DISEASES OF
Cattle
IN AUSTRALASIA

A COMPREHENSIVE TEXTBOOK

DISEASES OF Cattle IN AUSTRALASIA

SECOND EDITION

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Foreword

The second edition of *Diseases of Cattle in Australasia*, published by Massey University Press, is a revised version of the first edition, published in 2010 by the New Zealand Veterinary Association Foundation for Continuing Education (Vetlearn). The authors of the first edition, Tim Parkinson, Jos Vermunt and Jakob Malmo, have been joined by Richard Laven from Massey University.

Diseases of Cattle in Australasia is written from the perspective of the veterinary practitioner encountering the diseases in cattle on a farm. The reader is provided with a detailed outline of the diagnostic methodology based on clinical examination of body systems, with confirmation by ancillary tests and responses to treatment.

This textbook is arranged in 24 chapters, commencing with an overview of the dairy and beef industries in New Zealand and Australia and ending with a chapter on practical therapeutics. The black-and-white photographs in the first edition have been replaced by colour photographs.

Results from research completed since publication of the first edition in 2010 have been included to improve understanding in the chapters on diseases causing diarrhoea (Chapter 4), mastitis (Chapter 10), reproduction and disorders of the reproductive system (Chapter 11), management and diseases of calves (Chapter 17), lameness (Chapter 18), and genetic diseases (Chapter 21). New contributors to the second edition include Phil Poulton (downer cow), Gemma Chuck (calves) and John House, among others.

This remains the ultimate textbook on diseases of cattle in Australasia. All of the important diseases of cattle are covered. The book will be an essential reference for cattle practitioners throughout New Zealand and Australia and will have applications in other countries where cattle are kept under similar conditions.

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March 2019

Contents

Preface

The first edition of this textbook was published nearly 10 years ago, in response to an identified need for a book on the diseases of cattle in Australia and New Zealand. The first edition had a long gestation, having been conceived in about 2001, written between 2005 and 2008, and printed in 2009. We were delighted with the reception that the book was awarded, with the first printing sold out in a few months. Sadly, the New Zealand Veterinary Association, who published the first edition, was unable to take on a second edition — but just as we were becoming despondent, Massey University Press offered to take it over and the NZVA generously transferred the copyright of the text to MUP.

As with the first edition, this new edition has been written to serve as a reference text for the subject of diseases of cattle in Australasia, with the intention in particular to provide an immediate source of reference and information to veterinary students and veterinary graduates working in clinical practice. It is also intended to be useful to the progressive farmer, professional agricultural advisor and those in other scientific disciplines who require access to both general and detailed knowledge on diseases of cattle in Australasia.

In the 10 years since the first edition was published, some areas of cattle medicine have changed a great deal whilst others have largely remained unchanged. Thus whilst the overall content and layout of the book have not changed much, we have updated each chapter a little or a lot according to the extent of the changes that have taken place. This has also allowed us to bring in new authors and contributors, with Richard Laven playing a significant role in developing the new work. After the publication of the first edition, several colleagues suggested changes that could be made to the text, for which we were grateful; and some spotted mistakes — for which we tried to be properly grateful(!). We hope that all of those comments have been addressed in this new edition.

The temptation when producing a new edition is to add much new material — especially areas that are either new or only warranted a light treatment in the first edition. We have tried to stick to this principle and there has been a determined effort to prevent the new edition from evolving into an unwieldy text. In making this attempt, our intention was to concentrate on those aspects that will be of most assistance to the veterinary student and the veterinarian in the field. Hence, as in the first edition, the chapters are not fully referenced but include recommendations as to further reading that should assist those who wish to obtain more-detailed information on a particular topic. Key references to new, controversial or pivotal discoveries have, however, been included.

Many colleagues have contributed illustrations to the book; Keith Thompson has been especially generous in allowing us to trawl through more than 30 years of accumulated pathology slides — a unique collection that we were privileged to be able to access. While each of us has been responsible for the initial draft of portions of the text, the final version represents the consensus (sometimes hard-won) of our views. We like to think that there is advantage in our having gained extensive experience in clinical cattle practice, as well as at a variety of veterinary schools. We are also grateful for other specialists, from practice or academia, who have generously contributed to this work.

In preparing this book, care has been taken to ensure accuracy of reference ranges, dose rates, normal values, etc. It is possible, however, that some errors or inconsistencies may appear. Clinicians are therefore urged to read the manufacturer's recommendations carefully when administering medications. Similarly, reference ranges specific to the laboratory used should be consulted when interpreting laboratory results. In some situations it may be necessary for the clinician to use his/her own clinical judgement. Likewise, we have tried to ensure that all material, either illustrations or data, has been properly attributed. If there is anything that we have not fully acknowledged, we apologise.

Advances in printing technology have allowed us to move away from having some monochrome pages (i.e. the book is now full-colour throughout). It has also meant that some of the best illustrations that were previously provided as a supplemental CD in the first edition have now been incorporated into the text, making the CD redundant. One of the chief criticisms of the first edition was the weakness of the binding: MUP promises us that the new binding will be Very Robust Indeed.

Moving to a second edition has been a surprisingly demanding process. When we wrote what has now become the first edition, none of us envisaged returning to that work a decade later. It is our hope that this transition into a 'multi-edition' book will not stop at the second edition, but that future colleagues will maintain this as a key text in the armoury of the Australasian veterinary profession.

TIM PARKINSON, JOS VERMUNT, JAKOB MALMO, RICHARD LAVEN

Abbreviations

1,25DHD	1,25-dihydroxyvitamin D
AA	anovulatory anoestrus
AB	artificial breeding
ABARE	The Australian Bureau of Agriculture and Resource Economics
ABLD	acute bovine liver disease
ABPEE	acute bovine pulmonary oedema and emphysema
ABV	Australian Breeding Value
AcAc	acetoacetate
ACAN	aggrecan
ACV	Australian Cattle Veterinarians
ADH	antidiuretic hormone
ADHIS	The Australian Dairy Herd Improvement Scheme
AG	anion gap
AGID	agar-gel immunodiffusion test
AHB	New Zealand Animal Health Board
AI	artificial insemination
AIOD	artificial insemination on detection of heat
AIP	atypical interstitial pneumonia
δ–ALAD	δ-aminolevulinic dehydratase
ALAD	delta-aminolevulinate dehydratase
ALP	alkaline phosphatase
APR	Australian Profit Ranking
ARGT	annual ryegrass toxicity/staggers
ASS	argininosuccinate synthetase
AST	aspartate aminotransferase
ATP	adenosine triphosphate
AV	atrioventricular
AV	artificial vagina
BAL	British Anti-Lewisite, or bronchoalveolar lavage
BCG	Bacillus Calmette-Guèrin
BCS	body condition score
BDV	Borna disease virus
BEF	bovine ephemeral fever
BEFV	bovine ephemeral fever virus
BEH	bovine enzootic haematuria
BHM	bovine herpes mammillitis
BIV	bovine immunodeficiency-like virus
BLAD	bovine leukocyte adhesion deficiency
BLUP	Best Linear Unbiased Prediction
BLV	bovine leukaemia virus
BMD	bovine mucosal disease
BMSCC	bulk milk (somatic) cell counts
BNP	bovine neonatal pancytopenia
OHB	beta-hydroxybutyrate
BoHV	bovine herpesvirus
BPI	Balanced Performance Index
BPP	bovine pneumonic pasteurellosis
BPS	bovine papular stomatitis
BPV	bovine papillomavirus
BRD	bovine respiratory disease
BRSV, BSV	bovine respiratory syncytial virus
BSE	bovine spongiform encephalopathy
BSP	bromsulphalein
BTC	bulk tank culture
BTEC	Brucellosis and Tuberculosis Eradication Campaign
BTM	bulk tank milk
BTV	bluetongue virus
BV	breeding values
BVD	bovine viral diarrhoea
BVDV	bovine viral diarrhoea virus
BVLW	breeding value for liveweight
BW	Breeding Worth
CAAT	cross-agglutinationabsorption test
Ca-EDTA	calcium disodium ethylenediamine tetra-acetate
CarLA	carbohydrate larval antigen
CBC	complete blood count
CBPP	contagious bovine pleuropneumonia
CCN	cerebrocortical necrosis
CCP	corpus cavernosum penis
CCT	comparative cervical test
CFA	colonisation factor antigens
CFF	*Campylobacter fetus* subsp. *fetus*
CFT	caudal fold test
CFT	complement fixation test
CFU	colony forming units
CFV	*Campylobacter fetus* subsp. *venerealis*
CHF	congestive heart failure
CIDR	controlled internal drug release
CJD	Creutzfeldt-Jakob Disease
CJLD	congenital joint laxity and dwarfism
CK	creatinine kinase
CL	corpus luteum
Cmax	concentration maximum
CMI	cell-mediated immune response
CMR	commercial milk replacer
CMT	California Mastitis Test
CN	cranial nerves
CNS	central nervous system
CNS	coagulase-negative *Staphylococcus* spp.
COD	cystic ovarian disease
COWP	copper oxide wire products
COX	cyclo-oxygenase
CP	crude protein
CPPS	chronic pneumonia and polyarthritis syndrome
CR	conception rate
CSF	cerebrospinal fluid
Ct	cycle threshold
CUM	creatinine-corrected urinary Mg concentration
CVCT	caudal or posterior vena cava thrombosis
DCAD	dietary cation-anion difference
DCT	dry cow treatment
DD	digital dermatitis
DDBSA	dodecyl benzene sulphonic acid
DFA	d-hydrofolic acid
DIC	disseminated intravascular coagulation

DIM	days-in-milk
DJD	degenerative joint disease
DM	dry matter
DMI	dry matter intake
DMSA	meso-2,3-dimercaptosuccinic acid
DMSO	dimethyl sulfoxide
DUMP	deficiency of uridine monophosphate synthetase
EB	epidermolysis bullosa
EBL	enzootic bovine leukosis
eCG	equine chorionic gonadotrophin
ECG	electrocardiogram
ECP	oestradiol cypionate
ED1	ectodysplasmin gene
Edn	edition
EDTA	ethylenediamine tetra-acetic acid
EHEC	ENTEROHAEMORRHAGIC E. COLI
ELISA	enzyme-linked immunosorbent assay
eNDF	effective neutral detergent fibre
EPAF	enteropathic adhesive factors
epg	eggs per gram
ε toxin	epsilon toxin
ET	embryo transfer
EV	economic values
FARAD	The Food Animal Residue Avoidance Databank
FAT	fluorescent antibody test
FE	Facial eczema
FEC	faecal egg count
FECRT	faecal egg count reduction test
FFA	free fatty acids
FIGLU	forminoglutamic acid
FMD	foot-and-mouth disease
FPT	failure of passive transfer
FSE	focal symmetrical encephalomalacia
FSH	follicle stimulating hormone
FTAI	fixed-time artificial insemination
FW	fresh weight
g/h	grams per hour
GABA	gamma-aminobutyric acid
GDH, GLDH	glutamate dehydrogenase
GGT	gamma glutamyl transferase
GH	growth hormone
GHR	growth hormone receptors
GMA	glycerol monoacetate
GnRH	gonadotrophin releasing hormone
GPG	GnRH-prostaglandin-GnRH programme
GPX	glutathione peroxidases
GREP	Global Rinderpest Eradication Programme
Hb	haemoglobin
HCN	hydrogen cyanide
HE	haematoxylin and eosin
HGP	hormonal growth promotants
HMD	heat-mount detectors
HSS	hypertonic saline solution
HT	herbicide-tolerant
HUS	haemorrhagic uraemic syndrome
HWI	Health Weighted Index
IAA	indole-acetic acid
IBK	Infectious bovine keratoconjunctivitis
IBR	infectious bovine rhinotracheitis
ICSCC	individual cow somatic cell counts
ICT	immunochromatographic test
ID	interdigital dermatitis
IDC	Investigation and Diagnostic Centre
IDF	International Dairy Federation
IDH	L-iditol dehydrogenase
IFAT	indirect fluorescent antibody text
IFN	interferon–gamma
Ig	immunoglobulin
IgA	immunoglobulin A
IgE	immunoglobulin E
IGF-1	insulin-like growth factor 1
IgG	immunoglobulin G
IgM	immunoglobulin M
IH	Intermediate host
IHC	immunohistochemical, immunohistochemistry
IL	ineffective length (of teat-cup liner)
IMI	intramammary infection
iP	inorganic phosphorus
IPB	infectious pustular balanoposthitis
IPV	infectious pustular vulvovaginitis
ISF	interstitial fluid
ITEME	infectious thromboembolic meningoencephalitis
IVF	*in vitro* fertilisation
IVM	*in vitro* maturation
IVRA	intravenous regional anaesthesia
JHS	jejunal haemorrhage syndrome
LA	laparoscopic abomasopexy
LAMP	loop-mediated isothermal amplification
LC	lactating cow intramammary formulation
LC	liner compression
LDA	left-displaced abomasum
LDH	lactate dehydrogenase
LH	luteinising hormone
LIC	NZ Livestock Improvement Corporation
LMN	lower motor neuron
LPA	Livestock Production Assurance
LPS	lipopolysaccharides
LSD	lumpy skin disease
LW	liveweight
LYST	lysosomal trafficking regulator
MAC	MacConkey agar
MALDI-TOF	matrix-assisted laser desorption ionisation time-

	of-flight
MAM	methylazoxy-methanol
MAT	microscopic agglutination test
MCF	malignant catarrhal fever
MCH	mean corpuscular haemoglobin
MCHC	mean corpuscular haemoglobin concentration
MCV	mean corpuscular volume
MD	mucosal disease
MDBK	Madin-Darby bovine kidney epithelial cells
MDR	multiple drug resistance
ME	metabolisable energy
mEq/L	milliequivalents per litre
MetHB	methaemoglobin
MHC	major histocompatibility complex
MIC	minimum inhibitory concentration
MJ ME	megajoules of metabolisable energy
ML	macrocyclic lactones
MLA	Meat and Livestock Australia
MLW	mature liveweight
MMA	methylmalonic acid
MMACoA	methylmalonyl-CoA
MMP	metallo-proteinases
MPSP	major piroplasm surface protein
MRL	maximum residue limit
MRP	maternal recognition of pregnancy
MRSA	methicillin-resistant *Staph. aureus*
MS	milksolids
MSA	mannitol salt agar
MSD	Mating Start Date (Australia)
NAGase	N-acetyl-ß-D-glucosaminidase
NAIT	National Animal Identification and Tracing project
NDF	neutral detergent fibre
NEB	negative energy balance
NEFA	non-esterified fatty acids
NFC	non-fibre carbohydrates
NID	national identification of cattle
NIR	near infra-red
NIR	new infection rate
NLIS	National Livestock Identification Scheme
NMC	National Mastitis Council
NMD	nutritional muscular dystrophy
NPMS	National Pest Management Strategy
NPN	non-protein nitrogen
NPV	negative predictive value
NRC	National Research Council
NRG	non-regenerative
NRR	non-return rate
NSAID	non-steroidal anti-inflammatory drug
NSC	non-structural carbohydrate
NTS	non-typhoidal Salmonella
NVL	no visible lesion
NZAEL	New Zealand Animal Evaluation Limited
NZVA	New Zealand Veterinary Association
OA	ocular albinism
OAA	oxaloacetic acid
OAD	once-a-day (milking)
OCA	oculocutaneous albinism
OCD	osteochondrosis dissecans
ODB	oestradiol benzoate
OFCS	on-farm culture system
OIE	World Organisation for Animal Health
OR	odds ratio
OSCC	ocular squamous cell carcinoma
PABA	para-aminobenzoic acid
PAE	post-antibiotic effect
PAMP	pathogen-associated molecular pattern
PBP	penicillin-binding protein
PCR	polymerase chain reaction
PCV	packed cell (corpuscular) volume
PEF	physical effectiveness factor
PEM	polioencephalomalacia
peNDF	physically effective neutral detergent fibre
PFGE	pulsed-field gel electrophoresis
PGF2α	prostaglandin F2α
PI	persistently infected
PI3	parainfluenza virus 3
P-insert	progesterone releasing insert
PMI	point of maximum intensity
PMN	polymorphonuclear neutrophils
PMR	partial mixed ration
PPD	purified protein derivative
PPH	postparturient haemoglobinuria
PPV	positive predictive value
PRID	progesterone releasing intravaginal device
PrP	prion proteins
PRR	pattern recognition receptor
PSC	planned start of calving
PSDP	premature spiral deviation of the penis
PSM	planned start of mating (New Zealand)
PSP	phenosulphophthalein
PTH	parathyroid hormone
PUFA	polyunsaturated fatty acids
QC	quality control
RAGFAR	Reference Advisory Group of Fermentative Acidosis of Ruminants
RAPD	random amplified polymorphic DNA
RAV	right abomasal volvulus
RDA	right-sided dilation and displacement of the abomasum
RBC	red blood cell
RDA	right-displaced abomasum
RDF	rumen degradable fibre
RFID	radio frequency identification
RFM	retained fetal membranes
RG	regenerative

RGS	ryegrass staggers
RMT	Rapid Mastitis Test
RNA	ribonucleic acid
RVF	Rift Valley fever
S/P	sample-to-positive ratio
SAMM	Seasonal Approach to Managing Mastitis
SARA	subacute rumen acidosis
SBE	sporadic bovine encephalomyelitis
SC	subcutaneously
SCC	somatic cell count
SDH	sorbitol dehydrogenase
Se	sensitivity
SID	strong ion difference
SM	staphylococcal medium 110
SMCO	S-methyl L-cysteine sulphoxide
SOD	super-oxide dismutases
Sp	specificity
SPC	standard plate counts
SR	stocking rate
SR	submission rate
SWF	screw-worm fly
TAD	twice-a-day (milking)
Tb	bovine tuberculosis
TBA	tryptose blood agar
TCA	tricarboxylic acid
TEC	teat-end callosity
TEME	thromboembolic meningoencephalitis
TeNT	tetanus neurotoxin, tetanospasmin
TG	triglyceride
THI	temperature heat index
TMA	trimethylamine
Tmax	time at which concentration is reached
TME	thrombotic meningoencephalitis
TMR	total mixed ration
TNF	tumour necrosis factor
TPP	total plasma protein
TRP	traumatic reticuloperitonitis
TSE	transmissible spongiform encephalopathies
TST	targeted selective treatment
TTP	thrombotic thrombocytopenic purpura
TWI	type weighted index
UMN	upper motor neuron
vCJD	variant Creutzfeldt-Jakob Disease
Vd	volume of distribution
VFA	volatile fatty acids
VLDL	very low density lipoprotein
VNT	virus neutralisation test
VRE	vancomycin-resistant enterococci
VS	vesicular stomatitis
w/v	weight per volume
WBC	white blood cell
WBCC	white blood cell count
WD	winter dysentery
WMD	white muscle disease

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CHAPTER 1

Dairy and beef production systems in Australia and New Zealand

The basis of milk production systems is relatively simple: the cows consume feeds and convert them into milk efficiently, profitably and sustainably. Hence, dairy industries in Australia and New Zealand operate over a wide range of climatic conditions, using systems that have developed to best suit the needs of the various regions, and using diets that range from grazed pasture (lower costs, but also lower daily intakes and milk yields) to grains plus sufficient conserved forage to maintain a healthy rumen environment. All cows of modern dairy breeds can produce milk efficiently, and they should be able to conceive, calve and begin lactation at any time of the year. However, there are wide genetic differences between breeds and strains in important characteristics such as size, milk yield and composition and fertility, which have to be integrated alongside economic, geographical and climatic factors to determine the most appropriate system of dairy production.

Decisions such as calving date, type of cow and diet to be fed therefore depend on local conditions that must be considered in developing an appropriate dairy system. The cost and seasonality of pasture production, the availability and cost of other sources of feed, and the market for milk (and in many cases variation in milk price at different times of the year) are only some of the factors that a dairy producer must consider when developing the farming system appropriate to their circumstances.

Veterinarians need to recognise that dairy farmers require a wide range of skills to manage their business. As dairy farmers, they are required to manage:

- Livestock: herd health, fertility and nutrition
- Feedbase: pastures, crops and supplements
- Assets: land, infrastructure, machinery
- People: those who work on the farm, and those who provide support services for the farm
- Business: the need to manage the financial aspects of the business.

Different farmers will have varying degrees of interest in each of these areas, and varying levels of skill in them. Veterinarians need to recognise these differences when developing programmes for farmers. Good feeding and management of a herd can maintain a low incidence of diseases, and in most herds the cost of herd health is less than 10% of farm working expenses. Accordingly, to contribute most profitably and constructively to a herd's overall performance and profitability, the attending veterinarian must understand both the cows and the production system.

The aim of this chapter is to provide a background to dairy production in Australia and New Zealand and, in doing so, help veterinarians understand the goals and methods of their dairy-farming clients.

Very similar considerations apply to beef cattle production. Whilst veterinary input for many beef-production enterprises is less than would be provided for a similar number of dairy cows, there are still very substantial health-related issues that affect beef cattle farming and have the potential to have major effects on the viability and profitability of those enterprises. Hence, this chapter also provides an overview of the respective beef cattle production systems of Australia and New Zealand, particularly as they relate to animal health.

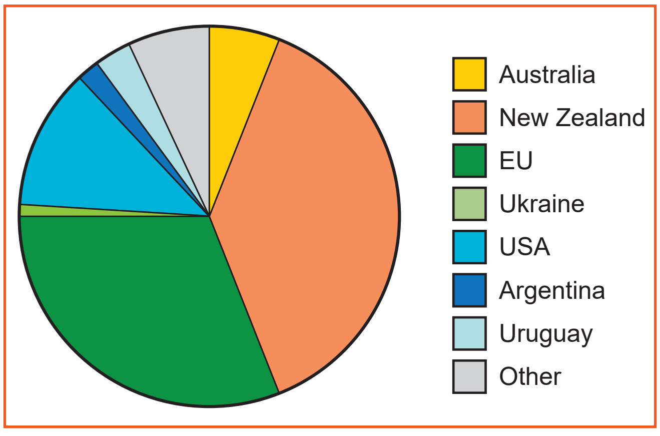

FIGURE 1.1.1 Contribution of Australia and New Zealand to the world dairy commodity trade in 2017. (Data from *The Australian Dairy Industry in Focus*, 2017)

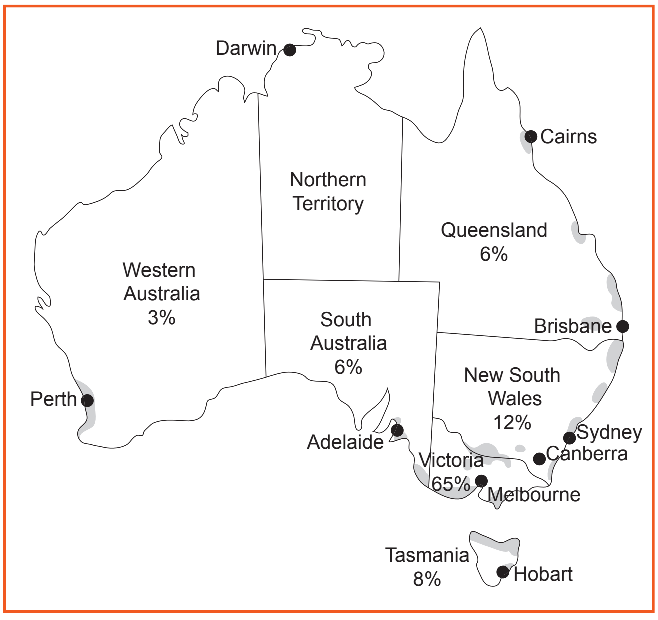

FIGURE 1.1.2 Geographical location of the Australian dairy industry. (Redrawn from http://www.abareconomics.com/interactive/09_SeriesPapers/Dairy/images/graphs/Dairy_map1.jpg)

1.1 Dairy production systems in Australia and New Zealand

Overview

Australia

The dairy industry is one of Australia's major rural industries, earning in excess of AU$2.75 billion in export income. However, its contribution to the world dairy trade is only about 6%, compared with New Zealand's 38%, the latter being the largest dairy exporter (Figure 1.1.1). Based on a farm-gate value of production of AU$3.7 billion in 2016/17, it ranks 3rd behind Australia's beef and wheat industries. It is estimated that approximately 42,100 people are directly employed on dairy farms and by dairy companies within Australia.

Dairying is also one of Australia's leading rural industries in terms of adding value through further downstream processing. Much of this processing occurs close to farming areas, thereby generating significant economic activity and employment in country regions. The Australian Bureau of Agricultural and Resource Economics (ABARE) estimates that the regional economic multiplier from the dairy industry is of the order of 2.5. The dairy industry is, therefore, a significant generator of economic activity and employment in rural Australia.

Most dairy production is located in coastal areas where pasture growth generally depends on natural rainfall. However, there are several inland irrigation schemes, including the northern irrigation area and the Macalister Irrigation District in Victoria, and irrigation systems in southern New South Wales. South-east Australia's climate and natural resources are generally favourable to dairying and allow the industry to be predominantly pasture-based, with approximately 70 to 75% of cattle feed requirements coming from grazing in a year of 'normal' seasonal conditions. Although the bulk of milk production occurs in the south-eastern seaboard states, all states have dairy industries that supply fresh drinking milk to nearby cities and towns (see Figure 1.1.2).

There exists a wide range of geographical and climatic conditions in which Australian dairy farms are operated, which affect their contributions to the country's total milk production (Fulkerson and Doyle, 2001). These include:

- Tasmania, south Victoria and the south coast of New South Wales: a temperate climate with a yearly rainfall of >700 mm. A relatively reliable long pasture-growing season; good for approximately 35% of Australia's total milk production.
- Western Australia (south of Perth), South Australia (south of Adelaide), south-west and north-east Victoria: a Mediterranean climate with >600 mm rain per year. Winter rain; long, hot summer with some irrigation; approximately 30% of total milk production.
- Southern New South Wales and northern Victoria: long, hot summers with 350 to 500 mm rain each year; inland irrigation region; approximately 25% of total milk production.
- Queensland and the north coast of New South Wales: a subtropical climate with variable rainfall; temperate and tropical grasses integrated; approximately 10% of total milk production.

TABLE 1.1.1 Number of registered dairy farms in Australia and New Zealand. (Partly adapted from Dairy Australia, *The Australian Dairy Industry in Focus*, 2017; sources: state milk authorities and *New Zealand Dairy Statistics 2016–17*)

	NSW	VIC	QLD	SA	WA	TAS	AUST (TOTAL)	NZ (TOTAL)
1979/80	3,601	11,467	3,052	1,730	622	1,522	21,994	16,089
1989/90	2,220	8,840	1,970	969	496	901	15,396	14,685
1999/00	1,725	7,806	1,545	667	419	734	12,896	13,861
2009/10	820	5,159	621	306	165	440	7,511	11,691
2016/17*	661	3,889	410	241	148	440	5,789	11,748

* Estimated

TABLE 1.1.2 Number of dairy cows in Australia and New Zealand ('000 head). (Partly adapted from Dairy Australia, *The Australian Dairy Industry in Focus*, 2017; sources: state milk authorities and *New Zealand Dairy Statistics 2016–17*)

	NSW	VIC	QLD	SA	WA	TAS	AUST (TOTAL)	NZ (TOTAL)
1979/80	311	1,047	247	103	71	103	1,880	2,027
1989/90	238	968	201	89	64	92	1,654	2,321
1999/00	289	1,377	195	106	65	139	2,171	3,269
2009/10	203	1,014	98	92	55	134	1,596	4,397
2016/17*	165	995	87	65	55	145	1,512	4,861

* Estimated

The domestic market, with its need for a relatively constant daily volume of milk throughout the year, requires about 50% of all the milk produced in Australia, compared with less than 5% of the total milk production in New Zealand. These differences in the use of milk and in the availability of reliable grazing or low-cost grain help to shape the dairy systems used in these two countries.

New Zealand

Dairying in New Zealand accounts for approximately 30% of export earnings and around 4% of gross domestic product (GDP); over the 5 years 2012 to 2016, average export revenues were NZ$14.4 billion (Ballingall and Pambudi, 2017). Over 40,000 people are employed in the industry, with 27,500 on farms and a further 13,000 in processing (Ballingall and Pambudi, 2017). Although New Zealand only produces around 2% of the global milk supply, because over 95% of this is exported, it accounts for over 30% of globally traded products, with around 40% of the products being value-added exports.

The latitude and topography of New Zealand result in a temperate climate and adequate rainfall in most regions. These conditions allow for year-round pasture growth and grazing, with only a few regions being suitable for grain production. Less than 20% of farms use irrigation, these being mainly located in the eastern region of the South Island and the lower part of the North Island. Traditionally, the majority of farms and cows have been located in the northern half of the North Island. However, with the rapid development of new and larger farms, and of dairy herds in the South Island since the 1980s, this region now exceeds the southern half of the North Island. Herds in the South Island also have higher yields than those in the North Island, which reflects the greater use of irrigation in the east of the South Island and through the Canterbury Plains, the use of more grain, and slightly higher pasture quality (associated with lower temperatures and less water stress).

Factors affecting farm profitability

Numbers of farms and cows, and their yields

Overall, the Australasian dairy industry has shown a progressive trend towards fewer farms, larger herds and increasing levels of milk production per farm, and both countries have shown a clear trend towards the emergence of very large dairy farm operations of more than 1000 head of milking cows.

The number of dairy farms in Australia has fallen by more than two-thirds over the past three decades, i.e. from 19,380 in mid-1985 to 5789 in mid-2016 (Table 1.1.1). This decline in the number of dairy farms in Australia has not been mirrored by a decrease in the number of dairy cows. In 1979/80, the number of dairy cows in Australia was 1.88 million. This number increased to 2.17 million in 1999/2000 and has since declined to a projected estimated number of 1.512 million in 2016/17 (Table 1.1.2). Herd sizes

TABLE 1.1.3 Key statistics for the Australian and New Zealand dairy industries for the year 2016/17. (Sources: *The Australian Dairy Industry in Focus 2017* and *New Zealand Dairy Statistics 2016–17*)

2016/17	NSW	VIC	QLD	SA	WA	TAS	AUST (TOTAL)	NZ (TOTAL)
Number of registered dairy farms	661	3,889	410	241	148	440	5,789	11,748
Number of dairy cows ('000 head)	165	996	87	65	55	145	1,512	4,861
Average annual milk production per cow (L)	6,309	5,761	4,731	6,521	6,504	5,651	5,819	4,259
Average herd size (cows)	250	256	212	270	372	330	261	414

have increased steadily over the past decade, from 229 in 2005 to 262 in 2016: currently 11% of farms nationally run more than 500 milking cows, producing some 33% of Australia's total milk volume. Conversely, the proportion of farms running fewer than 150 cows has nearly halved over the past 10 years. Furthermore, from 2000/01 to 2016/17 the number of farms milking fewer than 200 cows a year declined by around 71%, largely accounting for the decline in the total number of farms. Owner-operated farms continue to dominate the Australian dairy industry. Share farming is employed on around 18% of farms, while corporate farms make up just 2% of the total. New Zealand has 4.8 million cows on 11,800 farms (equating to just over 414 cows/farm); of these, 60% are in the North Island of New Zealand. The country has also seen a decrease in the number of registered dairy farms, albeit less dramatic than that in Australia, whilst the total number of dairy cows in the national herd has increased over the same period of time. Table 1.1.3 presents some key statistics for the Australian and New Zealand dairy industries for the year 2016/17.

Improved herd genetics, as well as advances in pasture management and supplementary feeding regimens, have seen the average annual yield per cow (as reported in the Australian Dairy Herd Improvement Report 2016) increase from 4047 L (314 kg MS) in the period 1985/1990, up to 6983 L (512 kg MS) in 2015/16. Whilst improvements in nutrition and management are responsible for much of this increase, it is estimated that over the past decade, approximately one-third of the improvement in productivity achieved by Australian dairy farmers should be credited to better genetics.

Profitability and farmer confidence

In the 1990s, prior to the deregulation of the Australian domestic milk market in 2000, the average milk price paid to farmers was higher in Australia than in New Zealand. However, since then it has decreased steadily in Australia but increased slightly in New Zealand, and there is now little difference between the two countries (Thorrold and Doyle, 2007).

Real profit per farm has been higher in New Zealand, especially since 2000, and the real value of assets has increased more rapidly and to much higher levels on New Zealand farms than on Australian farms. Returns (including capital gains) on assets varied between years in both countries, but were consistently higher in New Zealand.

All these trends reflect lower costs of production ($/kg milk solids produced) in New Zealand compared with Australia. Consequently, farmer confidence is relatively higher in New Zealand and the total area farmed for dairy production, the total number of cows, and overall milk supply are increasing steadily. In contrast, low profitability, increased grain feeding (and its associated costs), droughts and water-usage restrictions, and climate change are increasing the complexity of farm management and reducing farmer confidence in Australia. The total volume of milk produced in Australia has decreased slightly since 2000 (Thorrold and Doyle, 2007).

Environmental factors are also becoming increasingly important in both countries; in particular, access to water in Australia, and, in New Zealand, leaching of nutrients into groundwater, rivers and lakes, methane production and access to water (Clark *et al*., 2007).

Farm-gate milk pricing

Australia's farm-gate milk prices are based on the milk fat and protein solids content of the milk supplied. Australian dairy farmers operate in an open and deregulated market, so local Australian prices are driven by world commodity prices, which determine local export returns. Likewise, farm-gate milk prices received by farmers around Australia can vary significantly depending on how milk is being used in the domestic marketplace. Figure 1.1.3 shows the split between drinking milk, milk used for manufacturing for locally consumed product, and milk used for manufacturing export products, across the different regions of Australia.

While Australian processors are increasingly moving towards the production of value-added products, around 37% (in 2016/17) of Australia's milk production is still sold on the export market. The price received on the export market is very volatile, being influenced by both the demand for the product and the amount of product being placed on the market. Recent deregulation of milk production in the European Union (EU) has seen an increase in milk production in the EU, and this has been at least one of the factors responsible for the drop in world milk prices that occurred in 2015/16. A further factor, which markedly influences the price received for milk in Australia, is the value of the Australian dollar against the US dollar in foreign exchange markets. As the value of the Australian dollar against the US dollar goes up, it effectively reduces the price that producers will receive for products sold on the export market. Consequently, the exchange rate can significantly affect what the dairy companies are able to pay the producers for their milk. These same factors also apply to the New Zealand dairy industry.

Further, farm-gate milk prices may vary between manufacturing companies, with individual company returns being affected by factors such as the market and product mix, marketing strategies, utilisation and efficiencies in factory processing capacity, and exchange rate hedging policies. Payments between processors to individual farms can also vary significantly, as the companies operate a range of incentives and penalty payments related to milk quality, productivity or volume levels, and year-round supply as compared with a very seasonal milk supply.

Volatility in farm-gate milk prices and farm incomes has increasingly become part of the environment in which Australian dairy farmers must manage their businesses. Added to this volatility are varying climatic conditions and, in particular, prolonged dry spells that may result in the shortage of irrigation water in some areas. At least in some areas, this has resulted in significant on-farm adaptation strategies used to manage the highly variable seasonal conditions of the past decade, particularly in the inland irrigation regions of northern Victoria, and in central and southern New South Wales where water allocations have been very low for a number of years. In these areas there has been an increase on some farms in the use of feed pads, mixer wagons, and total or partial mixed rations.

The trend in farm numbers will often follow the trend in farm-gate milk prices from season to season, with strong prices either slowing the rate of attrition or even reversing the long-term trend. At times of low farm-gate milk prices, farmers often choose to leave the industry or else cease dairying operations until market conditions improve. Nevertheless, falling farm numbers do reflect a long-term trend observed in agriculture around the world, as reduced price support and changing business practices have encouraged a shift to larger, more efficient operating systems.

Industry structures

In New Zealand, the dairy industry is dominated by farmer-owned, cooperative companies. Fonterra Cooperative Group Limited (Fonterra) is a multinational dairy cooperative owned by around 10,500 New Zealand farmers, which processes around 80% of New Zealand's total milk production, with Westland and Tatua co-ops processing 3% and 1%, respectively. The remaining processors are corporates: Open Country Dairies (7%), Synlait (4%), Miraka (1%) and Oceania (1%).

The Australian dairy manufacturing sector is diverse and includes farmer-owned cooperatives and public, private and multinational companies. The farmer-owned cooperatives no longer dominate the industry and now account for less than 40% of Australia's milk production. Murray Goulburn (MG), which was recently taken over by the Canadian dairy giant Saputo, was the largest cooperative as well as the single largest milk processor, accounting for around 37% of all milk produced in Australia. Other companies involved in the manufacturing sector include Australian Consolidated Milk (ACM), Midfield Groups, Bega Cheese and Burra Foods.

Large multinational companies have operated in the Australian dairy industry for many years and currently include, among others, Fonterra (New Zealand), Kirin (Japan), Lactalis (France), Nestlé (Switzerland) and Parmalat (Italy). Fonterra has recently made significant changes to its manufacturing capabilities, citing a desire to refocus on key product lines such as cheese, spreads and milk powders.

Dairy New Zealand (DairyNZ) and Dairy Australia are farmer-owned organisations responsible for research into and extension of milk production, often in close cooperation with other organisations. Dairy Australia is an industry-owned research and development organisation that invests money into research and development projects on activities throughout the supply chain. The money that Dairy Australia receives is generated through the collection of levies, which are imposed on farmers on a cents per litre basis. These levies are matched dollar for dollar by Australia's federal government. The company is fully accountable to its members and peak industry bodies. In New Zealand, the Livestock Improvement Corporation Ltd (LIC) is a user-owned cooperative with responsibility for farm production activities and, in particular, dairy herd improvement and herd records. Services provided to farmers by LIC include farm management information, herd testing

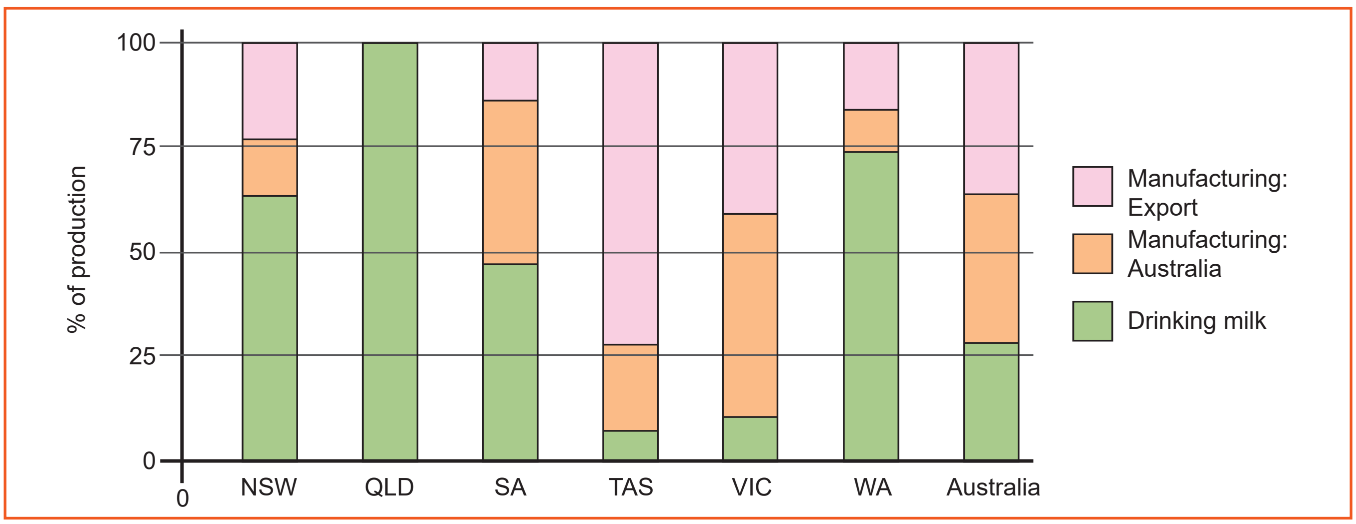

FIGURE 1.1.3 Destination of milk produced in each state of Australia. (Derived from Dairy Australia, *The Australian Dairy Industry in Focus*, 2017)

FIGURE 1.1.4 Milking facilities. **(a)** Rotary sheds are commonly used where there are >400 to 500 cows to be milked. **(b)** A modern rotary shed, equipped with automatic cluster removers and in-line milk recording. Herringbone sheds are more commonly used for smaller herds: **(c)** a high-line unit with a single set of cups for the two sides and **(d)** a low-line unit, with separate sets of cups for both sides of the shed.

and artificial breeding services, DNA analysis, a farm advisory service, statistical information related to the New Zealand dairy industry, and herd recording on the LIC database. The Australian Dairy Herd Improvement Scheme (ADHIS) maintains a national database of performance and pedigree details for individual dairy animals. This is regularly updated with data collected by milk recording organisations and breed societies. The database is used by artificial breeding companies and dairy farmers alike to assist genetic improvement in the dairy industry. The core activity of the ADHIS is to calculate Australian Breeding Values (ABVs) for dairy traits. Herd testing and artificial insemination services in Australia are provided by a wide range of service providers, including farmer-owned cooperatives.

Patterns of production

Milking systems

In both Australia and New Zealand, 80 to 90% of farms have herringbone milking sheds, with about 35% of these being 'doubled up' in Australia. Most herringbone sheds have less than 30 sets of cups, while the majority of rotary sheds are larger (Figure 1.1.4). Rotary sheds are commonly used for herds larger than ~400 cows, and are more common in New Zealand (24%) than in Australia (12%).

Low-input, pasture-based dairy farms have traditionally accepted twice-a-day milking as the optimum frequency of milk removal. However, this convention is increasingly being challenged, as farmers strive to improve their profitability. Once-a-day (OAD) milking is an alternative approach used to improve farm productivity and/or profitability.

OAD milking is not a new concept in New Zealand, having been used for many years during periods of marked feed shortage over late winter/early spring, or again in late summer. This has been done to reduce milk yield and the cow's energy demands slightly in an attempt to minimise any loss of body condition (and the risk of anoestrus in spring) caused by the feed deficit. More-widespread use of supplementary feeds, particularly grass and maize silage and now also palm kernel extract/expeller, have reduced these feed shortages and, therefore, reduced the need for short-time OAD on many farms.

The current interest in OAD milking is focused on a new system

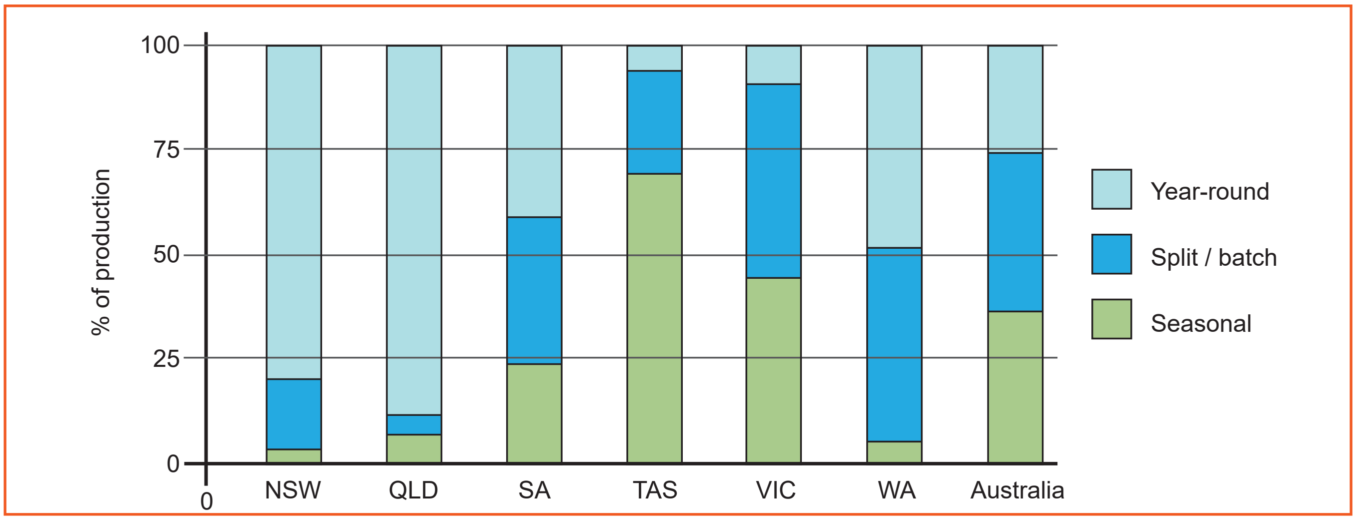

FIGURE 1.1.5 Proportion of dairy farms in each state in Australia using seasonal, split-batch or year-round-calving systems. (Derived from Dairy Australia, *The Australian Dairy Industry in Focus*, 2017)

of dairy farming, namely OAD throughout the whole lactation. An increasing minority of farms, some large, have adopted this system to reduce labour requirements, improve staff working conditions and lifestyle, reduce time and distances walked by the cows, and reduce dairy shed expenses. The adopters believe that these benefits outweigh the relatively small decrease in milk production that can be expected. Many dairy farmers that practise OAD milking are also reporting markedly improved animal health (and reduced animal health costs), and improved reproductive performance (see Vermunt, 2006; Anon, 2007).

DairyNZ, in a discussion on full-season OAD milking, stated that OAD can be as profitable as twice-a-day milking (TAD), with the main factors being minimisation of any decrease in production and the amount of cost savings achieved by adopting OAD. With regard to production, herds that did adopt OAD experienced on average an 11% decrease in milk solids in their first season on OAD, although there was variation between herds. Over time, cows that are not suitable for OAD milking can be removed from the herd, resulting in an increase in herd production. In general, OAD herds had better reproductive results than paired TAD herds. Both 3- and 6-week calving rates were higher for OAD herds following adoption of OAD and relative to their TAD peers after the first season on OAD. Individual cow somatic cell counts were increased by about 20,000 cells/mL after adopting OAD.

It is suggested that costs must be removed from the farm business in order to retain an equivalent level of profitability when changing to OAD milking.

Seasonality and calving patterns

The demand of the domestic milk market for a constant daily volume of liquid milk is most readily supplied by Holstein-Friesian cows in herds where some cows are calved at different times of the year (e.g. either in two sub-herds, in spring and autumn (split-calving), or with some cows calving in each month (year-round calving)). There has thus been a marked decrease in the number of dairy farms in Australia that calve down their cows over a limited period of time and dry off the entire herd for a short period of the year: non-seasonal systems now predominate in most of Australia apart from Tasmania. The 2015 national dairy farmer survey showed that 38% of farmers have split-calving herds, 37% seasonal-calving, and 26% year-round calving. However, in each state there is a marked variation in the proportion of farms using these calving systems (Figure 1.1.5). Recently, herds in Victoria, Australia, showed a major change in their pattern of seasonality of calving, with the percentage using split-calving or all-year-round calving increasing from 34% in 2004 to 59% in 2006 (Macmillan, 2006). In parallel with this change in calving pattern, most dairy cows in Australia are Holstein-Friesian.

In marked contrast, over 90% of all dairy cows in New Zealand have a strongly seasonal calving pattern, with most animals calving between July and September (late winter/early spring), and less than 35% are Holstein-Friesians. These differences are associated with important differences in mating management between the cows in the two countries, as well as genetic differences in fertility.

The extent of the seasonality of the Australasian dairy industry can be illustrated by using the ratio of the milk volume produced in the peak month (October or November in both countries) and that produced in the lowest month. For New Zealand this ratio is over 20, whereas for the whole of Australia it is only 2. Four Australian states (Western Australia, South Australia, New South Wales and Queensland) have ratios of 1.2 to 1.4, indicating very little seasonality, while the ratio in Tasmania is 4.

Grazed pasture, irrigation and grain

In Australia, the estimated percentages of total feed contributed by rainfall, irrigation, and bought-in feeds are 50, 30 and 20%, respectively. When compared with the respective New Zealand figures of 85, 5 and 10%, these clearly reflect the lower rainfall and greater reliance on irrigation and grain in Australia (Thorrold and Doyle, 2007) (Figure 1.1.6).

Little grain was fed to dairy cows in Australia before 1980, but the ability to feed grain as required has facilitated the operation of year-round milk production systems. The combination of grain feeding and year-round production systems has favoured the Holstein-Friesian cow, with its high volume of milk and

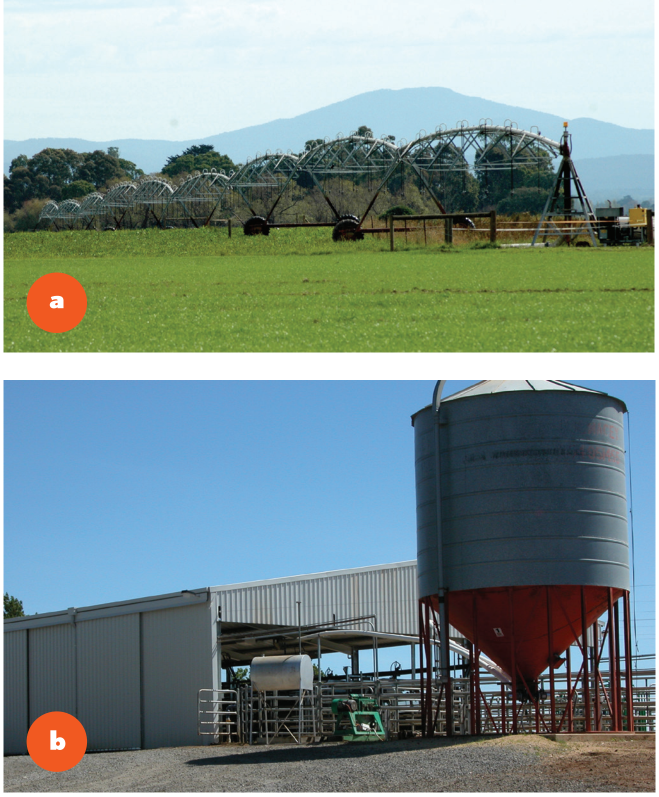

FIGURE 1.1.6 Some 50% of milk production in the Australian dairy industry is dependent on **(a)** the use of irrigation and **(b)** grain feeding.

greater response to extra concentrates. Such systems can also accommodate the lower fertility of the Holstein-Friesian more readily than can a strictly seasonal calving system. Over 90% of Australian farms now feed some grain and, on average, about 1.4 tonnes is fed per cow per annum, with less being fed on smaller farms and in spring-calving herds; however, more grain is being fed in New South Wales, South Australia and Western Australia (Australian Dairy Herd Improvement Report, 2016). About 80% of Australian milking sheds are fitted with grain-feeding equipment.

In New Zealand, most of the bought-in feed is maize silage and/or pasture silage, and the majority of herds do not use grain as a supplementary feed. However, the use of by-products, particularly palm kernel extract/expeller meal, has become much more important. In addition, most farmers graze some cattle away from the home farm for at least part of the year; most commonly this includes the replacement heifers, although it can also involve some of the dry cows.

As the level of grain feeding reaches higher levels, it can be argued that the risk profile also increases. Herds consuming large amounts of grain can be highly profitable when the ratio of milk price to grain price is high, but this profitability can significantly drop when the ratio changes, such that the ratio of milk price to grain price is low or even negative.

Litres or milk solids per cow, or per hectare

In the past, milk yields in Australia were commonly expressed as litres of milk. However, most Australian milk pricing systems are now based on a payment for kilograms of fat and protein with a charge for milk volume. Accordingly, in many Australian situations it is now more appropriate to express milk yields in terms of milk solids (i.e. total weight of fat and protein in the milk), as has been commonly done in New Zealand for many years.

Similarly, in the past, yields were commonly expressed in terms of litres of milk or MS per hectare. This reflects the heavy reliance on grazed pasture as the main or sole source of feed, with 1 hectare being a rough measure of feed supplied as grazed pasture, and the number of cows per hectare (stocking rate) being a key factor. However, this is now less logical than it used to be because more farms in both Australia and New Zealand are including larger quantities of other feeds in addition to their hectares of grazed pasture. Larger amounts of bought-in feeds have been offered on Australian farms since the 1980s; consequently, the hectare is no longer a logical basis for expressing stocking rates or yields in Australia.

Yield of MS or milk produced per tonne of feed offered, or eaten, is an important measure of efficiency in all systems. A primary element of on-farm efficiency is pasture consumption. The TasMilk60 projects concluded that, to remain profitable, all systems that include pasture must optimise not only the amount of pasture that is grown but also the amount that is consumed. The study of Hauser and Lane (2013) concluded that the most significant factor correlating with farm income, operating cost and capital investment was the proportion of directly grazed pasture in the diet. Their data showed that farms with less than 40% grazed pasture in the diet have a high-risk exposure to milk price and feed price. The quantities of feeds supplied or required, and feed conversion efficiencies, must be estimated for all farm systems in future.

1.2 Dairy systems

Introduction

Because the cow is able to feed and ruminate, milk can be produced in systems that range from those where cows graze on pastures for the whole year to those where cows never graze and are confined in a barn or on a feedlot, where they are fed conserved forages and concentrates.

Costs of milk production for grazing systems are lower (only 50 to 65%) than those for systems in which cows are confined (Holmes, 2007). Cows grazing pasture also have lower incidences of mastitis and lower culling rates. Maximum daily feed intakes and, consequently, maximum daily milk yields are, however, restricted in grazing cows, mainly because grazing is a slow method for consuming feed, and pasture is a bulky feed (Holmes and Roche, 2007).

Cows can produce approximately 1 L of milk per 1 kg of dry matter (DM) eaten; therefore, the feeding system is strongly influenced by the ratio of $/L of milk to $/kg of concentrates. Where this ratio is more than 2, concentrates can be fed profitably, resulting in high milk yields per cow. Where the ratio is 1 or less, concentrates will rarely be fed and yields per cow will be lower. This particular ratio has generally been about 2 in Australia and 1 in New Zealand.

In New Zealand, where pastoral farming is about profitably balancing feed supply and demand, five production systems have been described by DairyNZ:

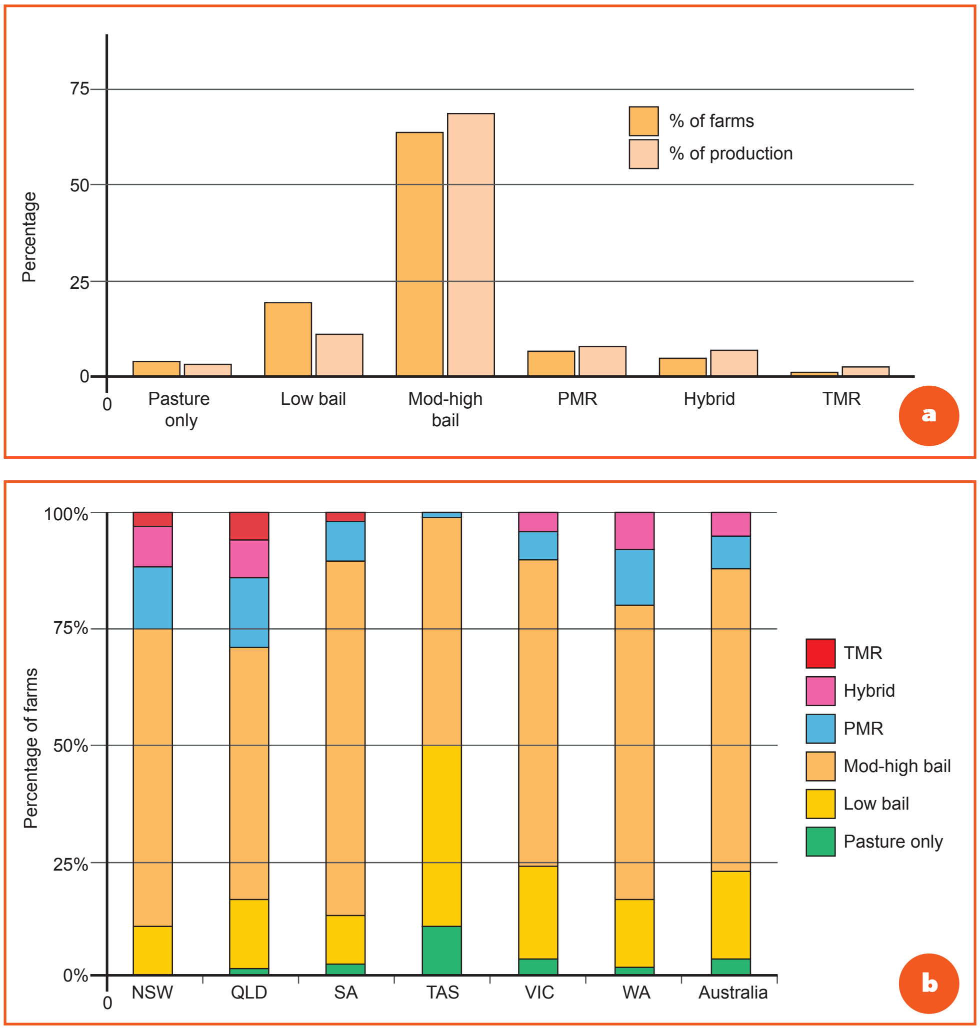

FIGURE 1.2.1 Feeding systems used on Australian dairy farms, expressed as: **(a)** proportion of farms using each system and proportion of total production accounted for by each system; and **(b)** proportion of farms in each state using each of the different feeding systems (see text for explanation of terms).

- **System 1:** all-grass, self-contained, 100% home-grown feed with all adult stock on the dairy platform. No feed is imported. No supplement is fed to the herd, except supplement harvested from the effective milking area, and dry cows are not grazed off the effective milking area.
- **System 2:** 90 to 99% of total feed is home-grown. 1 to 10% of feed is imported, either as supplement or grazing off for wintering dry cows.
- **System 3:** 80 to 89% of total feed is home-grown. 11 to 20% of feed is imported to extend lactation (typically autumn feed) and for wintering dry cows.
- **System 4:** 70 to 79% of total feed is home-grown. 21 to 30% of feed is imported, and is used at both ends of lactation and for wintering dry cows.
- **System 5:** 50 to 69% of total feed is home-grown. More than 31% of feed is imported and used throughout lactation. Feed imported could be greater than 50%.

A similar range of systems can be found in Australia, but with overall inputs of less pasture and more grain and concentrates. Grain and concentrates feeding ranges from 0.9 to over 2 tonnes grain/cow in different regions (Stockdale *et al.*, 1999). The use of high-yielding forage crops to complement pasture in well-designed systems is currently being explored in both countries (Garcia *et al.*, 2007). Total mixed rations (TMR) remain the exception in Australia, but the use of supplementary feeds, such as grains, hay and silage, has increased as farmers have adapted to drier conditions in many dairying regions.

Because of the variability in climatic conditions and production requirements, a wide range of production systems have developed on Australian dairy farms. In general, Australian dairy farmers use one of the following five key feeding systems.

- **Low-bail system:** grazed pasture plus other forages, plus up to 1.0 tonnes grain/concentrates fed in the bail.
- **Moderate-high bail system:** grazed pasture plus other forages, plus more than 1.0 tonnes grain/concentrates fed in the bail.
- **Partial mixed ration (PMR) system:** pasture grazed for most or all of the year, plus partial mixed ration fed on feedpad, ± grain fed in the bail.
- **Hybrid system:** pasture grazed for less than 9 months of the year, plus partial mixed ration fed on feedpad, ± concentrate fed in the bail.
- **Total mixed ration (TMR) system:** zero grazing, cows housed and fed a total mixed ration.

In 2015, 64% of farmers nationally used a moderate-high bail system (Figure 1.2.1a). This system produced 68% of the national

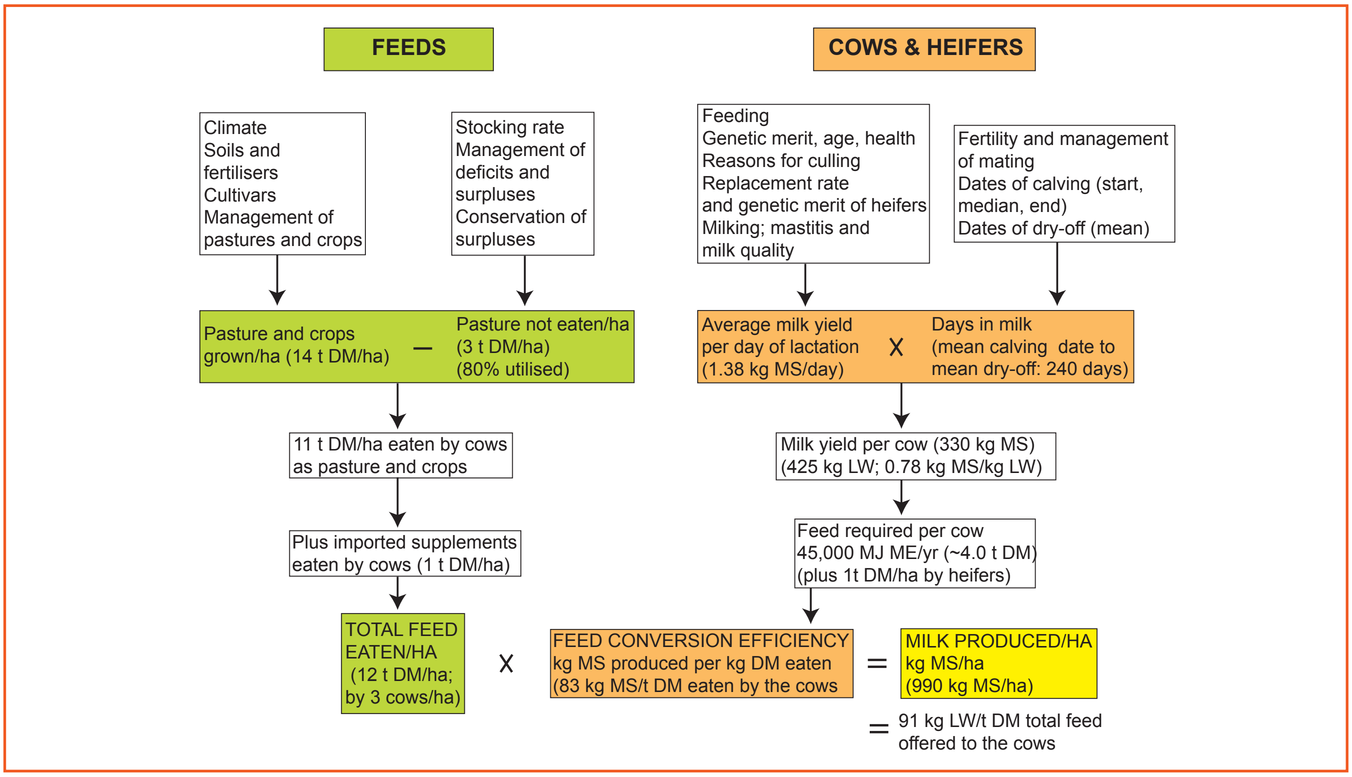

FIGURE 1.2.2 Illustration of the key factors that determine the productivity of the main components of grazing systems, and their integration.

TABLE 1.2.1 Comparison of two different dairy farm systems.

	FARM 1	**FARM 2**
Contribution of grazing	**90% grazing**	**45% grazing**
Other feeds	**10% silages**	**55% by-products and silages**
Calving pattern	**100% spring**	**70% spring, 30% autumn**
Area	86 ha	170 ha
Cows (HF × J)	220 cows	560 cows
Milk solids produced (kg)	84,000	320,000
kg MS/cow	380	570
tonnes DM required/cow	4.4	5.8
Feed conversion efficiency	86 kg MS/ tonne DM	98 kg MS/tonne DM
tonnes DM required by herd (t DM/year)	968	3,250
Supplements fed (t DM/ year)	100	1,760
Pasture eaten (by difference)	868 tonnes DM/ year	1,490 tonnes DM/ year
	(or 10.1 tonnes DM/ha)	(or 8.8 tonnes DM/ ha)
Pasture grown (estimated)	11 tonnes DM/ha	13 tonnes DM/ha
	(or 92% utilised)	(or 68% utilised)

milk production, with an average per cow milk production of 6433 L per year. Only 13% of farms nationally used feeding systems 3, 4 and 5. The proportion of farmers using each of the above feeding systems varied considerably between regions (Figure 1.2.1b).

Grazed pasture was used by 96% of dairy farms nationally in their feeding systems (systems 1 to 4); 11% of farms in Tasmania and 8% of farms in Gippsland (Victoria) fed grazed pasture only. The regions with the largest proportion of farmers using a PMR or hybrid system (systems 3 and 4) were Queensland (23%), New South Wales (22%), Murray (21%) and Western Australia (20%).

In general, cows fed generously to achieve high yields per cow do not graze pastures intensely, whereas relatively intense (hard) grazing is required for effective management and harvesting of the pastures. This obvious conflict requires constant attention within individual farming systems and must be managed carefully in order to optimise the whole system (Figure 1.2.2). Figure 1.2.2 also quantifies the feed supply and feed demand (calculated from the cows' actual liveweight and milk production, and theoretical energy requirements). These data provide an essential basis for assessing the efficiencies of all systems, including the animals' feed conversion efficiency and the physical utilisation of pasture and other feeds. This is illustrated further in Table 1.2.1, showing data from two actual farms, both of which have excellent mating management and fertility, and graze their replacements off-farm. However, they have very different feeding and calving systems. Farm 2 achieves a much higher yield per cow and, consequently, also a higher feed conversion efficiency by the animals, mainly by feeding generously (including supplements) throughout longer lactations. However, this system involves extra machinery, facilities and labour. Farm 1 utilises its pastures much more efficiently, with cows that are not fed so generously and with lower costs. The full financial performance of these farms, both well managed, depends on the price received for milk or milk solids and the costs associated with any extra feed.

TABLE 1.2.2 Nutrient quantities in various feeds.

	FEEDS				COW REQUIREMENTS
	RYEGRASS		KIKUYU	CEREAL GRAINS	
	YOUNG	STEMMY	AVERAGE	BARLEY/MAIZE	25 L/COW/DAY
Digestibility of DM (%)	80	60	56	86/90	>75
Metabolisable energy (MJ ME/kg DM)	12.0	9.0	8.4	13.0/13.6	>11.5
NDF* (%)	31	45	67	21/8	>35
Protein (%)	28	15	18	11/9	18
Calcium (%)	0.7	0.7	0.36	0.06/0.02	0.6
Phosphorus (%)	0.35	0.34	0.24	0.44/0.31	0.4

*NDF (neutral detergent fibre) is a measure of the total fibre content in the feed, and includes all the cellulose, lignin, hemicellulose and silica in that component of the ration. NDF is negatively correlated to the DM intake – in general, the higher the NDF, the lower the DM intake. (Based on Fulkerson and Doyle (2001); Holmes *et al.* (2003); Kellaway and Harrington (2004))

Feeds, nutrients and grazing management

The amount of useable energy consumed (megajoules of metabolisable energy: MJ ME) is the main overall driver of milk production. However, many other feed characteristics and nutrients are also important.

Two other key factors are the concentrations of nutrients contained in the feed and the digestibility of these nutrients. The quantity of a feed that a cow can eat daily is positively correlated to the digestibility of the feed. Therefore, a highly digestible feed will increase the animal's daily intake of DM and the nutrients digested per kg DM eaten. Some examples of different feeds are discussed below, together with the requirements for a cow with a moderate yield.

Using the figures in Table 1.2.2, this cow could meet her requirements by eating large quantities of leafy ryegrass; however, this would supply her with excess protein. On the other hand, she would not be able to eat enough of the low-digestible stemmy ryegrass or kikuyu, both of which contain too much neutral detergent fibre (NDF) but inadequate protein. In addition, kikuyu would not provide the animal with sufficient calcium and phosphorus.

The cereal grains have very high concentrations of metabolisable energy (ME), and large daily intakes of ME can be achieved. However, their NDF contents are too low to maintain a normal and healthy rumen environment. Their contents of protein and calcium are also too low.

Effective management of grazing must achieve two essential goals in the grazing system:

- Maximising the quantity and quality of pasture grown and eaten per hectare; and
- Enabling the cows to meet their feed requirements each day.

It is not easy to meet both consistently, and good grazing management therefore usually requires compromises. For example, with a pre-grazing pasture cover of 2700 kg DM/ha and 1700 kg DM/ha post-grazing, grazing 70 cows/ha for 24 hours, offering 40 kg DM/cow/day from pastures containing 80% young green leaf, about 15 kg DM/cow (170 MJ ME) will be eaten per day.

Offering less pasture, and thus forcing cows to leave a lower residual or post-grazing yield (to maintain future pasture quality and reduce pasture wasted), will reduce the animals' daily DM intake. On the other hand, offering more pasture and thus leaving a higher residual amount of pasture will increase the cows' daily DM intake but will waste more pasture and reduce its future quality. Good management of these compromises is the key to good feeding and grazing (Holmes and Roche, 2007).

The cows and the herd

The important factors regarding the cows, in addition to feeding, are their rearing up to two years of age (or their first calving), genetics, fertility, milking management and health.

Rearing and growing heifers

In seasonal- and split-calving herds, heifers should be between 13 and 15 months of age at the time of first breeding. This means that all heifers in a group must be grown so that they achieve liveweight targets by that time. In year-round-calving herds, there is some flexibility in deciding at what age maiden heifers should be first bred; however, it is less profitable to breed heifers so that they calve later than 24 months of age (i.e. are >15 months old at first breeding).

Heifers are more likely to conceive early if they reach puberty before 12 months of age. In addition, milk production and fertility of cows, especially in their first lactation, can be affected by the animals' liveweight and body condition at the time of calving. The age at which heifers reach puberty, and their subsequent fertility, are strongly affected by the animals' growth rate, which is mainly determined by feeding, parasite control and genetics (Figure 1.2.3).

FIGURE 1.2.3 Heifer growth is a key determinant of their longevity and productivity as cows. **(a)** Heifers that are well-grown reach puberty in good time and have acceptable bodyweights and frame stature by the time of their first calving. On the other hand, heifers that have inadequate feed supplies **(b and c)** are less likely to be profitable as adults or may be adversely affected by parasitism.

Research has shown that the desirable weight at first calving is at least 85% of mature liveweight. Therefore, for a herd with an optimum mature weight of 550 kg, the ideal heifer is around 470 kg liveweight at first calving. Failure to achieve the feeding and health required to meet the target increases the probability of lower fertility in the heifer and consequently later as a lactating cow in the herd.

Genetics

The average genetic characteristics in a herd can be changed over time by ensuring that all replacement heifers are of high genetic merit, due to being sired by a high-merit bull, and by culling the cows with 'low' genetic values. Currently, most selection programmes focus on all the genetic traits that have important effects on the cows' ability to convert feeds into milk, profitably, in the systems in which they will be managed.

Until the 1990s, genetic selection in most countries focused on yields of milk or, in New Zealand, milk fat. This selection resulted in genetic improvement in these yields, but has also led to increased loss of body condition of the cows during lactation and, in the past 20 years, reductions in fertility, especially in the Holstein-Friesian breed. Thus, genetically improving the modern dairy cow through the importation of Holstein-Friesian genetics has created a breed that is less fertile but is heavier, leaner and has a higher milk yield potential than previous dairy breeds in pasture-based systems.

To quantify the effects of genetic change upon fertility, in 2010 Dairy Australia commissioned an analysis of reproductive performance in a selection of Australian herds, which was compared with the original InCalf analysis conducted in 2000. This comparison identified a serious decline in fertility. Similarly, a review commissioned by the Gardiner Foundation also found that reproductive performance in dairy cows had declined in Australia (Woolaston and Shephard, 2011). The general decline in reproductive performance has not only directly affected the profitability of herds but has also led to a shift to split- and batch-calving systems due to the difficulty of maintaining a tight calving pattern in seasonal-calving herds. The review noted that a long-term solution to poor fertility associated with the typical high-producing cow was to select for increased milk production whilst including genetic merit for fertility in breeding plans. It concluded that restoration of fertility to previous levels through the genetic route would take many years and, therefore, recommended that alternative approaches needed to be identified through research, development and extension to the industry, including the use of crossbreeding as a mid-term solution for poor fertility. Australian research suggests that the ultimate benefit from an increased uptake of crossbreeding in commercial herds is a more sustainable operating system, with superior reproductive performance, reduced animal health issues and improved animal welfare standards. Very similar trends were identified in the New Zealand national herd so, in 2002, fertility was added to New Zealand's national breeding objective.

Crossbreeding has been suggested as a means of reducing the negative effects on fertility of selecting for high yield. Many farmers have come to recognise crossbreeding (i.e. where a second breed or strain of dairy cow is introduced into the breeding mix) as a fast-track solution to improve fertility and longevity in their herds. Systematic crossbreeding has been quite successful in improving reproductive performance in the New Zealand dairy

TABLE 1.2.3 Economic values used to calculate Breeding Worth for New Zealand dairy cows, as at February 2018. (Adapted from DairyNZ)

	MILK FAT ($/KG)	MILK PROTEIN ($/KG)	MILK VOLUME ($/KG)	LIVEWEIGHT ($/KG)	SOMATIC CELL COUNT ($/SCORE)	FERTILITY ($/CR42*)	BCS* ($/UNIT)	RESIDUAL SURVIVAL ($/DAY)
Breeding Worth	2.85	6.06	–0.088	–1.30	–38.33	6.55	100.60	0.124

* CR42 = 6-week conception rate; BCS = body condition score (1–10 scale)

herd, and has had similar but more modest effects in Australia, Ireland and the USA. The major effect of crossbreeding appears to be mediated through the heterosis (hybrid vigour) effect, which is generally important for traits associated with reproduction, survival and overall fitness. A systematic crossbreeding system, using two different breeds, exploits 67% of the heterosis expressed in the first cross. The three-breed rotational crossbreeding system uses three straightbred sires to exploit 86% of the heterosis. The advantages of crossbreeds (mainly Holstein-Friesian × Jersey) are now widely recognised in New Zealand and are also being explored by Australian farmers. The cow is an integral component in the whole integrated dairy system; the animal's capabilities must enable her to fit in with the conditions created by the farming system, and the market for her milk.

NEW ZEALAND COWS

The genetic merit of New Zealand dairy cows and sires is estimated using statistical methods that allow simultaneous evaluation of cows and sires of all breeds, using all recorded relationships. The national evaluation system is designed to compare animals irrespective of breed because the structure of the national herd reveals large numbers of crossbred cows, and large numbers of herds with mixed breeds. There are two types of animal evaluation used for dairy cattle; these are estimated and calculated by New Zealand Animal Evaluation Limited (NZAEL), a wholly owned subsidiary of DairyNZ:

- **Trait evaluations** are estimates of an animal's genetic merit (Breeding Values) for individual traits, including milk fat, protein, volume, liveweight, somatic cell count, fertility, body condition score (BCS) and residual survival. There are also estimates of an animal's lifetime productive ability (Production Values) for milk fat, protein, volume and liveweight.
- **Economic evaluations** combine an animal's individual trait evaluations to estimate its comparative ability to convert feed into profit, through breeding replacements (Breeding Worth) and lifetime production (Production Worth). They provide an estimate of the value of a trait to a New Zealand dairy farmer.

Selection focuses on the 'breeding worth' (BW) index, which represents the genetic ability to generate net income from feed eaten. It combines the breeding values (BV) for eight important traits (yields of protein, fat and milk, and liveweight, fertility, survival, BCS and somatic cell count) with their economic values (EV). For each economic index, the economic values are calculated for the relevant traits. For Breeding Worth, the economic values represent the net income per unit of feed from breeding replacements with a one-unit genetic improvement in the trait. Economic values are recalculated every February and are published on the DairyNZ website (Table 1.2.3; see also www.dairynz.co.nz/animal/animal-evaluation/interpreting-the-info/economic-values/).

AUSTRALIAN COWS

In Australia, breeding indices are developed for each breed, and cannot be compared between breeds. Three new breeding indices were introduced in April 2015:

- **The Balanced Performance Index** (BPI) is an economic index that aligns directly to net profit through a balance of production, functionality and type.
- **The Type Weighted Index** (TWI) has a stronger focus on overall type, mammary system, udder depth and fore-udder attachment. Gains in liveweight, stature and angularity (hindlimbs) will be faster and gains in fertility will be slower when using this index.
- **The Health Weighted Index** (HWI) has the strongest focus on fertility, somatic cell count, and survival. Gains in production and type will be slower than in the other two indexes.

Although herds using the HWI may have a slightly reduced rate of production improvement compared with their previous use of the Australian Profit Ranking (APR), it has been estimated that they are likely to benefit from a ~10% improvement in the 6-week in-calf rate, when used in a systematic fashion for the entire herd over a 10-year period.

For some traits, the economic value will change under different circumstances. For example, good fertility is essential for seasonal-calving systems, but might be less important in non-seasonal, year-round-calving systems. Milk yield has a negative economic value in New Zealand, as water is a cost to the processing industry. However, it may have a positive economic value in a liquid milk market which pays farmers per litre of milk. Liveweight also has a negative economic value in New Zealand due to the cost of the extra feed energy required to maintain heavier cows compared with the value of the extra carcass weight. However, this may not be the case if the value of beef is relatively high.