 1991.

Agriculture Canada

Food Production and Inspection Branch — Direction generale, Production et inspection des aliments

BEEF CARCASS APPRAISAL REPORT

PLANT: BURNS

PRODUCER: U of M.

SLAUGHTER DATE: JUNE 13, 1991

NUMBER OF CARCASSES: 10

Your file / Votre référence: 5765-2-8

GRADER:

BLUE TAG NUMBER	SEX	WARM CARCASS WEIGHT kg	WARM CARCASS WEIGHT lbs	FAT (mm) 1	FAT (mm) 2	FAT (mm) 3	AVE FAT (mm)	GRADE FAT (mm)	GRADE & SYMBOLS	RIB-EYE AREA (cm2)	CUT-ABILITY % (% LEAN)	MARBLING LEVEL
45441	S		556	8	6	6		6	A1	65	good m 60.07	6
45440	S		543	9	6	6		6	A1	62	good 59.61	7
45431	S		549	6	7	5		5	A1	73	good 62.48	7
45438	S		491	11	7	5		5	A1	61	good 60.75	8
45437	S		651	12	8	8		8	A1	97	excellent [illegible] 64.66	7
45433	S		537	10	10	7		7	A1	59	G 58.36	9
45436	S		567	8	8	7		7	A1	61	G 58.42	7
45432	S		549	8	5	5		4	A1	63	G 61.16	7
45442	S		518	9	9	7		7	A1	62	G 59.21	8
45439	S		561	10	8	7		5	A1	57	G 59.10	6

fat firm

Marbling Levels:
0. Practically Devoid
9. Traces
8. Slight
7. Small