Copyright is owned by the Author of the thesis. Permission is given for a copy to be downloaded by an individual for the purpose of research and private study only. The thesis may not be reproduced elsewhere without the permission of the Author.
APPLICATION OF INTRARUMINAL CHROMIUM
CONTROLLED RELEASE CAPSULES TO THE
MEASUREMENT OF HERBAGE INTAKE OF SHEEP AT PASTURE

A thesis presented in partial fulfilment
of the requirements for the degree of
Doctor of Philosophy
in Animal Science
at Massey University

WARREN JAMES PARKER
1990
Experimental evidence obtained since 1950 suggests that New Zealand sheep farm production and financial returns could be increased by adopting separate grazing management for ewes of different pregnancy and rearing status from 6 weeks before lambing until weaning. Progress in developing management systems for the differential allocation of pasture, favourable lambing paddocks and labour during this period has been restricted by the absence of equipment for diagnosing ewe pregnancy status and a lack of data relating pasture conditions to feed intake and ewe and lamb productivity. Accurate pregnancy diagnosis by realtime ultrasound scanning has been available to farmers since 1985, but research into ewe grazing management continues to be hampered by the absence of techniques for measuring feed intake. This thesis addressed the latter issue, first by validating controlled release capsule (CRC) technology for measuring feed intake and second by examining feed intakes of ewes differing in pregnancy and rearing status and relating intakes to productivity.

A series of 11 experiments were conducted with sheep CRC to validate this technology for measurement of intake and to develop appropriate systems for using the technology in experimental situations. These studies examined: the linearity and period of Cr₂O₃ release; the effect of presence of capsules in the rumen on voluntary feed intake; the effect of feed type and feeding level on Cr₂O₃ release rate; and the accuracy of faecal Cr₂O₃ concentration in predicting faecal output of sheep dosed with CRC when alternative sampling regimens were applied. These experiments, conducted under both indoor feeding and outdoor grazing conditions, established that CRC released Cr₂O₃ into the rumen in a uniform manner once initiation of matrix extrusion had been completed 2 to 3 days after capsule insertion. The subsequent period of linear release (25 to 100 days) was found to be primarily dependent upon characteristics of the capsules controlled at manufacture (i.e. orifice diameter, matrix composition and length of pressed tablet matrix core). In comparison, environmental factors, both within and outside the sheep, had relatively small effects on the rate or linearity of Cr₂O₃ release. Release rate decreased by c. 4% if daily feed intake was at 0.7 maintenance compared to an ad libitum level, increased by c. 2% if hay rather than fresh pasture was consumed and decreased by 10 to 13% if capsules were placed in rumen-fistulated sheep rather than in intact animals. Adoption of feeding level below 0.6 maintenance for 4 to 7 days reduced Cr₂O₃ release rate and could cause capsule failure. Between-capsule variation in release rate from CRC recovered from the rumen by slaughter was low (coefficient of variation 2.0 to 6.5%). Variation between capsules within sheep was usually lower still. Voluntary herbage intake was significantly reduced if sheep were dosed with prototype CRC with inflexible wing designs. Under indoor conditions, correlations of 0.90 to 0.99 between daily faecal output derived by Cr₂O₃ dilution and actual faecal output for individual sheep were obtained. The correlation between estimates of mean 3-day faecal output of sheep at pasture predicted from the Cr₂O₃ concentration in morning and evening grab samples and from total collections was 0.87.
Prediction of individual animal intakes (indoors) appeared less accurate \((r = 0.74)\) because of variation in capsule release rate and in the animal’s own ability to select and digest its diet. Group mean estimates, which are appropriate for practical grazing conditions, were usually within \(\pm 10\%\) of the actual value. Low diurnal variation in faecal \(\text{Cr}_2\text{O}_3\) concentration (non-significant) allowed flexible faecal sampling regimens to be applied. In summary CRC were demonstrated to be superior to existing feed intake measurement techniques and to be well suited to the estimation of mean intakes of sheep, provided that suitable faecal sampling regimens were applied.

A pilot study investigating the feed intakes and productivity of ewes of different pregnancy and rearing status indicated that intakes of twin-bearing ewes were reduced in comparison to those of single-bearing ewes during late pregnancy, when the two groups were grazed together under ‘commercial’ farming conditions. During lactation, intakes exhibited a curvilinear relationship with time and were generally higher (by up to 32%) in twin-rearing ewes than in single-rearing ewes. This pattern of feed intake was less clear in a subsequent nine-week lactation study. In that trial, experimental groups comprising equal numbers of ewes rearing single or twin lambs were continuously grazed on five different pastures maintained at fixed sward surface heights (2.5, 4.0, 6.0, 7.0 and 9.0 cm). Herbage intakes by both single- and twin-rearing ewes were maximised at a sward surface height of approximately 5.0 cm (1000 to 1100 kg dry matter/ha). Lamb growth rates were not affected by sward height during the first six weeks of lactation because the ewes mobilised body reserves to maintain milk production. All ewes lost liveweight during the first 6 weeks of lactation but only the ewes on the 2.5 cm sward failed to regain lost liveweight from weeks 6 to 9 of lactation. Wool production, strength and colour were not affected by sward conditions in either the ewes or lambs over the lactation period. These results suggest that New Zealand farmers would gain little benefit from differential management of ewes post-lambing where a minimum grazing height of 5.0 cm could be maintained provided that ewes were in good condition (i.e minimum condition score 3.0) at lambing.
AC KNOWLEDGEMENTS

This study programme was expertly supervised by Professor Stuart McCutcheon and Professor George Wickham of the Animal Science Department at Massey University. I am particularly grateful for their enthusiastic support, prompt and constructive marking of manuscripts and assistance with field trials. It has provided a model for student postgraduate supervision which I will attempt to apply to students under my care in the future.

I was fortunate to have excellent technical support from Ms Catriona Jenkinson for all but two experiments. Catriona cheerfully helped to record data during weekends and willingly worked through the difficult weather conditions encountered during some of the field trials. (We will not forget the cold wet spring of 1988). Mrs Sally Kannegeiter assisted with the first two experiments. Dr Hu Gao and Dr Malcolm Tait, visiting scientists from the People's Republic of China and Canada respectively, provided considerable help with field measurements during the final grazing trial.

Mr Barry Parlane provided excellent service and assisted with the running of the indoor experiments at the Animal Physiology Unit. Mr Phil Whithead (Manager of the Sheep and Beef Cattle Research Unit) and farm staff, Messrs Lloyd Williams and Kerry Kilmister and Miss Lynley Watt prepared and assisted with the management of livestock used for experiments. Staff of the Nutrition and Reproduction Laboratories were always helpful, and I especially thank Mrs Barbara Purchas and Mrs Kathy Morton for carefully completing the tedious task of digesting hundreds of faecal samples for chromium analysis. The atomic absorption spectrophotometer for measuring chromium was skillfully operated by Mr Rod McKenzie.

Dr Dorian Garrick's guidance with statistical analyses was much appreciated. Many helpful suggestions with respect to trial design and interpretation of results were provided by members of the Departments of Animal Science, Agronomy and Biochemistry.

Miss Christine Andricksen patiently typed most of the manuscript, with assistance from Mrs Denise Stewart and Mrs Kathy Hamilton. Graphs were prepared by Miss Yvette Cottam.

I have achieved each of the goals I set myself at the commencement of this study: to maintain my family and church responsibilities; to continue my normal teaching requirements; and to enjoy the PhD study programme. It was not always easy and I am particularly grateful to Vivienne, my wife, for her loyal support during the last four years. Without her help this thesis would never have eventuated.

Financial support for this research programme was provided by the C. Alma Baker Trust, the Vernon Wiley Trust, Captec (NZ) Limited, The Massey University Agricultural Research Foundation and the Massey University Research Fund.
TABLE OF CONTENTS

CHAPTER ONE
INTRODUCTION

BACKGROUND

EFFECTS OF NUTRITION DURING PREGNANCY AND LACTATION ON
PRODUCTIVITY OF THE EWE

Feed Requirements of Ewes of Different Pregnancy and Rearing Status 5
Effects of Grazing Management on Ewe and Lamb Performance 7
Potential to Modify Lamb Birthweights by Nutrition 8
Ewe Milk Production 10
Wool Production 12
Non-Nutritional Effects on Lamb Survival 13

DEVELOPMENT OF SYSTEMS FOR DIAGNOSING EWE PREGNANCY STATUS 13

Laparoscopy 13
Radiography 14
Ultrasound Scanning 14
Metabolic Status of the Ewe 15

TECHNIQUES FOR MEASURING HERBAGE INTAKE 16

Sward-Based Techniques 16
  Pasture difference 16
  Sward tissue turnover 17
Direct Animal-Based Measurements 18
  Short-term changes in animal liveweight 18
  Grazing behaviour 19
  Water intake and turnover rate 19
  Bolus size and swallowing 20
  Feeding standards and animal productivity 20
Indirect Animal-Based Techniques 20
  Estimating faecal output 20
  Commercial development of intraruminal CRC 27
Estimating Herbage Digestibility 28
Summary: Accuracy of Measurement Techniques for Estimating Faecal Output and Herbage Intake 31

PURPOSE AND SCOPE OF THE INVESTIGATION 33
CHAPTER TWO
VALIDATION OF AN ASSAY FOR THE ANALYSIS OF
FAECAL CHROMIUM CONCENTRATION

INTRODUCTION 36
DESCRIPTION OF THE ASSAY METHOD 38
RECOVERY OF CHROMIUM FROM FAECAL SAMPLES 40
EFFECT OF FAECAL ASH CONTENT ON RECOVERY OF CHROMIUM 42
RECOVERY OF CHROMIUM FROM GROUND FAECAL SAMPLES AND
FAECAL PELLETS 43
VARIATION IN BACKGROUND CHROMIUM LEVELS 45
INTRA- AND INTER-ASSAY VARIATION 47
SUMMARY 48

CHAPTER THREE
EFFECT OF HERBAGE TYPE AND LEVEL OF INTAKE
ON THE RELEASE OF CHROMIC OXIDE FROM
INTRARUMINAL CONTROLLED RELEASE CAPSULES IN SHEEP

INTRODUCTION 49
MATERIALS AND METHODS 49
Experiment 1 49
Experiment 2 50
Chromium analysis 53
Statistical analysis 53
RESULTS 53
Experiment 1 53
Feed intake 53
CRC plunger travel 54
Experiment 2 55
CRC plunger travel 55
Appearance of chromium in the faeces 56
Recovery of chromium 56
Diurnal variation in faecal chromium concentration 58

DISCUSSION 60
CHAPTER FOUR
EFFECT OF DIFFERENT GRAZING SYSTEMS ON THE RELEASE OF CHROMIC OXIDE FROM INTRARUMINAL CONTROLLED RELEASE CAPSULES IN SHEEP

INTRODUCTION

MATERIALS AND METHODS

Experiment 3
Pastures
Animals
Pasture measurements
Chromium analysis
Statistical analysis

RESULTS
Sward Conditions
Plunger Travel and Chromium Release Rate
Recovery of Faecal Chromium
Effect of CRC on Faecal Output
Within-Day Variation in Faecal Chromium Concentration

DISCUSSION

CHAPTER FIVE
EFFECT OF ADMINISTRATION AND RUMEN PRESENCE OF CHROMIUM CONTROLLED RELEASE CAPSULES (CRC) ON HERBAGE INTAKE

INTRODUCTION

MATERIALS AND METHODS
Experiment 4
Experiment 5
Statistical Analysis

RESULTS
Experiment 4
Faecal output and feed intake
Appearance of chromium in the faeces
Chromium release rates
Recovery of chromium
Prediction of faecal output and feed intake

Experiment 5
Effect of CRC on faecal output
Effect of method of capsule administration on faecal output

DISCUSSION
Effect of CRC on Faecal Output and Feed Intake
Prediction of Faecal Output and Feed Intake

CONCLUSIONS
CHAPTER SIX
EFFECTS OF HERBAGE ALLOWANCE AND FEED TYPE ON CHROMIUM RELEASE RATES IN TWO TYPES OF INTRARUMINAL CRC

INTRODUCTION

MATERIALS AND METHODS

Experiment 6
Experiment 7
Statistical Analysis

RESULTS

Recovery of CRC from Slaughtered Ewes
Plunger Travel and Chromium Release Rates
Prediction of Faecal Output

DISCUSSION

CHAPTER SEVEN
EFFECTS OF FEEDING LEVEL AND FEED TYPE ON THE PERFORMANCE OF COMMERCIAL CHROMIUM CRC UNDER CONTROLLED INDOOR FEEDING CONDITIONS

INTRODUCTION

MATERIALS AND METHODS

Experiment 8
Statistical analysis

RESULTS

Effect of Feed Type on CRC Plunger Travel
Effect of Feeding Level on Rate of Plunger Travel
Recovery of Chromium from Faeces
Diurnal Variation in Faecal Chromium Concentration

DISCUSSION
CHAPTER EIGHT
FACTORS AFFECTING THE RATE OF CHROMIUM RELEASE FROM INTRARUMINAL CRC IN SHEEP CONTINUOUSLY GRAZED AT PASTURE

INTRODUCTION 105

MATERIALS AND METHODS 106

Experiment 9
Statistical analysis 107

RESULTS 107

Recovery of CRC and Condition of Rumen Contents 107
Rate of CRC Plunger Travel 108
Plunger Travel in Rumen-Fistulated vs Intact Sheep 109
Variation Between CRC Within Ewes 109

DISCUSSION 110

CHAPTER NINE
INTRARUMINAL CHROMIUM CRC FOR MEASUREMENT OF FAECAL OUTPUT BY SHEEP AT PASTURE

INTRODUCTION 112

MATERIALS AND METHODS 112

Experiment 10
Animals 112
Pastures 113
Herbage digestibility 114
Faecal chromium analysis 114

Experiment 11
Animals 115
Pastures 116
Statistical Analysis 116

RESULTS 117

Experiment 10
Sward conditions and herbage digestibility 117
Rate of plunger travel 118
Recovery of faecal chromium 119
Within-day variation in chromium concentration 119
Prediction of faecal output 120
1. BULK-G, BULK-I and DAILY-C Estimates 120
2. Prediction of Faecal Output from Rectum Grab Samples 120
3. Prediction of Faecal Output by Sward Ring Sampling 121
Herbage intake estimated from total faecal collections and predicted faecal output 123

Experiment 11
Sward conditions and herbage digestibility 123
Comparison between sward ring and rectum grab sampling 124
Predicted faecal outputs and feed intakes of ewes 126

DISCUSSION 126
CHAPTER TEN

HERBAGE INTAKES AND PRODUCTIVE PERFORMANCE OF EWES OF DIFFERENT PREGNANCY STATUS AND REARING RANK: PILOT STUDY

INTRODUCTION

MATERIALS AND METHODS

Experiment 12
   Pastures and animals
   Chromium analysis
   Statistical analysis

RESULTS

Pregnancy Diagnosis and Lambing Performance
Lamb Birthweights and Growth Rates
Ewe Liveweights and Wool Production
CRC Performance
Faecal Output and Herbage Intake Prior to Lambing
Faecal Output and Herbage Intake After Lambing

DISCUSSION

CHAPTER ELEVEN

THE APPLICATION OF CRC FOR ESTIMATING THE HERBAGE INTAKE OF EWES OF DIFFERENT REARING RANKS DURING LACTATION

INTRODUCTION

MATERIALS AND METHODS

Experiment 13
   Experimental design
   Selection and management of trial animals
   Animal measurements
      1. Liveweights
      2. Condition Scoring and Ultrasonic Backfat Depth
      3. Wool Production
      4. Faecal Output
      5. Pasture Digestibility
      6. Botanical Composition of the Ewe's Diet
   Pasture measurements
      1. Pasture Mass
      2. Pasture Accumulation
      3. Pasture Composition
      4. Pasture Height

GENERAL OVERVIEW OF TRIAL IMPLEMENTATION

Weather Conditions
Animal Health
CHAPTER TWELVE
GENERAL DISCUSSION

INTRODUCTION

VALIDATION OF INTRARUMINAL CRC FOR USE IN SHEEP

Improvements to the Chromium Assay

APPLICATION OF CRC TO THE MEASUREMENT OF HERBAGE INTAKE BY EWES

MODELLING ALTERNATIVE SHEEP PRODUCTION SYSTEMS

CONCLUSIONS
APPENDICES

APPENDIX I  Split-Plot Analysis : An Example  195
APPENDIX II  The Measurement of Intraruminal CRC Plunger travel by Realtime Ultrasound Scanning  197
APPENDIX III  Herbage Intakes of Ewes at Flushing and During the First Trimester of Pregnancy  200
APPENDIX IV  Experimental Procedures  205
APPENDIX V  Pasture and Ewe Feed Intake Data (Experiment 13)  211
APPENDIX VI  Prediction of Feed Intake of Indoor-fed Sheep Using Intraruminal Chromium CRC  215
APPENDIX VII  Publications  220

BIBLIOGRAPHY  249

TABLES

Table 2.1  Recovery of added Cr from separate batches of duplicate spiked faecal samples from sheep fed pasture.  41
Table 2.2  Effects of ash content on recovery of added chromium.  43
Table 2.3  Mean atomic absorption readings, coefficient of variation between duplicates within sheep and estimated chromium recoveries from ground and pellet faecal samples for a single day’s collection from sheep fed lucerne chaff (10 days after CRC administration).  44
Table 2.4  Background concentrations of chromium in plant and soil samples collected from different sites at Massey University.  46
Table 3.1  Dry matter composition of pasture feeds, experiment 2.  51
Table 3.2  Group mean dry matter intakes and digestibilities of feeds at each feeding level, experiment 2.  52
Table 3.3  Total CRC plunger displacement from day 0-42, linear regression of plunger travel on time and average daily chromium release rates in fistulated wethers on different feed types, experiment 2.  55
Table 3.4  Chromium recoveries from faeces of fistulated and intact wethers bulked across the last four days of each feeding level, experiment 2.

Table 4.1  Sward conditions during experiment 3.

Table 4.2  Sheep liveweight, CRC plunger travel and average daily chromium release rates, experiment 3.

Table 4.3  Actual faecal output, faecal ash content, estimated OMI and recovery of chromium for different grazing treatments, experiment 3.

Table 4.4  Faecal outputs of ram hoggets with or without intraruminal chromium CRC, experiment 3.

Table 4.5  Faecal output estimated from the concentration of chromium in rectum grab samples at 0830, 1200 and 1630 h and a subsample of faeces (24 h) taken by the total collection of faeces (actual) on the final day of each grazing period, experiment 3.

Table 5.1  Effect of rumen presence of chromium controlled release capsules on liveweight, feed intake, feed digestibility and faecal output in capsule-treated and control groups, experiment 4.

Table 5.2  Actual and predicted rates of CRC chromium excretion and recoveries of chromium for alternative faecal sampling methods in slaughtered and other sheep, experiment 4.

Table 5.3  Predicted and actual faecal dry matter output and feed intakes of yearling sheep for alternative faecal sampling methods over a 5-day collection period, experiment 4.

Table 5.4  Daily group mean predicted and actual faecal dry matter outputs, feed digestibility and dry matter intakes, experiment 4.

Table 5.5  Effect of rumen presence of controlled release capsules on faecal output of control and capsule-treated hoggets during pre-treatment and treatment periods, experiment 5.

Table 5.6  Effect of mock insertion of CRC on faecal outputs during the pre-treatment and treatment periods, experiment 5.

Table 6.1  Trial location and associated feeding conditions of ewes, experiment 6.

Table 6.2  Linear regression parameters and correlation coefficients for CRC plunger travel on time in intact ewes and fistulated wethers, experiments 6 and 7.

Table 6.3  Average daily release rates of chromium from 3.0 cm and 6.0 cm core CRC to the end of each feeding level, experiment 7.
<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Table 6.4</td>
<td>Group mean DMI and faecal outputs predicted from DMD values and faecal chromium concentrations, for three feed types offered indoors during experiment 7.</td>
<td>95</td>
</tr>
<tr>
<td>Table 7.1</td>
<td>CRC plunger travel, parameters for the regression of plunger travel on time from d4 to d 28 and average daily release rates of chromium, experiment 8.</td>
<td>99</td>
</tr>
<tr>
<td>Table 7.2</td>
<td>Mean dry matter intake, DM digestibility and faecal output at each feeding level for pasture and hay, experiment 8.</td>
<td>100</td>
</tr>
<tr>
<td>Table 7.3</td>
<td>Recovery of chromium, at each feeding level, from the faeces of wethers fed pasture and hay, experiment 8.</td>
<td>101</td>
</tr>
<tr>
<td>Table 7.4</td>
<td>Comparison of average CRC performance in different environments.</td>
<td>103</td>
</tr>
<tr>
<td>Table 8.1</td>
<td>Proportions of Rumen dry matter and organic matter in rumen contents from ewes grazed at different feeding levels, experiment 9.</td>
<td>108</td>
</tr>
<tr>
<td>Table 8.2</td>
<td>Regression analysis of plunger travel on time at different herbage allowances and estimated average daily release rates of chromium from CRC in intact ewes and rumen-fistulated wethers, experiment 9.</td>
<td>108</td>
</tr>
<tr>
<td>Table 8.3</td>
<td>Within-sheep variation in plunger displacement between two chromium CRC recovered by slaughter, experiment 9.</td>
<td>109</td>
</tr>
<tr>
<td>Table 9.1</td>
<td>Sward characteristics of high and medium grazing allowance treatments, experiment 10.</td>
<td>117</td>
</tr>
<tr>
<td>Table 9.2</td>
<td>Plunger travel in CRC from insertion until slaughter and daily chromium release rates, experiment 10.</td>
<td>118</td>
</tr>
<tr>
<td>Table 9.3</td>
<td>Recovery of chromium from BULK-G faecal samples, experiment 10.</td>
<td>119</td>
</tr>
<tr>
<td>Table 9.4</td>
<td>Mean within-day coefficient of variation between am and pm faecal chromium concentrations, experiment 10.</td>
<td>119</td>
</tr>
<tr>
<td>Table 9.5</td>
<td>Actual and predicted faecal outputs over 5 days from daily samples of intact faeces (DAILY-C), and faecal samples bulked across days (BULK-G and DAILY-I), experiment 10.</td>
<td>120</td>
</tr>
<tr>
<td>Table 9.6</td>
<td>Actual and predicted group mean faecal outputs for alternative 3-day rectum grab sampling routines, experiment 10.</td>
<td>121</td>
</tr>
<tr>
<td>Table 9.7</td>
<td>Faecal ash contents, and actual and predicted group mean faecal outputs for sward ring sampling on individual sampling days, experiment 10.</td>
<td>122</td>
</tr>
<tr>
<td>Table 9.8</td>
<td>Estimates of faecal output and feed intake based on total collection or the concentration of Cr2O3 in rectum grab samples from ram lambs grazed at two pasture allowances, experiment 10.</td>
<td>123</td>
</tr>
</tbody>
</table>
Table 9.9  Pasture mass, composition and in vitro digestibilities of herbage, experiment 11.

Table 9.10  Comparison between sward ring and rectum grab sample estimates of faecal output and OMI, experiment 11.

Table 9.11  Total weight, DM content and proportion of daily output of faecal samples collected from sward rings on the high and low pasture swards each day, experiment 11.

Table 9.12  Predicted faecal outputs and apparent herbage intakes of ewes, experiment 11.

Table 10.1  Pregnancy diagnosis and actual lambing performance of ewes, experiment 12.

Table 10.2  Effects of rank and sex on lamb birth and weaning weights and average daily liveweight gains, experiment 12.

Table 10.3  Effect of pregnancy status and rearing rank on ewe liveweights and wool production, experiment 12.

Table 10.4  Effect of pregnancy status on faecal output and estimated dry matter intake of ewes during the last trimester of pregnancy, experiment 12.

Table 10.5  Effect of rearing rank on faecal output and estimated DMI of ewes during the first nine weeks of lactation, experiment 12.

Table 11.1  Summary of September and October 1988 weather conditions at Massey University, experiment 13.

Table 11.2  Herbage mass on each of the swards at five harvests during the trial period, experiment 13.

Table 11.3  Net herbage accumulation rates on the five swards during the trial period, experiment 13.

Table 11.4  Parameters of linear regression calibration equations of herbage mass and EPM sward height for individual harvest dates, experiment 13.

Table 11.5  Botanical composition of swards, estimated from cut herbage and by point analysis of oesophageal fistulated sheep extrusa, experiment 13.

Table 11.6  Ash content and in vitro digestibility values of extrusa collected by oesophageal fistulated wethers from each sward, experiment 13.

Table 11.7  Effect of sward surface height on herbage intakes of ewes rearing single or twin lambs at three stages of lactation, experiment 13.

Table 11.8  Effect of sward surface height on ingestion of soil by ewes of different rearing ranks, experiment 13.
Table 11.9 Organic matter intakes of ewes predicted from the concentration of chromium in faeces collected from ring sites on swards with different herbage mass, experiment 13.

Table 11.10 Effect of sward treatment and rearing rank on ewe liveweight at the commencement and end of continuous grazing, experiment 13.

Table 11.11 Effect of sward treatment on liveweight change in ewes of different rearing rank, experiment 13.

Table 11.12 Coefficients for the multiple regression of ewe liveweight change during lactation and ewe liveweight at the end of continuous grazing on sward surface height, rearing rank and ewe age, experiment 13.

Table 11.13 Effect of sward treatment and ewe rearing rank on condition score and backfat depth, experiment 13.

Table 11.14 Lamb birthweights and effects of sward treatment, rearing rank and sex on final weight and growth rates, experiment 13.

Table 11.15 Multiple regression coefficients for lamb growth rates from L 0-45 and L 46-76 of lactation on rearing rank, sex and sward surface height, experiment 13.

Table 11.16 Effects of treatment and rearing rank on ewe clean wool growth, fibre diameter, fibre strength and colour, and total wool production since the previous shearing, experiment 13.

Table 11.17 Effects of sward treatment and rearing rank on lamb midside wool growth, fibre diameter and colour, experiment 13.

Table 11.18 Effect of sward treatment on estimated metabolisable energy intakes of single- and twin-rearing ewes during lactation, experiment 13.

Table 12.1 Liveweight, dry matter digestibility and actual or predicted intakes of sheep fed ryegrass/white clover pasture.

Table III.1 Characteristics of pasture swards grazed by ewes, during flushing and early pregnancy.

Table III.2 Ewe liveweight, predicted faecal output and voluntary herbage intakes of ewes during flushing and early pregnancy.

Table IV.1 Inorganic solvents used in wool scouring process.

Table IV.2 Estimated endpoints of linear release of Cr₂O₃, average rates of plunger travel and associated daily outputs of Cr for CRC administered on L 10 and L 45.
### Table IV.3
Derivation of herbage intakes for a sheep faeces sample with 0.25 mg Cr/g DM, and assuming different rates of CRC chromium release, an OMD of 80% and plant ash content of 15%.

### Table IV.4
Predicted and actual soil contamination of sheep faeces samples collected by Scofield (1970).

### Table V.1
Botanical composition of pasture samples collected manually from swards at the time of each pasture mass determination, experiment 13.

### Table V.2
Oesophageal fistulate extrusa ash contents and in vitro digestibility coefficients for three collection periods, experiment 13.

### Table V.3
Sward botanical composition, by point analysis, of bulked extrusa samples collected from oesophageal fistulated wethers, experiment 13.

### Table V.4
Effect of sward surface height on herbage intakes of ewes rearing either single or twin lambs at three stages of lactation.

### Table VI.1
Recovery of chromium from faeces using either daily or bulked sampling of faeces.

### Table VI.2
Group mean and actual faecal output DMI of rams fed cut pasture ad libitum indoors for two methods of faecal sampling.

### FIGURES

- **Figure 1.1** Prototype and commercial intraruminal chromium controlled release capsules
- **Figure 3.1** Controlled release capsule plunger travel from insertion until expiration of the first matrix core in fistulated wethers, experiment 1.
- **Figure 3.2** Recovery of chromium from the faeces of fistulated and intact wethers, experiment 2.
- **Figure 3.3** Diurnal variation in chromium concentration of faecal samples taken at 4-hour intervals in sheep feed clover or hay, experiment 2.
- **Figure 5.1** Mean daily voluntary intakes of control and capsule treated groups, experiment 4.
- **Figure 5.2** Pattern of recovery of chromium in the faeces after insertion of CRC in yearling sheep, experiment 4.
- **Figure 5.3** Mean daily faecal outputs of control and capsule-treated ram hoggets, experiment 5.
Figure 7.1  Diurnal variation in the chromium concentration of faecal grab samples expressed as a percentage deviation from the 24 h mean, experiment 8.

Figure 11.1 Grazing trial location and layout, experiment 13.

Figure 11.2 Mean weekly Ellinbank Pasture Meter heights on each of the five swards, experiment 13.

Figure 11.3 Mean weekly HFRO sward stick green leaf contact heights on each of the five swards, experiment 13.

Figure 11.4 Effect of sward surface height on organic matter intake by lactating ewes, experiment 13.

Figure 11.5 Relationship between sward surface height and backfat depth of single- and twin-rearing ewes, experiment 13.

Figure 11.6 Effect of sward surface height on group mean changes in ewe liveweight during lactation, experiment 13.

Figure 11.7 Effect of sward surface height on average growth rates of lambs during the first 45 days of lactation and from L 46 to L 76, experiment 13.

Figure VI.1 Mean pattern of faecal chromium recovery from indoor-fed rams fitted with chromium CRC.
# ABBREVIATIONS

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AA</td>
<td>atomic absorption spectrophotometer</td>
</tr>
<tr>
<td>ANOVA</td>
<td>analysis of variance</td>
</tr>
<tr>
<td>c.</td>
<td>circa (approximately)</td>
</tr>
<tr>
<td>CIDR</td>
<td>controlled internal drug release device</td>
</tr>
<tr>
<td>Cr</td>
<td>chromium (III)</td>
</tr>
<tr>
<td>Cr₂O₃</td>
<td>chromium sesquisioxide</td>
</tr>
<tr>
<td>CRC</td>
<td>controlled release capsule</td>
</tr>
<tr>
<td>CS</td>
<td>condition score</td>
</tr>
<tr>
<td>CSIRO</td>
<td>Commonwealth Scientific and Industrial Research Organisation</td>
</tr>
<tr>
<td>cv.</td>
<td>cultivar</td>
</tr>
<tr>
<td>d</td>
<td>day</td>
</tr>
<tr>
<td>DM</td>
<td>dry matter</td>
</tr>
<tr>
<td>DMD</td>
<td>dry matter digestibility</td>
</tr>
<tr>
<td>DMI</td>
<td>dry matter intake</td>
</tr>
<tr>
<td>DOMD</td>
<td>digestible organic matter in the dry matter (D-value)</td>
</tr>
<tr>
<td>DOMI</td>
<td>digestible organic matter intake</td>
</tr>
<tr>
<td>DSIR</td>
<td>Division Scientific and Industrial Research</td>
</tr>
<tr>
<td>EPM</td>
<td>Ellinbank pasture meter</td>
</tr>
<tr>
<td>F.O.B.</td>
<td>free on board</td>
</tr>
<tr>
<td>h</td>
<td>hours</td>
</tr>
<tr>
<td>ha</td>
<td>hectare</td>
</tr>
<tr>
<td>HFRO</td>
<td>Hill Farming Research Organisation (Scotland)</td>
</tr>
<tr>
<td>ICPES</td>
<td>Industively coupled plasma emission spectrophotometry</td>
</tr>
<tr>
<td>L</td>
<td>lactation</td>
</tr>
<tr>
<td>M</td>
<td>maintenance</td>
</tr>
<tr>
<td>MA</td>
<td>mixed age</td>
</tr>
<tr>
<td>min.</td>
<td>minute</td>
</tr>
<tr>
<td>MJME</td>
<td>megajoules of metabolisable energy</td>
</tr>
<tr>
<td>NHA</td>
<td>net herbage accumulation</td>
</tr>
<tr>
<td>NA</td>
<td>not applicable</td>
</tr>
<tr>
<td>N/ktx</td>
<td>Newtons per kilotex</td>
</tr>
<tr>
<td>OM</td>
<td>organic matter</td>
</tr>
<tr>
<td>OMD</td>
<td>organic matter digestibility</td>
</tr>
<tr>
<td>OMI</td>
<td>organic matter intake</td>
</tr>
<tr>
<td>P</td>
<td>pregnancy</td>
</tr>
<tr>
<td>RDM</td>
<td>residual dry matter</td>
</tr>
<tr>
<td>RH</td>
<td>relative humidity</td>
</tr>
<tr>
<td>RMT</td>
<td>rumen mean retention time</td>
</tr>
<tr>
<td>X</td>
<td>tristimulus value (red)</td>
</tr>
<tr>
<td>Y</td>
<td>tristimulus value (green)</td>
</tr>
<tr>
<td>Z</td>
<td>tristimulus value (blue)</td>
</tr>
</tbody>
</table>

## Weights, volumes and measures

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>µg</td>
<td>microgram</td>
</tr>
<tr>
<td>mg</td>
<td>milligram</td>
</tr>
<tr>
<td>g</td>
<td>gram</td>
</tr>
<tr>
<td>kg</td>
<td>kilogram</td>
</tr>
<tr>
<td>ml</td>
<td>millilitre</td>
</tr>
<tr>
<td>nm</td>
<td>nanometre</td>
</tr>
<tr>
<td>µm</td>
<td>micrometre</td>
</tr>
<tr>
<td>mm</td>
<td>millimetre</td>
</tr>
<tr>
<td>km</td>
<td>kilometre</td>
</tr>
<tr>
<td>mA</td>
<td>milliamper</td>
</tr>
<tr>
<td>°C</td>
<td>degrees centigrade</td>
</tr>
</tbody>
</table>
Statistical terms

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>CV</td>
<td>coefficient of variation</td>
</tr>
<tr>
<td>df</td>
<td>degrees of freedom</td>
</tr>
<tr>
<td>n</td>
<td>number</td>
</tr>
<tr>
<td>r</td>
<td>correlation</td>
</tr>
<tr>
<td>RSD</td>
<td>residual standard deviation</td>
</tr>
<tr>
<td>SD(s)</td>
<td>standard deviation</td>
</tr>
<tr>
<td>sem</td>
<td>standard error of the mean</td>
</tr>
<tr>
<td>TSS</td>
<td>total sum of squares</td>
</tr>
<tr>
<td>var</td>
<td>variance</td>
</tr>
<tr>
<td>( \bar{x} )</td>
<td>mean</td>
</tr>
<tr>
<td>NS</td>
<td>not significant</td>
</tr>
<tr>
<td>+</td>
<td>significant at ( P &lt; 0.1 )</td>
</tr>
<tr>
<td>*</td>
<td>significant at ( P &lt; 0.05 )</td>
</tr>
<tr>
<td>**</td>
<td>significant at ( P &lt; 0.01 )</td>
</tr>
</tbody>
</table>
| ***          | significant at \( P < 0.001 \)