Dairy Australia
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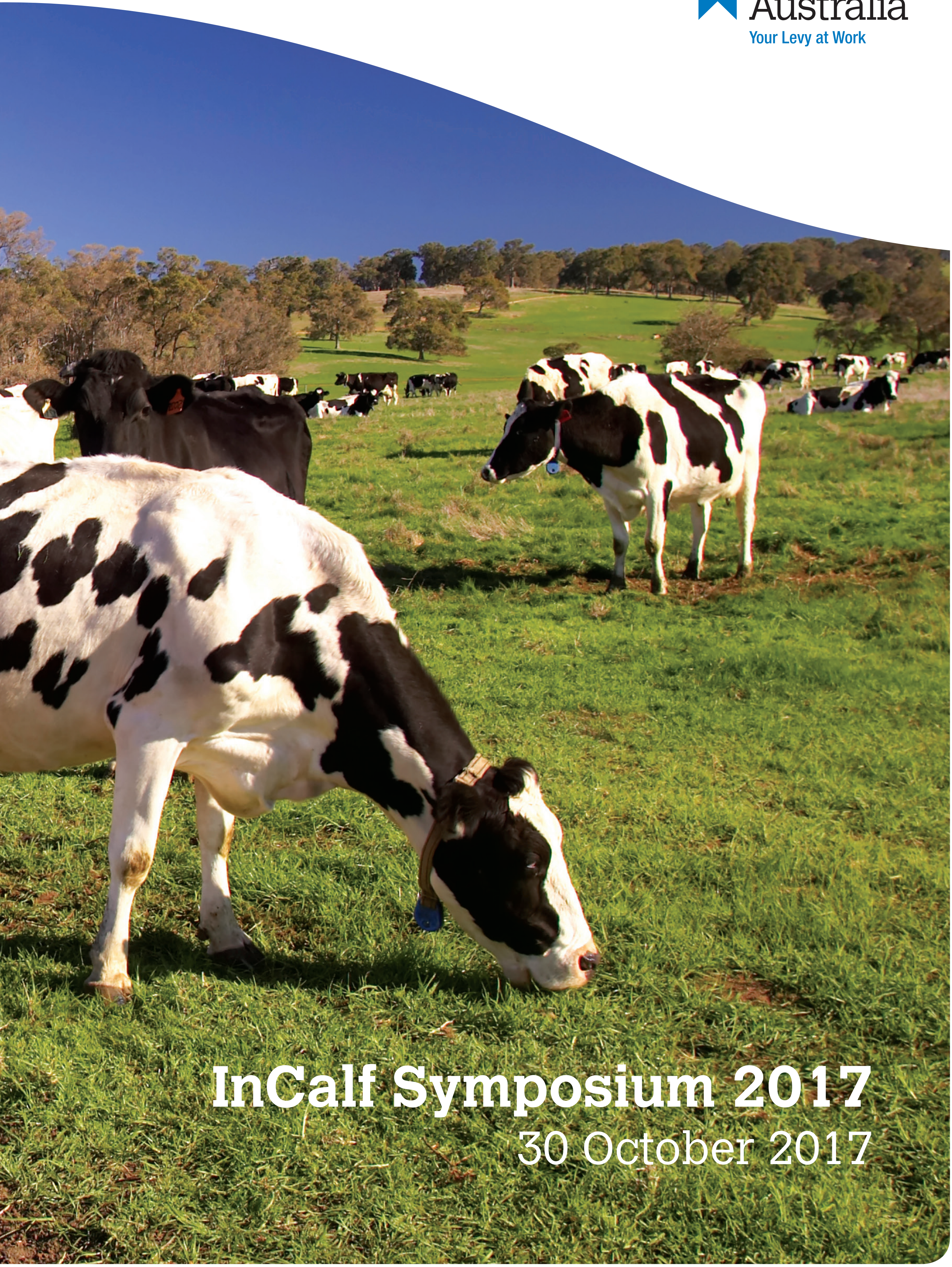

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Speaker biographies

José Santos

José is a Research Foundation Professor in the Department of Animal Sciences at the University of Florida, USA. He received his DVM degree from São Paulo State University in Brazil and the MSc and PhD degrees from University of Arizona, USA. He spent 10 years as a professor in the School of Veterinary Medicine at the University of California Davis with a research and clinical appointments in dairy production medicine. At the University of Florida, his primary research and extension efforts focus on the interface between nutrition and reproduction and methods to improve postpartum health and fertility in dairy cows.

Debbie Berg

Dr. Debbie Berg received her PhD from the University of Minnesota with the research portion completed in New Zealand in conjunction with a Fulbright scholarship. Her work is focused on ruminant embryology, specifically embryo development during the first two weeks of gestation using in vitro reproductive technologies. She is a senior scientist at AgResearch, Hamilton, New Zealand. Recent work, in collaboration with DairyNZ, is focused on understanding and reducing conception losses in seasonal, pastoral-grazed dairy cows. Debbie owns a small seasonal pastoral dairy farm located in Central Minnesota, USA.

Richard Shepherd

Richard worked as a veterinarian in mixed mainly dairy practice for fifteen years and morphed this into a farm management and industry consultancy along the way. He completed post-graduate studies in veterinary epidemiology and now combines his clinical and population medicine skills with a focus on cattle health, farm production and economic performance and computer modelling to explore the farming system.

Jo Coombe

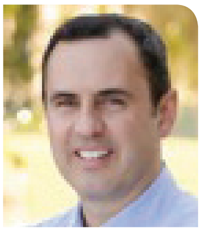
Jo is a tutor in the Faculty of Veterinary and Agricultural Sciences at the University of Melbourne. After leaving clinical dairy practice in Timboon, she completed her PhD (the health of dairy cows in flexible feeding systems) at Melbourne. Jo has provided input into several Dairy Australia programs, including the Healthy Hooves, Rearing Healthy Calves and InCalf programs. She has just completed her post doctorate which investigated crossbreeding in Australian dairy herds, and is currently investigating digital dermatitis in Australian dairy cows.

John Mulvany

John Mulvany has been involved in the Victorian Dairy Industry for over 25 years as an educator, factory field officer and private consultant. John works with individual dairy farms in pasture-based dairying providing advice and analysis on feeding systems, profitable dairy production, grazing management and financial analysis. He has also consulted to many organisations. John's strength lies in his exposure to such a broad clientele. He is exposed to a wide variety of grazing systems, variable seasons and changing economic conditions and he helps his clients to manage their ever-changing farming conditions. This gives him ability to observe both the "big picture" industry issues and the specific "on farm" problems that require informed decision making. John is an accredited Consultant of the Australian Association of Agricultural Consultants (CPAg).

Bill Malcolm

Associate Professor Bill Malcolm has a lifetime of involvement in farming and asking questions about dairy farm management economics. He teaches and researches and writes about farm management economics at the University of Melbourne and has done so for many a long day.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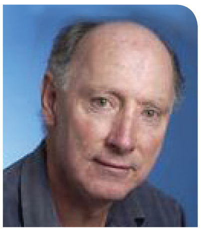
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Impact of animal health on reproduction of dairy cows

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Abstract

Many of the diseases that affect dairy cattle either in confinement or pasture-based systems typically occur in the first two months of lactation, before the first postpartum insemination. This increased susceptibility to diseases poses a major challenge to reproduction. A wealth of information in the scientific literature is available linking disease with depressed reproduction in dairy cows. Unfortunately, only few studies have established a causal relationship between disease and fertility, and little is known about the mechanisms that underlie the decrease in pregnancy in dairy cows that had disease in early lactation. It is clear today that dairy cows that suffer from disease processes have impaired resumption of postpartum ovulation, compromised fertilization and pre- and peri-implantation conceptus development, altered conceptus gene expression, increased pregnancy loss and, ultimately reduced pregnancy per insemination that causes an extension in time to pregnancy. Because mechanisms are poorly understood, no target intervention is available at this time to reverse the poor reproduction in cows that develop disease, except methods to induce cyclicity in anovular cows or to improve insemination rate in cows not detected in estrus. Regardless of a better understanding of the underlying biology of poor fertility in diseased cows, a pivotal approach is to implement strategies that mitigate the risk factors that predispose cows to disease. Such interventions include, but are not limited to, improving transition cow management and grouping, proper dietary formulation to prevent periparturient diseases associated with intermediary and mineral metabolism, strategies for reducing calving-related disorders, and methods to prevent mastitis and lameness. Future developments in target strategies to improve reproduction of cows suffering from diseases will require a better understanding of the impaired biological processes that compromise establishment and maintenance of pregnancy in this subfertile population of cows.

Keywords: dairy cattle, disease, embryo, pregnancy

Introduction

Reproductive efficiency of the lactating herd is a major component of profitability in dairy farms (Ribeiro et al., 2012). Reproduction determines when primiparous cows become multiparous leading to increments in milk yield, alters the average milk yield per day of calving interval, affects the number of replacement animals available and the risk of culling, and influences the rate of genetic progress. Unfortunately, improving fertility is not trivial. Establishment and maintenance of a pregnancy to term are affected by several genetic, physiological, and environmental factors that can be manipulated in order to sustain high fertility. Although causality is not always proven, it is well established that diseases negatively influence reproduction in dairy cows.

During early lactation, dairy cows undergo a period of extensive tissue catabolism because of negative nutrient balance. The latter has been linked to unrestrained metabolic disturbances that often lead to diseases which, in turn, dramatically decrease both productive and reproductive performance. Negative nutrient balance has been associated with compromised immune and reproductive functions in dairy cows. Two of the most common clinical diseases in dairy cattle are metritis and mastitis, both of which have been negatively associated with subsequent reproductive performance.

In addition, dairy cows develop the so called subclinical disorders, such as subclinical ketosis and hypocalcemia. The first, being more an adaptation to inadequate caloric intake, has been linked to reduced fertility but, to date, little evidence exists to establish causation between elevated ketones and animal performance. Improper adaptation to increased demands of Ca results in suboptimal concentrations and increased risk of uterine diseases and impaired fertility. Subclinical and clinical hypocalcemia reduces cytosolic ionized Ca in immune cells and compromise innate and, possibly, acquired immunity. Establishing nutritional and management methods to minimize the incidence of diseases in early lactation is one of the multiple steps to improve fertility in a dairy herd.

Prevalence of diseases postpartum and impact on fertility of dairy cows

Transition from the dry period (nonlactating pregnant state) to lactation (nonpregnant lactating state) requires the high-producing dairy cow to drastically adjust her metabolism so that nutrients can be partitioned to support milk synthesis, a process referred to as homeorrhesis. A sharp increase in nutrient requirements generally occurs at the onset of lactation, when feed intake is usually depressed, which causes extensive mobilization of body tissues, particularly body fat, but also amino acids, minerals and vitamins. Despite tight homeostatic controls and homeorrethic adjustments to cope with the changes in metabolism caused by milk production, 45 to 71% of dairy cows across different levels of milk production, breeds and management systems develop metabolic and infectious diseases in the first months of lactation (Santos et al., 2010a; Ribeiro et al., 2013).

Calving-related disorders and diseases that affect the reproductive tract are major contributors to depression of fertility. Dystocia, metritis, and clinical endometritis were observed in 14.6, 16.1, and 20.8% of postpartum dairy cows in large U.S. confinement herds, respectively (Santos et al., 2010a). Cows that presented at least one of the aforementioned disorders were 50 to 63% less likely to resume ovarian cyclicity by the end of the voluntary waiting period, and were 25 to 38% less likely to become pregnant following the first artificial insemination (AI) postpartum compared with healthy cows. Moreover, cows with dystocia and those diagnosed with clinical endometritis were 67 and 55% more likely to lose their pregnancies during the first 60 days of gestation compared with healthy cows. The negative effects of reproductive disorders on subsequent fertility are also observed in dairy cows kept under grazing systems (Ribeiro et al., 2013). Even though the prevalence of dystocia, metritis, and clinical endometritis are numerically less in grazing-based herds (8.2, 5.7, and 14.7%, respectively), cows with metritis had 2.7-fold increased odds of being anovular at 50 days postpartum compared with unaffected herdmates. Cows affected with uterine diseases had marked depression in pregnancy at the first postpartum AI and increased risk of pregnancy loss. In fact, when diseases were classified as clinical (calving problem, metritis, clinical endometritis, mastitis, pneumonia, digestive problems, and lameness), subclinical [subclinical hypocalcemia, subclinical ketosis, and severe negative energy balance (NEB) based on excessive plasma non-esterified fatty acids (NEFA)], or both, affected cows had increased anovulation and reduced pregnancy per AI (Table 1; Ribeiro et al., 2013). These data strongly indicate that diseases during early lactation have a profound impact on fertility of dairy cows. Maintaining metabolic health to minimize the risk of clinical and subclinical health problems are expected to benefit fertility of dairy cows.

Diseases are associated with impaired embryo development

Mechanisms by which diseases in the periparturient period impair reproduction are not clearly understood. Most studies are of epidemiological nature and the overwhelming majority associates negative effects of diseases during early lactation with reduced pregnancy per AI or extended intervals to pregnancy. In general, cattle affected by diseases have reduced appetite, increased body weight loss, altered partitioned of nutrients, and exacerbated immune response (Gifford et al., 2012). Inflammatory diseases create an acute phase response that partitions more nutrients, particularly amino acids, for synthesis of hepatic acute phase proteins (Gifford et al., 2012). This response to contain invading pathogens, although desired, alters the partition of nutrients away from productive functions. Moreover, inflammatory mediators produced during activation of the immune system can reach the reproductive tract and influence uterine function, follicle growth, oocyte quality, and subsequent embryo development (Turner et al., 2012). To evaluate this idea, we conducted retrospective analyses of data from multiple studies in which day 5 to 6 and day 15 to 16 embryos were collected from single ovulating dairy cows to determine if peripartum diseases were associated with reduced embryo quality and impaired development in lactating dairy cows (Ribeiro et al., 2016a). Embryos-oocytes collected from 419 cows on day 5 to 6 after AI were evaluated for fertilization and early cleavage, and grade quality (Table 2; Ribeiro et al. 2016a). It is clear that cows suffering from at least 1 case of clinical disease had reduced fertilization, compromised embryo quality, and reduced embryo development as early as 5 to 6 days after insemination.

After ovulation and fertilization of the oocyte in the oviduct, embryonic cells derive from cleavages of the zygote and stay enclosed the zona pellucida, forming a morula by day 4 of development (Spencer et al., 2007). These early events are dependent on oocyte inherited molecules, and glucose and amino acids uptake from the oviduct (Gardner, 1998; Duranthon et al., 2008). It is also during this period that the zygote's genome is activated, more precisely at 8-16-cell stage transition in ruminants (Duranthon et al., 2008). The morula becomes compacted and enters the uterus, where the totipotent blastomeres undergo the first cell differentiation. Therefore, it is plausible to suggest that diseases influence oocyte competence and/or oviductal/endometrial support for fertilization and early embryo development in dairy cows.

In a process dependent of cell adhesion, polarity, and expression of specific transcription factors, the blastomeres from morula differentiate in either inner cell mass or trophectoderm cells, forming the blastocyst (Duranthon et al., 2008). The spherical blastocyst will then expand and hatch from the zona pellucida by day 8 of development (Spencer et al., 2007). After blastocyst shedding from the zona pellucida, trophectoderm cells of the spherical blastocyst proliferate and elongate along the uterine lumen prior of the initiation of implantation (Spencer et al., 2007). In a first moment, the spherical embryo stays free-floating into the uterine lumen and cell proliferation leads to formation of an ovoid conceptus (embryo and associated extra-embryonic membranes) by day 13. Up to this point, endometrial physiology is coordinated mainly by progesterone and there is no distinction between the endometrium of a pregnant and a nonpregnant female (Bauersachs and Wolf, 2013). Around day 14, however, the 1-mm ovoid conceptus starts to elongate by intensive proliferation of trophoblast cells and become a 12-cm filamentous structure by day 17. This process of conceptus elongation is dependent of histotroph secretion by the glandular epithelium of the endometrium (Gray et al., 2000). Concomitant with conceptus elongation, the highly active trophoblast cells secrete bioactive products that affect endometrial physiology, establishing a complex crosstalk between the two tissues that coordinate critical events for pregnancy establishment, formation of a functional placenta, and pregnancy survival to term, including: 1) maternal recognition of pregnancy by secretion of interferon-τ; 2) establishment of a servomechanism of conceptus nourishment; 3) differentiation of binucleated trophoblast cells; and 4) immunomodulation of the maternal immune system in the endometrium to avoid conceptus rejection (Spencer et al., 2007; Bauersachs and Wolf, 2013). These aforementioned events highlight the importance, complexity, and potential reasons for developmental failures during conceptus elongation. Not surprisingly, on average 33% of viable blastocysts fail to elongate and establish a health pregnancy in dairy cows (Ribeiro et al., 2016a).

Results from conceptuses collected on day 15 to 16 after AI from 198 lactating dairy cows that had a synchronized ovulation (progesterone < 1 ng/mL on the day of AI, and > 1 ng/mL on days 7 and 15 after AI) indicated that cows with clinical diseases had similar pregnancy, but marked reduction in development (Table 3; Ribeiro et al., 2016a). Conceptuses of cows with clinical disease were less developed and secreted less interferon-τ in the uterine lumen compared to those from healthy cows, which suggests impaired signaling for maternal recognition of pregnancy and establishment of crosstalk between conceptus and endometrium for pregnancy establishment.

To investigate the carryover effects of diseases on the biology of trophectoderm cells during elongation, 22 conceptuses, 12 from day 15 and 10 from day 16 after AI, were subjected to transcriptome analysis using the Affymetrix GeneChip Bovine Genome Array (Ribeiro et al., 2016a). Half of the conceptuses on each day were recovered from cows affected by diseases postpartum and the other half from cows that were not affected by diseases from parturition until the day of uterine flushing. Conceptuses subjected to this analysis were similar in size, and the analysis revealed few changes in transcript expression, although some of the transcripts differently expressed are likely important for conceptus elongation and maintenance of pregnancy that could explain the phenotypic differences observed in embryo development and pregnancy outcome.

On day 15 after AI, only 7 transcripts were differently expressed (Ribeiro et al., 2016a). Among them, the fatty acid translocase cluster of differentiation (CD) 36 had the greatest difference in mRNA abundance. The trophectoderm cells of conceptuses recovered from cows affected by diseases postpartum did not express CD36, but the same gene was relatively highly expressed in conceptus from healthy cows. CD36 is a scavenger receptor related to cell adhesion and fatty acids uptake, two important cellular events during conceptus elongation (Ribeiro et al., 2016b). In fact, lipid metabolism seems to be an essential cellular function in conceptus elongation (Ribeiro et al., 2016b). Thus, the lack of expression of CD36 in conceptuses recovered from cows that suffered diseases and might be related with their impaired elongation. On day 16 after AI, 35 transcripts were differently expressed (Ribeiro et al., 2016a). Among those, there was upregulation of transcripts of major histocompatibility complex (MHC) I and II, and proteins associated with inflammatory process such as lactotransferrin, serum amyloid A3, and S100 calcium binding protein A12 in conceptus recovered from cows affected by diseases. Transcript expression of MHC has been reported to be reduced as the conceptus elongate (Ribeiro et al., 2016b), which could be a mechanism to minimize the presentation of paternal alloantigens and the risk of tissue rejection by the maternal immune system as reported in other species (Bainbridge et al., 2000). In fact, bovine clone embryos have been reported to have greater expression of MHC, which is believed to be one of the reasons for the greater incidence of pregnancy losses when transferred into recipients (Davies et al., 2004). Thus, greater expression of MHC molecules might be related to the greater pregnancy loss observed in cows affected by clinical diseases. On the other hand, the greater expression of inflammatory proteins might be related to altered uterine environment cause by diseases and consequent physiological responses and their importance is still unclear.

The gestation period between early implantation and early pregnancy diagnosis is not well studied in cattle. The lack of detailed information is probably caused by the inability to examine conceptuses at this period without slaughtering cows. Measuring peripheral responses to pregnancy might be a non-invasive alternative for comparative studies with large number of animals (Ribeiro et al., 2014). Recent studies demonstrated that interferon-τ produced by trophectoderm cells reaches the maternal circulation (Oliveira et al., 2008) and induces expression of interferon-stimulated genes (ISGs) in leukocytes (Ott and Gifford et al., 2010), which parallels the total amount of interferon-τ in utero (Matsuyama et al., 2012). In addition, pregnancy associated glycoproteins (PAG) secreted by binucleated cells in early placentation such as pregnancy-specific protein B (PSPB) are abundantly expressed and can be detected in peripheral blood (Sasser et al., 1986). Both expression of ISGs in leucocytes and concentration of PSPB in plasma during the peri-implantation period have been associated positively with pregnancy establishment and maintenance in dairy cows and can be used as non-invasive methods to study the bovine pregnancy at peri-implantation stages (Ribeiro et al., 2014).

To investigate the effect of diseases on peripheral responses to pregnancy, blood samples from 481 lactating cows were collected on day 19, 26, 30 and 37 after first insemination postpartum. Samples from day 19 had leukocytes isolated for analysis of gene expression, and the remaining samples had plasma harvested for measurement of PSPB concentration. Incidence of diseases was recorded and cows were classified as having or not suffered from clinical diseases from parturition until pregnancy diagnosis on day 34 after AI (Ribeiro and Santos, unpublished results). There were no evident differences in concentrations of PSPB in plasma of healthy cows and those affected by clinical diseases. However, transcriptome analysis of leukocytes from 36 lactating cows, half healthy and half diseased, revealed distinct responses to pregnancy. There were 14 and 10 transcripts differently expressed between pregnant and nonpregnant cows in the healthy and diseased groups, respectively, and only one interferon stimulated gene (IFI6) was common. In pregnant cows, disease influenced the expression of 12 transcripts, whereas in nonpregnant cows, disease influenced the abundance of 3 transcripts in leukocytes. Pregnancy in healthy cows upregulated transcripts commonly reported to be affected by the conceptus such as RTP4, MX1, MX2, OAS1, whereas a different set of genes were upregulated by pregnancy in the disease group. These findings are likely related with distinct conceptus elongation and secretion of interferon-τ described previously and the relevance of these findings need further investigation.

Collectively, it is clear that a negative association between health problems and early embryo development exists such that fertilization and cleavage, morula development, conceptus elongation and embryo survival are negatively affected by diseases. These processes involve changes in the transcriptome of the conceptus and cells influenced by the conceptus, but likely in many other reproductive tissues.

Negative nutrient balance impacts health and reproduction in dairy cows

Increased nutrient needs associated with suppression of appetite generally drive dairy cows into a state of negative energy balance (NEB), which is often observed during the last week of gestation and the first 1 to 2 months postpartum. Under normal conditions, dry matter intake (DMI) increases from 9.6 kg/d during the week preceding parturition to more than 22 kg/d at 11 weeks postpartum (Reynolds et al., 2003). In contrast, caloric requirements are only partially met by feed consumption during the first weeks postpartum. Consequently, high-producing dairy cows experience NEB during the first 4 to 6 weeks postpartum, which often averages –5 Mcal of net energy/day, the equivalent of approximately 1 kg of body weight loss/day, mostly from adipose tissue. Reduced circulating concentrations of glucose and insulin up-regulate the lipolytic signals that result in hydrolysis of stored triglycerides in adipose tissue and increase availability of nonesterified fatty acids (NEFA) to be used as an energy source. Some of the NEFA are removed by the liver, and uptake of NEFA depends on the type of fatty acid present in the circulation (Mashek and Grummer, 2003). Reesterification to triglycerides in the hepatocytes and ketogenesis increase when uptake of NEFA by the hepatic tissue is excessive.

Energy balance during early lactation has been positively associated with reproductive performance of dairy cows (Butler, 2003). Severity and duration of NEB can be estimated by changes in body condition score (BCS). Cows losing more body condition during the first 65 days postpartum were more likely to be anovular at the end of the voluntary waiting period, had decreased pregnancy per AI, and increased risk of pregnancy loss after the first AI postpartum (Santos et al., 2009). Using circulating concentration of NEFA as an indicator of the energetic status of grazing dairy cows in the first 2 weeks postpartum, Ribeiro et al. (2013) reported that cows in NEB (NEFA ≥ 0.7 mM) were less likely to resume ovarian cyclicity before 50 days postpartum and to become pregnant to the first AI of the breeding season. Others have reported similar results in dairy herds managed in confinement (Walsh et al., 2007; Santos et al., 2010a; Ospina et al., 2010b).

Rate of pregnancy during the first 70 days of breeding was 16% less for cows with blood NEFA ≥ 0.7 mM than for those with concentrations below this threshold (Ospina et al., 2010b). Ketosis resulting from extensive fat mobilization also has been associated with compromised fertility. Both the relative circulating concentration of β-OH-butyrate (BHBA) and the duration of elevated BHBA concentrations were associated negatively with the probability of pregnancy following the first postpartum AI (Walsh et al., 2007). In fact, for every 100 μm increase in BHBA concentration during 1 and 2 weeks after calving, the proportion of pregnant cows at first AI was reduced by 2 and 3%, respectively. Furthermore, rate of pregnancy by 70 days after the end of the voluntary waiting period was 13% less among cows with blood BHBA concentration ≥ ~1.0 mM compared with herdmates with BHBA below 1.0 mM (Ospina et al., 2010b). In fact, as the prevalence of cows with elevated concentrations of serum NEFA or BHBA increases, reproductive performance declines (Ospina et al., 2010a). In the latter study, the 21-day cycle pregnancy rate was reduced by 0.9 percentage units in herds in which more than 15% of the sampled cows had serum NEFA concentration ≥ 0.7 mM, and by 0.8 percentage units if more than 15% of the sampled cows had serum BHBA concentrations ≥ 1.15 mM. Therefore, circulating concentrations of these metabolites can be used as indicators of excessive lipid mobilization, which impairs fertility.

Reduced fertility associated with low nutrient intake and NEB is, at least in part, mediated by the damaging effects on immunity and postpartum health. Exposing immune cells in vitro to NEFA at concentrations compatible with those observed in high-producing postpartum dairy cows (0.12 to 1 mM) reduced function and viability. Increasing the concentration of NEFA in the culture media abridged the synthesis of interferon-τ and IgM by peripheral blood mononuclear cells (Lacetera et al., 2004). Furthermore, NEFA reduced phagocytosis-dependent oxidative burst in polymorphonuclear leucocytes (Scalia et al., 2006). When concentrations of NEFA in the culture medium were further increased to 2 mM, polymorphonuclear oxidative burst was not altered, but more leukocytes underwent necrosis, thereby impairing function. Not only NEFA, but also BHBA has been implicated with immunosuppression in postpartum dairy cows. Incubation of bovine neutrophils with increasing concentrations of BHBA reduced phagocytosis, extracellular trap formation, and killing (Grinberg et al., 2008). In vivo observations support the immunosuppressive effects of NEB. Cows in severe NEB had increased concentrations of NEFA and BHBA in plasma, which was associated with decreased leukocyte numbers (Wathes et al., 2009). It is likely that cows that are unable to recover feed consumption after parturition, and therefore, remain in more severe NEB, are more susceptible to diseases. It is known that reduced nutrient intake and NEB even before calving are associated with poor uterine recovery from parturition and the occurrence of uterine diseases (Hammon et al., 2006). These observations seem to be linked with changes in patterns of endometrium gene expression mediated by the energetic status of the cows. Wathes et al. (2009) evaluated global gene expression of the endometrium of cows at 2 weeks postpartum. They reported that several transcripts linked with inflammation and active immune response were upregulated in cows undergoing severe NEB compared with those exhibiting a more modest caloric deficit, suggesting a delay in uterine involution. In addition, cows that developed uterine diseases early postpartum had greater concentrations of NEFA and BHBA in blood around calving than healthy cows (Hammon et al., 2006; Galvão et al., 2010). It is important to highlight that occurrence of diseases early postpartum can further accentuate the adverse effects of NEB, as sick cows have reduced appetite and oftentimes lose more body weight than healthy cows.

In addition to the changes in energy balance, circulating concentrations of antioxidants such as β–carotene, and vitamins A (retinol) and E (α-tocopherol) also are regulated temporally and decrease during the periparturient period (Goff et al., 2002). As these compounds play important roles in immune function, low concentrations of these vitamins have been associated with increased susceptibility to disease and, potentially, with reduced fertility in dairy cows. Prepartum circulating β–carotene and, more importantly, vitamin E were reduced in cows that retained their placenta than for healthy cows (LeBlanc et al., 2004). In fact, for every 1 µg/mL increase in circulating vitamin E during the week preceding parturition, the risk of retained placenta decreased by 21%. Furthermore, the decrease in circulating concentrations of β-carotene, vitamin A, and vitamin E associated with parturition was more accentuated among cows that developed mastitis during the first 30 days postpartum than among healthy cows (LeBlanc et al., 2004). During the last week prepartum, a 100 ng/mL increase in circulating vitamin A concentration was associated with a 60% de-crease in the risk of clinical mastitis (LeBlanc et al., 2004).

Impact of energy balance on oocyte competence

During lactation, most of the glucose produced by the liver is used for synthesis of lactose to support milk production. A transient insulin resistance early postpartum diminishes utilization of glucose by peripheral tissues to secure its availability for the mammary gland. Although the follicle is capable of controlling fluctuations in glucose availability, which generally results in concentrations in the follicular fluid greater than those observed in blood, intra-follicular glucose concentrations also decrease around parturition (Leroy et al., 2004). It has been shown that glucose is critical for adequate oocyte maturation, affecting cumulus expansion, nuclear maturation, cleavage, and subsequent blastocyst development. In fact, glucose concentrations compatible with those observed in cows suffering from clinical ketosis (1.4 mM) reduced rates of cell cleavage and the proportion of embryos developing to blastocysts (Leroy et al., 2006). Although the oocyte does not directly use glucose as an energy source, it must be readily available to cumulus cells for glycolysis to provide pyruvate and lactate, oocyte's preferred substrates for ATP production (Cetica et al., 2002). Therefore, it is possible that hypoglycemia during early lactation might compromise oocyte competence in dairy cows.

Follicular fluid is derived from blood originating from capillaries in the theca cells by osmotic pressure (Rodgers et al., 2010). Production of hyaluronan and proteoglycan by granulosa cells creates an osmotic gradient that draws fluid from the thecal vasculature through the thecal interstitium, the follicular basal lamina and the mural granulosa cells (Rodgers et al., 2010). As fluid accumulates in the antrum, it bathes the cumulus cells and the oocyte. Changes in nutrient supply that leads to either hypo- or hyperglycemia may influence lipid metabolism and alter composition of follicular fluid. For instance, hyperglycemic insults influence the composition of the follicular fluid, which may lead to long-term negative effects on oocytes by altering nuclear maturation (Jungheim et al., 2010; Sutton-McDowall et al., 2010).

Extensive fat mobilization and the release of large amounts of NEFA into the bloodstream have been shown to exert a direct effect on fertility of postpartum dairy cows. Concentrations of NEFA in the follicular fluid parallel those of serum, and they increase around parturition (Leroy et al., 2005). Maturation of oocytes in vitro in the presence of saturated fatty acids reduced oocyte competence and compromised the initial development of embryos.

Specifically, addition of palmitic and stearic acids to the maturation media induced apoptosis and necrosis of cumulus cells, impaired fertilization, cleavage, and development to the blastocyst stage (Leroy et al., 2005). Changes in circulating concentrations of BHBA are promptly reflected in follicular fluid (Leroy et al., 2004). In vitro models developed to study the effects of subclinical ketosis on fertility of dairy cows, however, have failed to demonstrate a direct effect of BHBA on oocyte competence, which seems only to aggravate responses to low concentrations of glucose during oocyte maturation (Leroy et al., 2006). Therefore, it is proposed that the oocyte is vulnerable to potential harmful effects of an altered biochemical milieu in the follicular micro-environment (Leroy et al., 2012).

Energy balance and ovarian function postpartum

The stage set by NEB modulates the activity of the hypothalamic-pituitary-ovarian axis. Undernutrition has been linked to the inability of the hypothalamus to sustain high frequency of luteinizing hormone (LH) pulses by the pituitary gland (Schillo, 1992). Indeed, LH pulse frequency was shown to be positively correlated with energy balance and negatively correlated with blood NEFA concentration (Kadokawa et al., 2006). The underlying mechanism by which NEB reduces LH release is likely to involve the supply of oxidizable fuels to neurons and hormonal modulation of hypothalamic and pituitary cells (Schneider, 2004). Glucose is a preferred substrate for neuron energy metabolism and inadequate supply of glucose inhibits the GnRH pulse generator (Schneider, 2004). Under a favorable nutritional status, the hormonal milieu to which the hypothalamus and pituitary gland are exposed favors the release of GnRH and gonadotropins. For instance, leptin, a hormone known to have increased concentrations during positive energy balance, stimulates release of GnRH by the hypothalamus, and blood leptin was found to be strongly correlated with both LH pulse frequency and amplitude (Kadokawa et al., 2006). In addition to low LH support, cows in NEB have limited hepatic expression of growth hormone (GH) receptor 1A triggered by low circulating concentrations of insulin (Butler et al., 2003; 2004). This phenomenon uncouples the GH insulin-like growth factor (IGF) 1 axis, which reduces the synthesis of IGF-1 by the liver. Reduced concentrations of IGF-1 in blood have been associated with diminished follicle sensitivity to LH, follicle growth, and steroidogenesis (Lucy et al., 1992; Butler et al., 2004). Conversely, increase in circulating concentrations of insulin as energy balance improves seems to be one of the signals to reestablish GH receptor expression in the liver and restore IGF-1 synthesis in dairy cows (Butler et al., 2003). Restricting follicular growth and synthesis of estradiol delay resumption of postpartum ovulation and might compromise oocyte quality, which likely hampers expression of estrus and pregnancy in dairy cows.

In addition to extensive nutrient shortage, high producing dairy cows also undergo extensive ovarian steroid catabolism. This is thought to be mediated by the high DMI and subsequent increased splanchnic blood flow (Sangsritavong et al., 2002). Hepatic blood flow doubles during the first 3 months postpartum averaging 1,147 L/h in the week preceding parturition and 2,437 L/h in the third month postpartum (Reynolds et al., 2003). Increased clearance of ovarian steroids can have important implications to the reproductive biology of dairy cows and indirectly influence follicle development (Wiltbank et al., 2006), which can have implications for oocyte quality and subsequent embryo development. Progesterone-induced uterine histotroph secretion is critical for the nourishment and elongation of the bovine conceptus (Robinson et al., 2006). Therefore, an increase in the rate of progesterone clearance is expected to result in a slower rise in progesterone concentrations after insemination, reducing embryo development (Robinson et al., 2006), which has implications for pregnancy maintenance. Similarly, reduced circulating concentrations of estradiol because of hepatic catabolism in cows with high DMI can result in a shorter and less intense estrus period (Lopez et al., 2004). In addition, estradiol catabolism requires follicles to grow for longer periods of time to be able to trigger estrus and ovulation (Sartori et al., 2004; Wiltbank et al., 2006). Longer periods of follicular dominance reduce embryo quality (Cerri et al., 2009a) and pregnancy per AI in cows inseminated on estrus (Bleach et al., 2004) or following timed AI (Santos et al., 2010b).

Calcium homeostasis and uterine health early postpartum

Control of blood concentrations of Ca is critical to maintain normal muscle contractility, transmission of nerve impulses, and immune function. Nonetheless, homeostatic controls during early lactation might not prevent decreases in Ca concentrations during the first week post-partum. Amount of Ca secreted in colostrum on the day of calving is almost 8 to 10 times the entire serum Ca pool in a dairy cow (Goff, 2004). Therefore, it is no surprise that most cows undergo a period of subclinical hypocalcemia and a proportion of them develop milk fever. In fact, surveys in the US indicate that 25, 41, 49, 51, 54, and 42% of cows in their first through sixth lactation are hypocalcemic (Ca < 8 mg/dL or 2 mM) during the first 48 h after calving (Reinhardt et al., 2011). In order to maintain postpartum serum total and ionized Ca (Ca^{2+}) concentrations, dairy cows must increase bone remodeling for Ca resorption or increase intestinal Ca absorption.

Impact of milk fever on the health of dairy cows is very conspicuous, as it can result in downer cows and death if left untreated. Nevertheless, milder depressions of serum Ca concentrations are often not diagnosed and can have a pronounced negative effect on postpartum health and fertility. Recently, Martinez et al. (2012) observed that cows with serum Ca < 8.59 mg/dL during at least 1 of the first 3 days postpartum had reduced neutrophil phagocytic and killing activities in vitro, increased odds of developing fever (adjusted odds ratio [OR] = 3.5; 95% confidence interval [CI] = 1.1 to 11.6) and metritis (adjusted OR = 4.5; 95% CI = 1.3 to 14.9). These associations were observed for cows considered to be of large and small risk of developing metritis based on calving problems (Martinez et al., 2012). Ionized Ca is an important second messenger in cellular signal transduction. Fluctuations in intracellular Ca^{2+} concentrations are critical to activate immune cells (Lewis, 2001). Cows with retained placenta have reduced neutrophil function (Kimura et al., 2002). Intracellular stores and flux of Ca^{2+} in response to cell activation are reduced in lymphocytes of dairy cows with milk fever (Kimura et al., 2006).

To reiterate the findings by Kimura et al. (2006), recent work by our group (Martinez et al., 2014) demonstrated that induction of sub-clinical hypocalcemia compromises innate immunity (Figure 1). Holstein dry cows were subjected to a normocalcemic ($Ca^{2+} > 1.1$ mM) or a subclinical hypocalcemic ($Ca^{2+} < 1.0$ mM) treatment for 24 h. The induction of subclinical hypocalcemia was accomplished by continuous infusion of a solution containing 5% ethylene glycol tetraacetic acid (EGTA), a specific chelating agent for Ca^{2+}. Normocalcemic cows received saline i.v. and an oral bolus of 43 g of Ca at 0 and 12 h after initiating the infusion. Heart and respiratory rates, rectal temperature, and rumen contractions were measured during and after infusion at 6- to 12-h intervals. Ionized Ca, K, Mg, and blood pH were evaluated at 0 h, hourly during the infusion period, and at 24, 48 and 72 h after the infusion to monitor Ca^{2+}. In addition, DMI, neutrophil function, and white blood cell differential count were evaluated at 0, 24, 48 and 72 h after treatments. As expected, infusion of a 5% EGTA solution successfully induced subclinical hypocalcemia in cows (0.78 ± 0.01 vs. 1.27 ± 0.01 mM Ca^{2+}) during 23 h. No differences were detected in heart and respiratory rates, rectal temperature, and white blood cell counts between subclinical hypocalcemia and normocalcemic cows. On the day of infusion, cows induced to have subclinical hypocalcemia had lesser K (2.92 ± 0.07 vs. 3.47 ± 0.07 mM) and greater Mg (0.94 ± 0.03 vs. 0.68 ± 0.03 mM) in blood. The decrease in blood Mg was likely caused by supplemental oral Ca in normocalcemic cows. Subclinical hypocalcemic cows had reduced ($P < 0.01$) DMI on the day of infusion (5.1 vs. 10.0 kg/d) and decreased ($P = 0.01$) rumen contractions every 2 min (1.7 vs. 2.7) during the second half of the infusion period. Cows induced to have subclinical hypocalcemia had a reduced percentage of neutrophils with phagocytosis (79.9 ± 8.8 vs. 119.2 ± 13.0, % baseline) and oxidative burst (80.2 ± 17.9 vs. 140.3 ± 17.9, % baseline), evident at 24 h after the end of the infusion (Figure 1; Martinez et al., 2014). It was concluded that subclinical hypocalcemia compromises DMI, rumen function, and innate immunity, all of which likely related to the immunosuppression observed in cows at calving and increased risk of uterine diseases in cows with marginal blood Ca (Martinez et al., 2012).

Collectively, these data indicate that Ca status is linked with immune cell function and plays a role in the risk of uterine diseases of dairy cows. Cows suffering from uterine diseases have delayed postpartum ovulation, reduced pregnancy per AI, and increased pregnancy loss (Santos et al., 2010a). In fact, reduced serum Ca concentrations immediately before or after calving reduced pregnancy at first AI in lactating dairy cows (Chapinal et al., 2012), and impaired pregnancy rate (Martinez et al., 2012).

Management of transition cows to improve periparturient health and fertility

The multifactorial nature of reproduction requires a "holistic" and integrated approach to management from housing to feeding and breeding, such that risk of periparturient diseases are reduced and pregnancy is improved.

Cow movement and dry period duration

Regrouping of cows induces social behaviors that oftentimes disturb feeding and resting patterns, thereby resulting in a temporary increase in aggression concurrently with a reduction in DMI (von Keyserlingk et al., 2008). Therefore, regrouping cows upon imminent calving is not advised as it would further suppress intake and increase the risk of ketosis and fatty liver. The question of when cows can and cannot be moved, however, still remains. Recent work from Wisconsin refuted the concept that weekly addition of cows to the close-up group is detrimental to postpartum metabolism and production (Coonen et al., 2011). A recent study by the Minnesota group (Silva et al., 2013) reinforced the findings of Coonen et al. (2011) and indicated that weekly regrouping of cows had no impact on subsequent lactation so long as stall availability, bunk space, and 3 to 4 weeks in the close-up group were offered to cows. It seems that when appropriate feedbunk space and number of stalls are available, transition cows can adapt to the weekly regrouping.

A strategy to improve postpartum intermediary metabolism is to manipulate the duration of the dry period. Reducing the dry period from 55 to 34 days increased BCS between 2 and 8 weeks postpartum and reduced the concentrations of plasma NEFA at week 3 postpartum (Watters et al., 2008), suggesting improved postpartum energy status. When energy balance was measured, cows subjected to a 28-d dry period had a less severe NEB postpartum, which resulted in reduced BCS and body weight losses compared with cows having the traditional 56-d dry period (Rastani et al., 2005). Some of the benefit to a less NEB is the result of less milk production, particularly in cows starting their second lactation (Watters et al., 2008; Santschi et al., 2011a). Improved energy balance with a short dry period likely ex-plains the earlier first postpartum ovulation and reduction in anovular cows (Gümen et al., 2005; Watters et al., 2009). Despite changes in energy status and an earlier resumption of estrous cycles, cows with dry periods of 28 to 35 days had similar reproductive performance to those with a standard 8-week dry period (Gümen et al., 2005; Watters et al., 2009; Santschi et al., 2011b). Nevertheless, in observational studies, extending exposure of cows to the prepartum diet was associated with reduced number of days open and increased proportion of pregnant cows at weeks 6 and 21 after the initiation of the breeding season (DeGaris et al., 2010).

Prepartum diet formulation

Altering prepartum caloric intake influences postpartum metabolism in dairy cows. Ad libitum nutrient intake during the entire dry period tended to increase prepartum body weight and BCS and predispose cows to increased lipid mobilization during early lactation (Douglas et al., 2006). Several studies have evaluated the impact of manipulating the energy density of the prepartum diet on postpartum performance. In some cases, nutrient intake was restricted not by altering the diet formulation but by limiting the amount of feed offered. Bisinotto et al. (2011) summarized data from several studies in which the caloric intake prepartum was manipulated. In general, restricting nutrient intake resulted in an average reduction of 2 kg/d of fat-corrected milk, with minor effects on plasma concentrations of BHBA. In some studies, high caloric intake resulted in greater triacylglycerol accumulation in the liver (Douglas et al., 2006; Janovick and Drackley, 2011) because of greater fat mobilization measured as plasma NEFA. The increased postpartum lipid mobilization is likely the result of increased milk yield without a concurrent increase in DMI. Therefore, restricting prepartum caloric intake can be used to minimize lipid mobilization and triacylglycerol accumulation in the liver, but at the expense of milk production.

Altering protein content of the prepartum diet has little impact on performance of postpartum multiparous cows; however, increasing prepartum dietary protein from 12.7 to 14.7% of the diet DM with a high ruminally undegradable protein source enhanced milk production in primiparous cows (Santos et al., 2001). Nonetheless, dietary protein fed prepartum had negligible impacts on measures of reproduction. Time to resumption of postpartum ovulation, days open, and pregnancy per AI were not affected by prepartum dietary protein concentration. Similarly, incidence of diseases postpartum was not affected by prepartum dietary protein. Therefore, diets for cows during the last weeks of gestation should contain between 12% (multiparous cows) and 15% (primigravid cows) crude protein to result in an estimated 1 kg/d of metabolizable protein intake (National Research Council, 2001).

Increasing postpartum blood insulin

A number of studies have demonstrated the importance of insulin as a signal mediating the effects of acute changes in nutrient intake on reproductive traits in dairy cattle. Feeding more dietary starch or enhancing ruminal fermentability of starch in the diet usually results in increased plasma insulin concentrations. Insulin mediates recoupling of the GH and IGF-1 axis (Butler et al., 2003), which is important for follicle development and ovulation. Gong et al. (2002) fed cows of low- and high-genetic merit isocaloric diets that differed in the ability to induce high or low insulin concentrations in plasma. Feeding the high-starch diet reduced the interval to first postpartum ovulation and resulted in a greater proportion of estrous cyclic cows by 50 days postpartum. Nevertheless, this response has not been consistent (Garnsworthy et al., 2009). It is important to remember that although diets high in starch favor increases in plasma insulin, excessive amounts of readily fermentable starch has the potential to suppress DMI and offset any potential benefits of dietary manipulation on ovarian function.

Altering hepatic lipid metabolism

During periods of extensive fat mobilization, fat accumulates in the hepatic tissue. In early lactating cows with relatively low plasma NEFA concentrations (0.36 mM), the liver extracted 724 g of NEFA from blood during a 24-h period (Reynolds et al., 2003). Thus, in cows with concentrations of NEFA > 1 mM, as those with extensive lipid mobilization immediately after calving, the liver might remove as much as 2 kg of NEFA per day, the equivalent of 20% of its weight. Most of the NEFA reaching the liver are oxidized for energy production or converted into BHBA, with a smaller contribution for synthesis of very low-density lipoprotein (VLDL). The bovine liver has limited capacity to synthesize and secrete VLDL, thereby compromising export of triacylglycerol during periods of extensive hepatic NEFA uptake. The resulting hepatic lipidosis has been associated with retained placenta, ketosis, displaced abomasum, and impaired immune function and reproduction (Jorritsma et al., 2000; Bobe et al., 2004). Thus, reducing the risk of lipid-related disorders might improve reproduction of dairy cows. Supplementing periparturient dairy cows with rumen-protected choline has been used as a strategy to improve lipid metabolism and alleviate hepatic lipidosis. When feed intake was restricted to 30% of the maintenance to simulate a period of NEB and induce hepatic lipidosis, the supplementation of rumen-protected choline reduced triacylglycerol accumulation in the liver (Cooke et al., 2007). Furthermore, inclusion of supplemental choline in the diet from approximately 25 days before to 80 days after calving reduced loss of postpartum body condition and concentrations of BHBA in plasma, which resulted in lower incidence of clinical and subclinical ketosis despite the increase in fat-corrected milk (Lima et al., 2012). Although feeding rumen-protected choline reduced morbidity, and improved metabolic health, no benefits were observed for reproduction. Supplemental rumen-protected choline did not affect the resumption of postpartum estrous cyclicity, pregnancy per AI at the first and second inseminations, or maintenance of pregnancy in the first 60 days of gestation.

Supplementing ionophores to periparturient dairy cows

Ionophores are lipophilic molecules involved with ionic transport across cell membranes. Monensin is a carboxylic polyether ionophore that has been used in animal nutrition because it selectively inhibits gram-positive bacteria. The shift in the ruminal microbiota caused by monensin favors propionate production and N conservation by reducing ruminal proteolysis. Feeding monensin typically increases blood glucose and insulin and reduces the concentrations of NEFA and BHBA in blood (Duffield et al., 2008a). In association with improved metabolic health, monensin was effective in reducing the incidence of ketosis, displaced abomasum, and mastitis (Duffield et al., 2008b). When monensin was supplemented as a controlled-release capsule, it reduced the incidence of metritis (Duffield et al., 2008b). Surprisingly, feeding monensin to dairy cows during the transition period has not been shown to hasten resumption of postpartum ovulation, reduce days to pregnancy, or increase the rate of pregnancy in spite of consistent improvements in metabolic health (Abe et al., 1994; Duffield et al., 2008b).

Improving postpartum calcium homeostasis

Improving serum concentrations of Ca during early lactation is achieved by enhancing bone mineral resorption, intestinal absorption of dietary Ca, and by increasing the ionized Ca fraction in blood. A common method to improve Ca homeostasis is to manipulate the dietary cation-anion difference (DCAD) prepartum (Goff et al., 1991; Goff, 2004; Seifi et al., 2010). Reducing the DCAD by feeding salts containing strong anions decreases blood pH and enhances the affinity of the parathyroid hormone (PTH) for the PTH receptor present on cells in the bones, intestine, and kidneys (Goff, 2004). Although altering the DCAD of the diet by feeding strong anions can reduce feed intake during supplementation, the improved postpartum Ca metabolism often results in greater postpartum feed intake (DeGroot et al., 2010). Feeding acidogenic diets prepartum did not reduce the incidences of retained placenta, lameness, or subclinical ketosis (Seifi et al., 2010). In contrast, supplementing cows with calcium chloride in a gel formulation 12 h before the expected calving and at 0, 12, and 24 h after calving reduced the incidence of clinical and subclinical hypocalcemia, and displacement of abomasum (Oetzel, 1996). Despite the benefits of feeding acidogenic diets on Ca homeostasis and the link between serum Ca and uterine diseases and reproduction in dairy cows (Martinez et al., 2012), intervals to first insemination and pregnancy were not affected by feeding a low DCAD diet prepartum (Seifi et al., 2010). Additional research is needed with properly powered experiments to critically evaluate the impact of reducing subclinical hypocalcemia by manipulating the DCAD of prepartum diets or supplementing postpartum Ca on reproductive traits of dairy cows.

Our group has attempted to increase serum total Ca and Ca^{2+} by supplementing Ca orally as boluses containing 50% of the Ca as calcium chloride (CaCl2) and 50% as calcium sulfate (CaSO4•2H2O). The amount of supplemental Ca needed to have appreciable changes in blood total and Ca^{2+} were at least 86 g/d when such boluses were used and the increase in blood Ca lasted for no longer than 8 h (Martinez et al., 2016). Therefore, if postpartum Ca supplementation is used, it is likely that cows must receive at least 80 g/d for 3 to 4 days to minimize risk of subclinical hypocalcemia with the goal of preventing the development of uterine diseases. Because reproduction is impaired in cows with subclinical hypocalcemia (Martinez et al., 2012), it is plausible to suggest that manipulation of the prepartum diets to avoid low serum Ca and postpartum supplementation of Ca may likely improve uterine health and subsequent fertility.

Feeding antioxidants to influence health and reproduction

During the immediate postpartum period, the cow's immune system is challenged severely, and the innate and humoral defenses are suppressed (Martinez et al., 2012). Incidence of diseases and disorders can be elevated during this phase of the lactation cycle and they have several negative impacts on reproductive performance. Reduction in adaptive and innate immunity at parturition increases the risk of health disorders such as retained placenta, metritis, and mastitis.

Selenium has long been associated with immunity. Cattle supplemented with Se-yeast had an 18% increase of Se in plasma in comparison with cows fed sodium selenite in some studies (Weiss, 2003). Depending soil type and content, plants can be deficient in Se, which reflects in the supply of this mineral to cattle. Under the conditions of a Se inadequacy during the heat stress season in Florida, supplementing dairy cows with an organic source of Se in the form of selenized yeast elevated plasma Se concentrations compared with sodium selenite (Silvestre et al., 2007). Conversely, in 2 subsequent experiments, when the same supplementation scheme was applied to cows in a Se adequate area, Se concentrations in plasma did not differ (Rutigliano, 2006; Rutigliano et al., 2008; Cerri et al., 2009b). Measures of innate and humoral immune responses, embryo quality, and fertility of dairy cows were unaltered by source of Se in the Se-adequate area (Rutigliano et al., 2008; Cerri et al., 2009b). Nevertheless, selenized yeast improved neutrophil function, serum titers against ovalbumin, and uterine health in cows in the Se-deficient area (Silvestre et al., 2007). These findings indicate that responses to supplemental antioxidants such as Se in a more bioavailable form depend on the Se status of the animal.

Conclusions

It is accepted that reproduction is important for the profitability of dairy farms, and health of dairy cows during the peripartum period is one of the many determinants of reproductive success. Cows that experience periparturient problems have delayed return to ovulation, reduced pregnancy per AI, and increased pregnancy loss. The negative effects on fertility occur at multiple stages of gestation, with reduction in fertilization, hindered morula and day 15 conceptus development, and altered pattern of gene expression in conceptus and peripheral tissues influenced by the conceptus, which ultimately compromise establishment and maintenance of pregnancy in dairy cows. Because our understanding of the underlying biology of subfertility in cows with diseases is poor, methods to mitigate depression in pregnancy have to be holistic and attain to minimizing the risk factors that predispose cows to diseases.

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Table 1 Association among clinical and subclinical diseases and fertility responses in grazing dairy cows[1]

				Contrast[3]	
Item	Incidence	AOR (CI)[2]	P value	C1	C2
Estrous cyclic on day 49 postpartum				< 0.01	0.02
Healthy	95.6^{a}	1.00	…		
Subclinical disease only	$88.9^{b,c}$	0.35 (0.16-0.76)	< 0.01		
Clinical disease only	$93.0^{a,b}$	0.63 (0.23-1.75)	0.37		
Subclinical and clinical disease	83.5^{c}	0.23 (0.10-0.50)	< 0.01		
Pregnant day 30				< 0.01	0.10
Healthy	73.5^{a}	1.00	…		
Subclinical disease only	63.1^{b}	0.67 (0.44-0.99)	0.05		
Clinical disease only	$54.8^{b,c}$	0.44 (0.26-0.75)	< 0.01		
Subclinical and clinical disease	50.0^{c}	0.39 (0.24-0.61)	< 0.01		
Pregnant day 65				< 0.01	0.07
Healthy	66.2^{a}	1.00	…		
Subclinical disease only	$57.1^{a,b}$	0.72 (0.49-1.05)	0.09		
Clinical disease only	$46.3^{b,c}$	0.45 (0.26-0.76)	< 0.01		
Subclinical and clinical disease	42.1^{c}	0.39 (0.25-0.61)	< 0.01		

[a,b,c] Superscript letters within item estrous cycle, pregnant on day 30, and pregnant on day 60 differ ($P < 0.05$).

[1] Data from Ribeiro et al. (2013).

[2] AOR = adjusted odds ratio; CI = confidence interval.

[3] Contrasts: C1 = effect of disease (healthy vs. all others); C2 = effect of having both clinical and subclinical diseases combined versus only clinical or subclinical (subclinical and clinical disease vs. subclinical disease only + clinical disease only).

Table 2 Impact of health problems during early lactation on embryo quality in dairy cows[1]

	Group[2]			P[3]	
Item	Healthy	Single disease	Multiple diseases	Disease	Number of diseases
Embryos-Ova					
Number	252	87	80	---	---
Fertilized, %	86.1	81.6	73.8	0.03	0.22
Grades 1-3, %	73.4	62.1	51.3	<0.01	0.16
Grades 1-2, %	61.9	50.6	41.3	<0.01	0.23
Embryos					
Grades 1-3, %	85.3	76.1	69.5	<0.01	0.40
Grades 1-2, %	71.9	62.0	55.9	0.01	0.49
Cell number	38.8	35.6	33.3	0.04	0.49

[1] Data from Ribeiro et al. (2013).

[2] Healthy = no diagnosis of clinical disease; Single disease = diagnosis of a single clinical disease in early lactation; Multiple diseases = diagnosis of more than one clinical disease event in early lactation.

[3] Orthogonal contrasts. Effect of disease: healthy vs. single disease + multiple diseases; Effect of number of diseases: single disease vs. multiple diseases.

Table 3 Impact of health problems during early lactation on embryo quality in dairy cows[1]

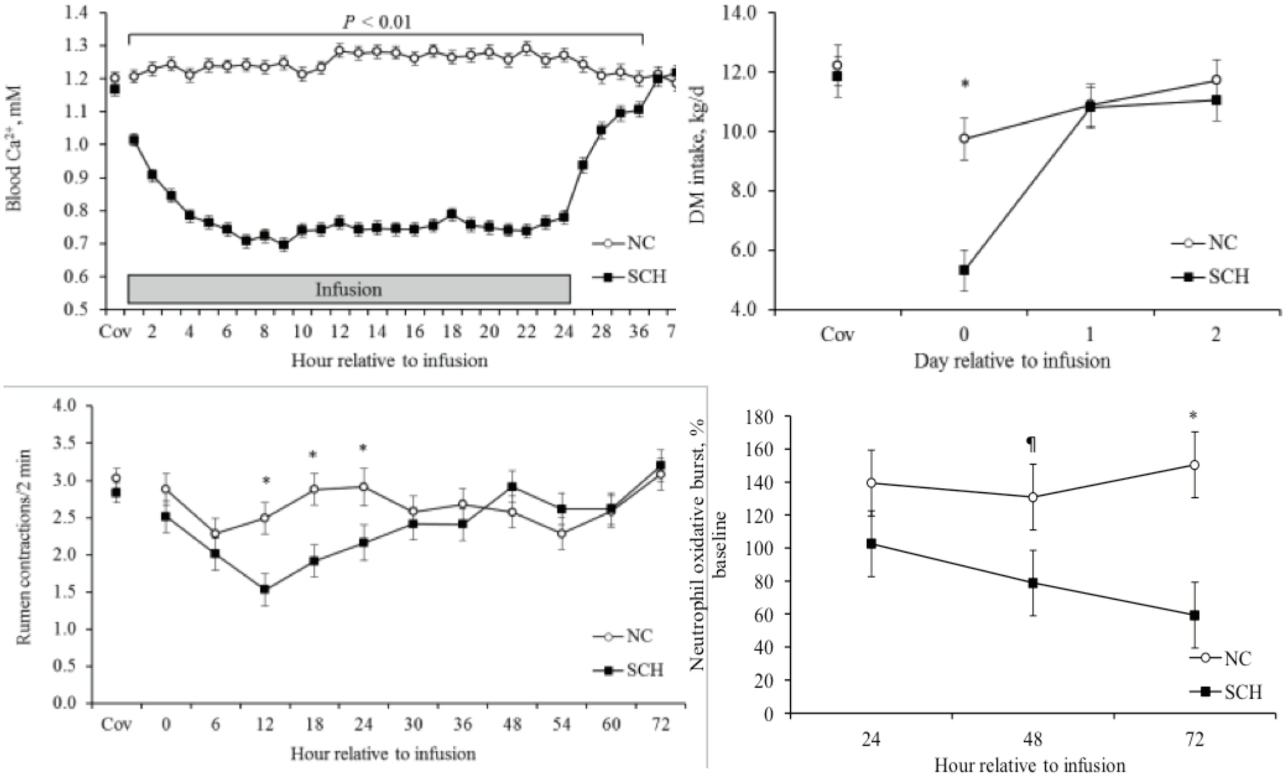
Item	Group[2]			P[3]	
	Healthy	Single disease	Multiple diseases	Disease	Number of diseases
Number	114	64	20	---	---
Pregnant day 15, %	47.7	52.9	53.9	0.58	0.88
Interferon-β, pg/mL	404.9	184.3	29.2	< 0.01	0.06
Size, mm	25.1	17.5	16.9	< 0.01	0.23
Progesterone day 7, ng/mL	3.3	3.5	3.3	0.84	0.71

[1] Data from Ribeiro et al. (2013).

[2] Healthy = Healthy = no diagnosis of clinical disease; Single disease = diagnosis of a single clinical disease in early lactation; Multiple diseases = diagnosis of more than one clinical disease event in early lactation.

[3] Orthogonal contrasts. Effect of disease: healthy vs. single disease + multiple diseases; Effect of number of diseases: single disease vs. multiple diseases

Figure 1 Blood Ca2+ concentrations (upper left), dry matter intake (upper right), rumen contractions (bottom left), and neutrophil killing of E. coli (bottom right) of cows subjected to normocalcemia (NC) or induced subclinical hypocalcemia (SCH). Cov = mean of measurements taken during 48 h preceding treatments and used for covariate adjustment of data during statistical analyses. * = within day or hour treatments differ (P < 0.05); ¶ = within day or hour treatments tend (P < 0.10) to differ. Data from Martinez et al. (2014).



Conception and embryo losses in New Zealand seasonal pasture-grazed dairy cattle

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Introduction

It is well-established that worldwide fertility in dairy cows has declined over time (Lucy, 2001). Has fertilisation and embryo loss declined for the seasonal pasture-grazed dairy cow in New Zealand?

This study aimed to define the period of early embryo loss in cows from first insemination to 70 d, and identify on-farm factors associated with early loss. The study animals were spring-calving, pasture-grazed dairy cows (N=1,821) in the North Island, New Zealand. The findings provide new insights of when embryo loss occurs in this type of dairy system, and identifies some of the factors involved.

For optimal performance of seasonal, dairy-grazing systems, the peak energy demand of the herd should be aligned with the seasonal peak in pasture growth (Roche et al., 2017b; Dillon et al., 1995). This requires that the herd maintain a calving interval of 365-d with a compact 6 to 9 week calving period. The short, intense calving period is immediately followed by a similarly compact period of re-breeding, beginning just 12 weeks after the herd starts calving. The re-breeding is concentrated over a 9 to 13 week period, and the cows need to conceive by 85 d postpartum (assuming a 280 d gestation length).

The most efficient cows in seasonal systems are those that resume having fertile oestrus cycles before the start of mating. They also need to achieve at least a 60% conception rate between their first AI to the first 21 d of the breeding period. First service conception rates are substantially impacted by many factors such as premating ovulatory status, inaccurate oestrus detection, insemination of cows early in the postpartum period (late calving cows), body condition score, and pregnancy loss (Burke et al., 2012).

Pregnancy loss or embryo mortality is, therefore, an issue of importance and has been the subject of many recent reviews (Diskin and Morris, 2008, Wiltbank et al., 2016, Diskin et al., 2016). To ensure that a pregnancy proceeds through each stage of development, a developmental cascade of embryo competence is required. Failure at a key developmental milestone during pregnancy will result in termination, allowing the cow another opportunity to get pregnant.

Moderate-producing dairy cows managed under a seasonal pasture grazed system have a 50 to 55% calving rate from each insemination. Fertilisation rates are greater than 90% with early embryo and foetal loss rates of approximately 35 to 40% (excluding fertilisation failure). Previously, the greatest embryo loss (28%) was reported to occur between days 8 to 16 after insemination (Diskin et al., 2006). However, these data were acquired over 20 years ago (Sreenan and Diskin, 1986).

Materials and methods

Farms and cows

A total of 1,821 cows participated in the study over two consecutive years. Cows were enrolled over a 21 day period following the first insemination, and began on the first day of mating. Four commercial dairy farms from the North Island of New Zealand participated in the study, and management of the farms and cows were specific for each farm. The herds consisted of Holstein-Friesian by Jersey (HFxJ) crossbred cows on three farms and predominately a Jersey (J) herd on the 4th farm. For each farm, previous year's 6-week in-calf rate ranged from 68 to 73%.

Experimental design

Four collection points were chosen to cover key developmental milestones during embryo and foetal development. Blood sampling for retrospective progesterone analyses were used to calculate submission errors and identify non cycling cows. Experienced personnel assessed body condition of individual cows using a 1 to 10 scale (1 = emaciated, 10 = obese) (Roche et al., 2004). Scoring was conducted 1 week before calving, and again on the day of AI on each of the four farms for both years of the experimental period. These are outlined in Table 1.

Table 1 Collections groups and sample collection

Group (n)[1]	Day of embryo collection (Development) milestone	Day of pregnancy diagnosis (ultrasonography)	Blood sample & BCS Day 0	Blood sample Day 7	Blood sample Day 15
E7 (625)	7 (Fertilisation & early embryo development)	No	Yes	Yes	No
E15 (449)	15 (Embryo elongation & pregnancy recognition)	No	Yes	Yes	Yes
E 35 (370)	No	28 and 35 (late embryo development)	Yes	Yes	No
E 70 (control) (377)	No	70 (control pregnancy rate)	Yes	No	No

Records for reproductive and non-reproductive outcomes were obtained from a commercial database using data-linking software (MINDA; LIC, Hamilton, New Zealand).

These data included individualised information such as calving date, AI dates, sire used for insemination, age, breed; as well as herd test data, including milk volume, composition, and somatic cell counts.

Percentage data were analysed using Fisher's Exact Test where reported and presented with 95% confidence intervals. Binary variables were analysed by logistic regression in Genstat (GenStat for Windows 14th Edition. VSN International, Hemel Hempstead, UK).

Model variables on embryo viability included:

- farm
- year
- collection group
- cow age (coded as 2, 3, 4, 5, 6, 7, 8+ years old)
- breed of embryo (coded as % HF)
- BCS at calving and insemination
- the change of BCS from calving to first insemination
- calving to first insemination interval (DPPI)
- October herd test milk volume
- percentage milk-fat and protein
- log10 progesterone at days 0 and 7 (progesterone fitted as a linear and a quadratic term)

Model random effects were cow and insemination sire.

Odds ratios were converted back to probabilities (P) using the following equation: P=odds/(1+odds).

Results

Submission rate

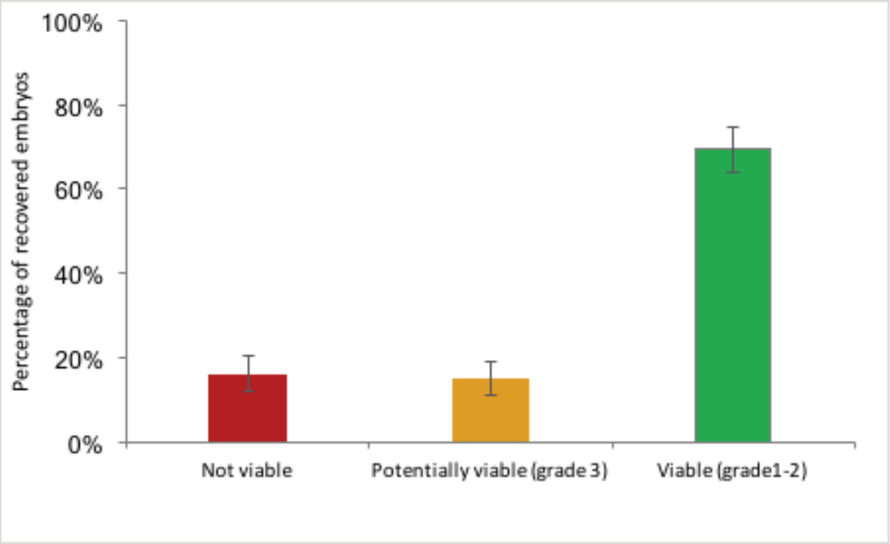
The submission rate across all farms was 76.5%, with a 95% confidence interval (95% CI) of 74.8-78.2%. However, the submission rate was lower on 1 farm, 66.3% (95% CI; 62.2-70.2%), P<0.05. In total, 1,821 cows were submitted within 21 days.

Retrospective circulating progesterone analysis showed that 104 cows were submitted in error (5.6%; 95% CI, 4.6-6.7%).

Early embryo loss - Day 7

The ova/embryo recovery rate was 63.8% (95% CI, 59.8-67.7%; 372/583). Of those, 83.3% were fertilised (95% CI, 87.2-79.4; 311/372). Of the fertilised embryos, 69.5% embryos recovered were viable at Day 7 (95% CI, 64.0-74.5; 216/311). Figure 1 illustrates the percentage of embryo loss by Day 7.

Figure 1 Embryo loss by Day 7. Not viable embryos are single cells through morula. Potentially viable embryos are grade 3 tight morula and blastocyst. Viable embryos are grade 1-2 tight morula and blastocyst grade 1-2.



Early embryo loss - Day 15

At Day 15, 61.2% (95% CI, 56.4-65.9; 262/428) of embryos were recovered, and of those 85.9% (95% CI, 81.1.4-89.9; 225/262) were recovered intact and evaluated. Of the embryos evaluated, 91.6% were viable (95% CI, 87.1-94.8; 206/225). Between Day 7 and Day 15 an additional 8.4% embryos were lost. The total embryo loss for the first 15 d post-insemination was 37.9%.

Late embryo loss - Day 28 and 35

Pregnancy rate at Day 28 was 63.7% (95% CI, 58.3-68.8; 219/334), and 62.2% (95% CI, 56.9-67.4; 214/334) by Day 35. By Day 35, the total embryo loss from first insemination was 37.8%. These findings suggest a very low rate of embryo loss between Day 15 and Day 35.

Pregnancy rate – Day 70

The pregnancy rate at Day 70 was 56.4% pregnancy rate (95% CI, 51.1-61.5; 204/362), and was lower than the Day 35 pregnancy rate (P=0.045).

Conception loss

Conception loss was determined by the number of viable embryos or pregnant cows divided by number of cows submitted for AI for each group. Pregnancy rates were predicted by embryo evaluation at days 7 and 15. Conception loss is presented in Figure 2.

Risk factors associated with conception loss are outlined in Table 2. The odds of a successful pregnancy increases by 13% for every 7 day increase in days post-partum interval (DDPI). One extra oestrous cycle is equivalent to an extra 8 days post-partum. A one unit increase in Day 7 $\log_{10}$ progesterone concentration increased the probability of an embryo surviving by 0.84.

Figure 2 Conception loss (95% CI) after the first insemination in New Zealand Dairy cows. Conception loss is the number of pregnant cows divided by number of cows submitted for AI. Predicted pregnancy rates were based on embryo evaluation at days 7 and 15.

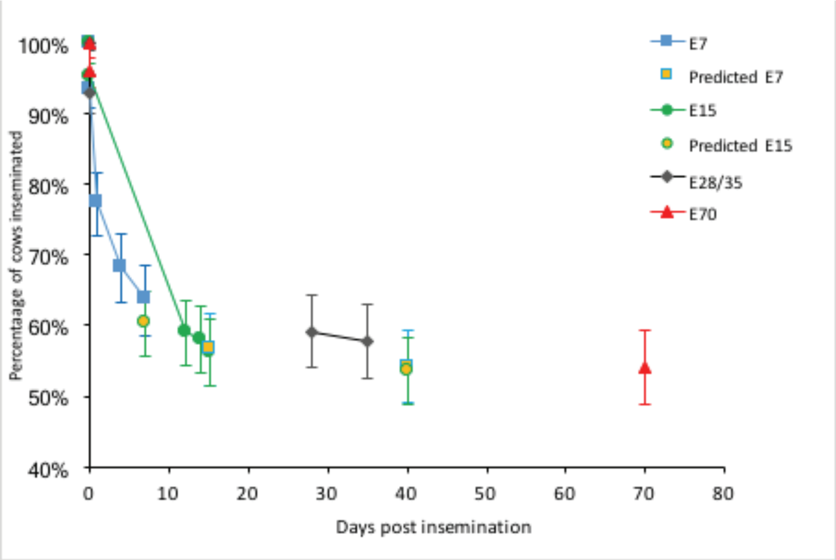


Table 2 Logit model of cow and risk factors associated with conception and embryo loss for New Zealand Dairy cows

Variable	Fixed or random factor in the model	P-value
[1]Cow	random	<0.001
Sire used for insemination	random	<0.001
Collection group	fixed	<0.001
Days post-partum interval	fixed	<0.001
$\log_{10}$ day 7 progesterone	fixed	0.003
[2] Number of oestrous cycles before insemination	fixed	0.05
Milk yield (Oct herd test)	fixed	0.171
BCS pre calving	fixed	0.191
[3] Change of BCS	fixed	0.200
BCS at insemination	fixed	0.532
Year and farm	fixed	0.411
Milk fat %	fixed	0.535
Cow Holstein-Friesian %	fixed	0.693
Cow age	fixed	0.750
Milk protein %	fixed	0.779
Embryo/foetus % Holstein-Friesian	fixed	0.895

[1] The same cows were enrolled in the study two consecutive years on the two farms.

[2] Data from one farm 2015, 490 cows.

[3] The difference in BSC score from calving to first insemination.

Implications and Conclusions

We found that the highest rate of conception and embryo loss occurred during the first week after insemination. This was followed with a smaller loss during the second week, which is inconsistent with the general belief that pregnancy failure or success is largely determined during the maternal recognition of pregnancy phase beginning in this time.

Late embryo and early foetal loss of 6% was similar to previous reports in seasonal grazing dairy cows (7.5%, Horan et al 2005; 4.2%, McDougall) and has not changed over time.

Late calving cows inseminated on their first oestrus cycle had less chance of conception failure. We are now focusing our studies on the peri-ovulatory period, especially oocyte quality. The role of the oviduct in explaining these early losses should not be ruled out.

Acknowledgements

This work was funded by the NZ Ministry of Business, Innovation and Employment, New Zealand dairy farmers through DairyNZ Inc., and AgResearch's Strategic Science Investment Fund. The in-kind support of Fonterra for herd access is also gratefully acknowledged. In particular we would like to thank the farm managers involved in the trial for allowing us to disrupt their calving pattern the following year.

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Pregnancy loss in dairy cows after day 35 of gestation

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Abstract

Spring-mated cows from 4 Victorian pasture-based dairy herds found pregnant at ultrasound testing at around day 35 were followed for subsequent pregnancy loss in 2015-16. Ultrasound (US) pregnancy tests and milk ELISA pregnancy tests were conducted at around 60 days interals between test modalities with either a US or ELISA test every approximately 30 days until around day 140 of mating. Pregnancy loss was identified when previously identified pregnancies were confirmed absent or pregnancy to a later conception was identified. The relationships between cow age, breed, number of days calved at conception, body condition score at the start of mating, milk production and milk composition at peak lactation and pregnancy to a fixed-time (synchronized) artificial insemination and pregnancy loss were described using a causal diagram. Strength of associations were examined using Cox proportional hazards regression for interval-censored data. Significant predictors or models with significant predictive ability (p-value < 0.05) are reported. 1,756 spring-calving cows provided 1,149 pregnancies with subsequent pregnancy tests after first diagnosis. 90 pregnancy losses were identified (7.8%). Significant risk factors were peak lactation litres and clinical mastitis after conception. Risk of pregnancy loss increased as cows production at peak deviated from 30 litres. Cows experiencing clinical mastitis after conception had a 2.7 fold increased risk of loss. Risk tended to increase in cows with a milk fat test at peak lactation that was less than or greater than 4.10%. No effects of breed, breeding value for daughter fertility, age, fixed time insemination pregnancy, body condition score at the start of mating, number of days calved at conception or milk composition on pregnancy loss were observed. Controlling mastitis, management of high-producing grazing cows and selection of cows that better balance milk production and fertility is recommended.

Introduction

The proportion of cows identified pregnant at early pregnancy testing and who then fail to calve or who calve to a later conception date is reportedly increasing. This appears to: contribute to increased cow attrition; devalues early pregnancy testing information; and necesitates extra pregnancy testing. Embryo losses between days 7 and 16 of pregnancy have recently been estimated at 26% in heifers and 34% in multiparous cows (Berg et al., 2010). Losses after day 30 of pregnancy have been measured ranging from 7–15% in high-producing cows (Chebel et al., 2004, Starbuck et al., 2004) and at 7.5% in pasture-based cows in Ireland (Horan et al., 2004) and 6.4% in a New Zealand (McDougall et al., 2005).

This field study was designed to measure the incidence of pregnancy loss after the first confirmed early (5–13 week) pregnancy test and to identify risk factors for pregnancy loss in Australian pasture-based dairy cows.

Materials and methods

Four seasonally-calving pasture-based dairy herds located in the Macalister Irrigation District of Victoria, Australia within a corporate farming enterprise were selected for the study. The 2015 spring-calving cows in each herd were eligible for inclusion into this study. Each farm used a whole-herd estrus synchrony program with fixed time artificial insemination (FTAI) on the first day of the spring mating period. A professional AI technician undertook all inseminations and an experienced veterinarian performed transrectal ultrasound (TRUS) pregnancy testing of all cows at or around day 35 of mating with repeat ultrasound pregnancy testing with foetal aging at an interval of approximately 60 days until around 140 days after the start of mating. Cow milk ELISA pregnancy testing was performed on individual cow milk samples obtained from bimonthly herd tests that were timed to occur approximately midway between TRUS examination time points.

Data from cows confirmed pregnant at a TRUS and providing at least one other TRUS after the first positive pregnancy test were analysed. These cows provided a known period of pregnancy observation. Pregnancy loss was defined as occurring when a negative test followed a previous positive test or if the estimated conception date obtained from foetal aging at a subsequent TRUS was 3 weeks or more after the estimated conception date identified at first positive TRUS.

Body condition score (BCS; 1–8 scale) was measured during milking at the start of mating. Cow age, breed, sire and dam identification and sire and dam estimated Australian breeding values for daughter fertility (ABV_{DF}) and last calving date were obtained from MISTRO Farm™ herd management records (Larcombe, 2010). Cow milk production (litres), milk composition (fat percent and protein percent) and individual cow somatic cell count (ICCC) were recorded at monthly herd-tests conducted across the study period. Individual cow clinical mastitis events were recorded.

The unit of allocation was pregnancy. However, because no individual cow was identified as having two separate pregnancies in the study so this unit of study was equivalent to cow. The R Language and Environment for Statistical Computing V3.2 was used for all data cleaning, manipulation and analysis (R Core Team, 2012). Continuous variables were examined for normality and appropriate conversions undertaken if required. Subtracting the mean from each value centred each continuous variable and this was used to explore any curvilinear relationships by entering both the centred variable and the centred variable squared into statistical models. The levels and number of observations within each level of categorical variables were examined. Where necessary, levels were aggregated to provide sufficient observations to be meaningful for analysis.

The first herd milk recording after the start of mating was used to define the lactation production of the cow. The timing of the first herd test relative to calving date varied between cows so the observed production (litres, fat and protein) was adjusted to account for this observed variation in stage of lactation.

A modification of the Cox proportional hazards regression (CPHR) analysis for interval-censored data was used to examine pregnancy loss because the exact day of pregnancy loss cannot be determined from sequential pregnancy testing conducted at long intervals. The R library icenReg 1.3.6 was used for all interval-censored CPHR models.

A causal diagram describing proposed causal and confounding pathways between explanatory variables and the outcome variable (pregnancy loss) was developed and this diagram was used to guide statistical analysis. Only variables with a plausible relationship (causal or confounding) to pregnancy loss were analysed for a relationship. Use of causal diagrams provides the essential link between biological understanding of relationships by defining statistical models that explore the relationships. Individual interval-censored CPHR models were built for each explanatory variable with appropriate adjustment for confounding. Farm was forced into all models to adjust for confounding at this level.

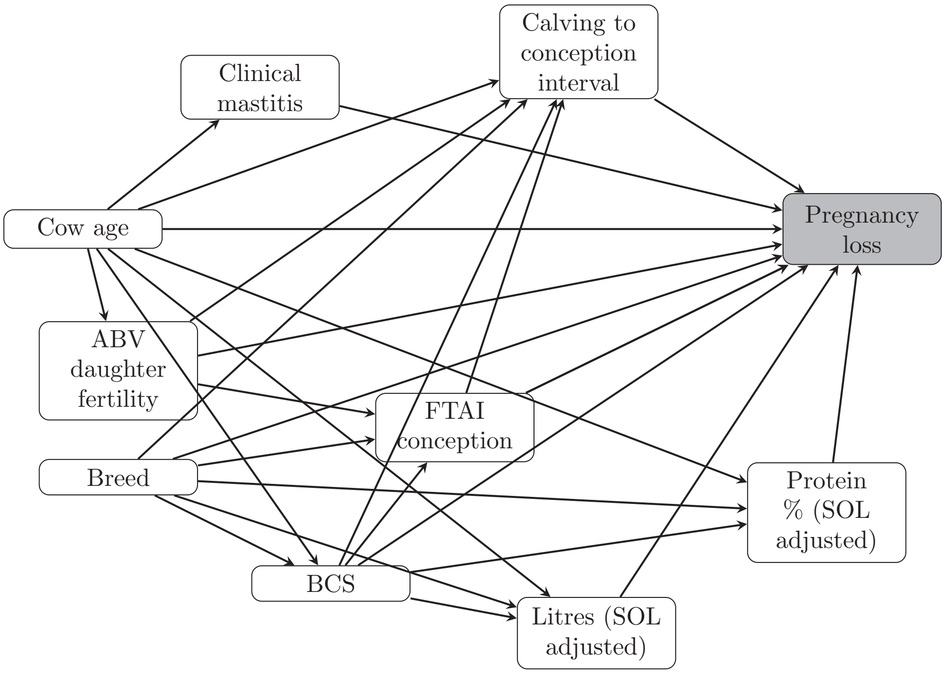
The strength of the relationship between proposed explanatory variables and pregnancy loss was assessed using a combination of the CPHR hazard ratio (controlled for confounding) p-value and the p-value of improvement in model fit arising from including the variable of interest over the baseline model. Competing models were assessed using a $\beta 2$ distribution with appropriate degrees of freedom comparing -2 times the log likelihood difference between the nested models. Statistical significance was set at $p \leq 0.05$ with a trend set at $0.05 > p \leq 0.10$. Models with significant predictive power and containing non-significant (purported) confounding variables (as defined by the causal diagram) were further examined. A non-significant confounding variable was removed from the model if this did not result in any significant reduction in model fit and when any change to the hazard ratio coefficient of the explanatory variable was below 20%.

Results

The causal diagram describing the (potential) relationships between predictor variables and pregnancy loss are presented in Figure 1.

A total of 1,756 cows were available for spring mating on the farms (452, 322, 330, and 652 on farms 1 to 4 respectively). Of these 1,212 became pregnant during spring mating (305, 247,246 and 419 on farms 1 to 4 respectively) with 1,149 cows providing at least one ultrasound pregnancy test after being first confirmed pregnant (302, 210, 237 and 400 on farms 1 to 4 respectively). The distribution of number of cows, number of pregnancy losses and the rate of pregnancy loss for each of study variable are presented in Table 1. A total of 90 pregnancy losses were observed across 1,149 pregnancies. This equates to a loss rate of 7.8% between approximately days 35 to 120 of pregnancy.

Figure 1 Causal diagram of pregnancy loss from the first confirmed pregnant pregnancy test until around 140 days after the start of mating.



Variable	Class	Number (No. Aborted)	Proportion aborted (95% CI)
Farm	Farm 1	302 (33)	0.109 (0.074-0.144)
	Farm 2	210 (11)	0.052 (0.022-0.083)
	Farm 3	237 (13)	0.055 (0.026-0.084)
	Farm 4	400 (33)	0.083 (0.056-0.109)
	Total	1149 (90)	0.078 (0.063-0.094)
Breed	Friesian	357 (41)	0.115 (0.082-0.148)
	Jersey	8 (0)	0.000 (0.000-0.000)
	Crossbreed	160 (14)	0.088 (0.044-0.131)
	Unknown	624 (35)	0.056 (0.038-0.074)
Age (years)	2	38 (4)	0.105 (0.008-0.203)
	3	89 (10)	0.112 (0.047-0.178)
	4-7	362 (27)	0.075 (0.048-0.102)
	8+	135 (5)	0.037 (0.005-0.069)
	Unknown	525 (44)	0.084 (0.060-0.108)
BCS	< 4.5	488 (40)	0.082 (0.058-0.106)
	4.5-<5.0	508 (40)	0.079 (0.055-0.102)
	≥ 5	22 (1)	0.045 (0.000-0.132)
	Unknown	131 (9)	0.069 (0.025-0.112)
Calv. to conc. interval	<0	1 (0)	0.000 (0.000-0.000)
	1-30	45 (1)	0.022 (0.000-0.065)
	31-60	164 (11)	0.067 (0.029-0.105)
	61-90	516 (47)	0.091 (0.066-0.116)
	91-120	64 (10)	0.156 (0.067-0.245)
	> 120	358 (21)	0.059 (0.034-0.083)
	Unknown	1 (0)	-
FTAI pregnancy	Yes	375 (33)	0.088 (0.059-0.117)
	No	774 (57)	0.074 (0.055-0.092)

Variable	Class	Number (No. Aborted)	Proportion aborted (95% CI)
Peak lact. litres	<25	238 (16)	0.067 (0.035-0.099)
	25-35	685 (48)	0.070 (0.051-0.089)
	>35	224 (26)	0.116 (0.074-0.158)
	Unknown	2 (0)	-
Peak lact. protein %	<3.00	229 (25)	0.109 (0.069-0.150)
	3.00-3.40	632 (43)	0.068 (0.048-0.088)
	>3.40	285 (21)	0.074 (0.043-0.104)
	Unknown	3 (1)	0.333 (-0.200-0.867)
Peak lact.fat %	<3.70	274 (29)	0.106 (0.069-0.142)
	3.70-4.40	550 (34)	0.062 (0.042-0.082)
	>4.40	322 (26)	0.081 (0.051-0.111)
	Unknown	3 (1)	0.333 (0.00-0.867)
Clin. mast. post conc.	Yes	1106 (36)	0.033 (0.022-0.043)
	No	43 (7)	0.163 (0.052-0.273)

The hazard ratios and 95% confidence intervals for the total effect of individual explanatory variables adjusted for confounding are presented in Table 2 (continuous variables) and Table 3 (categorical variables). The mean value and standard deviation for continuous variables is presented and the count of pregnancy loss and the percentage experiencing pregnancy loss are presented in the respective tables.

Peak lactation litres (adjusted for body condition score) and clinical mastitis post conception were found to be significant predictors of pregnancy loss. Inclusion of the quadratic term improved fit of the peak lactation litres model such that (grazing) cows producing less than or more than 30 litres per day at peak lactation had higher rates of pregnancy loss than cows peaking at 30 litres with the risk increasing the further peak production was from 30 litres. The effect of litres was explored further to better define the associations and inter-relationship with other variables. Inclusion of milk protein percentage at peak lactation did not improve model fit and there was no interaction between peak milk litres and farm. The effect of litres was independent of breed. The peak lactation litres model captured the association between production and pregnancy loss better than a competing total solids model. The correlation between litres and total solids was observed to decrease at increasing litres increased suggesting that two measures of production (litres and total solids) are not equivalent. Survival curves for cows peaking at 20, 30 and 40 litres of milk per day are presented in Figure 2.

Cows experiencing clinical mastitis after conception also had an increased rate of pregnancy loss compared to cows not affected by clinical mastitis after conception. Clinical mastitis provided a 2.77 increase in the odds of pregnancy loss. In practical terms, if cows free from clinical mastitis between 30–100 days of gestation experience an incidence of pregnancy loss of 5%, the equivalent rate in cows experiencing clinical mastitis is 12.7%. Survival curves for cows free from clinical mastitis and for cows experiencing clinical mastitis after conception are presented in Figure 3.

No effect of breed, age body condition score at the start of mating, calving to conception interval, FTAI pregnancy, peak lactation milk protein percentage of ABV for daughter fertility on risk of pregnancy loss was observed.

Discussion

A New Zealand dairy study identified a 2.8% of pregnancy to be lost between days 28–100 of mating (McDougall et al., 2005). This is less than half the rate that we observed in our study (7.8%) from across a similar observation period and suggests that the rate of pregnancy loss may have increased over the intervening 10 year period. The New Zealand study also identified clinical mastitis to be a significant risk for pregnancy loss (hazard ratio: 1.57). However, in contrast to our findings, they also found being treated for anestrous and a calving-to-conception interval of less than 63 days were also significant risk factors for pregnancy loss. An Irish study found a similar embryonic loss rate to the current study in cows (7.2%) and heifers (6.1%) (Silke et al., 2002). In contrast to our findings, this study found no association between milk production or milk composition and embryonic loss rate.

We identified a strong quadratic relationship between milk production and pregnancy loss. Grazing cows producing less than or more than 30 litres at peak lactation were of increasing risk of losing their pregnancy the further their peak was from 30 litres. The relationship between time of peak milk production, cow negative energy balance and the time of pregnancy loss was not able to be determined due to interval censoring. Therefore we are unable to confirm if negative energy balance at or around peak lactation, genetic potential for high milk production or the combination of the two is the driver of pregnancy loss risk. The observed trend of an increased risk of loss in cows with a milk fat composition at peak lactation greater than 4.10% suggests that negative energy balance may be a risk factor as fat

Figure 2 Interval-censored survival curves for cows peaking at 20, 30 and 40 litres. Interval censoring indicated by solid boxed regions of the curves

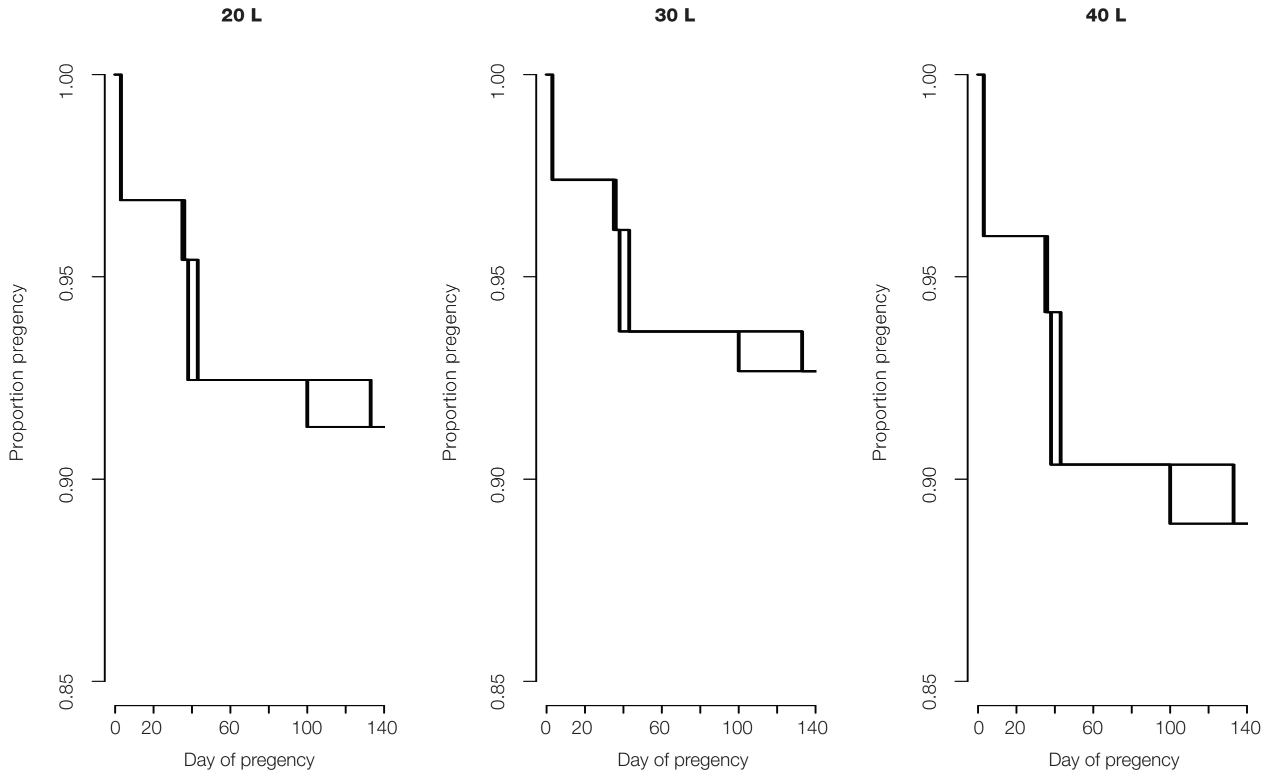
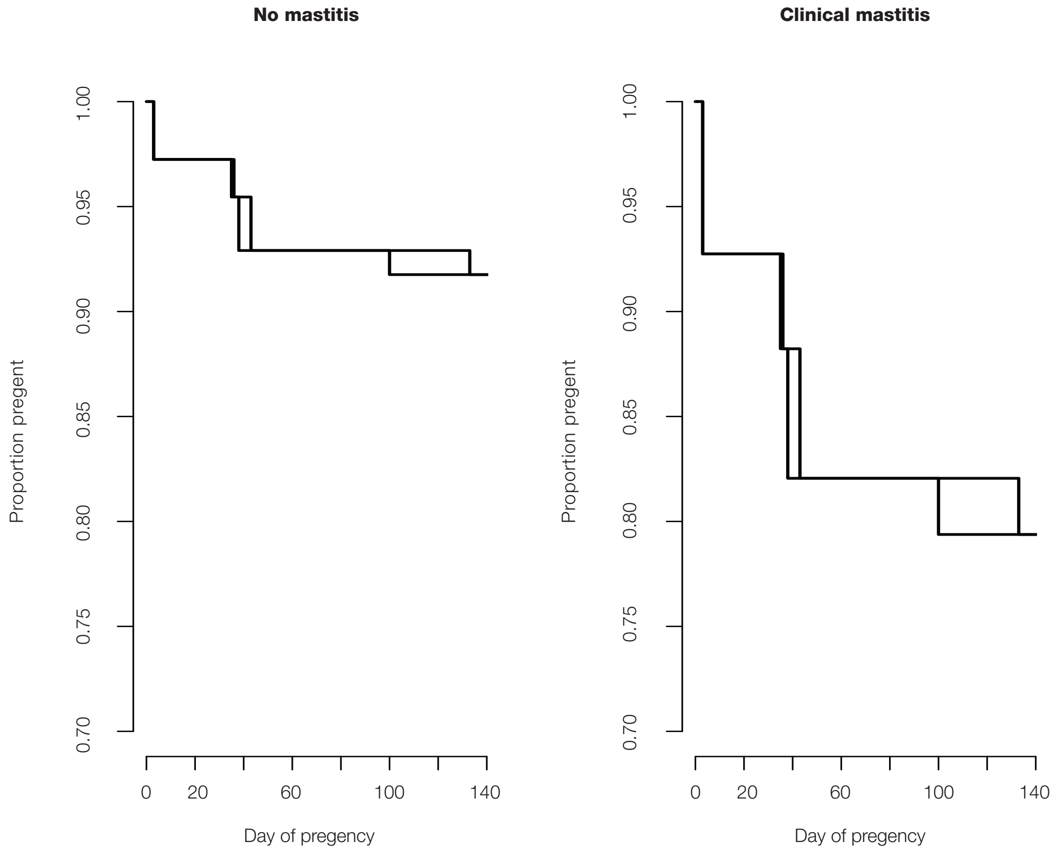


Figure 3 Interval-censored survival curves for cows free from clinical mastitis and cows experiencing clinical mastitis post conception. Interval censoring indicated by solid boxed regions of the curves



test tends to increase in cows that are mobilising excessive body fat in response to inadequate energy intake. It is possible to state that cows with capacity to peak above 30 litres on pasture are less able to retain pregnancy under current management practices. The observed associations between milk yield and milk contents and foetal survival (and fertility) imply that some metabolic process is impacting foetal survival beyond day 35 of pregnancy.

Conclusions

An average of 7.8% of pregnancies in Australian grazing dairy cattle identified at early pregnancy testing are lost before day 140. These cows are significant risk of being non-pregnant at the end of the mating period. Identification and implementation of improvements to the management of high-producing dairy cows on pasture is required to reduce rates of pregnancy loss. Selection of cows that peak at or around 30 litres whilst grazing pasture and control of clinical mastitis during and after mating is also recommended to minimise loss of pregnancies after early pregnancy testing.

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Table 2 Hazard ratios and 95% confidence intervals for the total effects of continuous explanatory variables from separate interval-censored Cox proportional hazards models

Potential risk factor	Pregnancy loss		No pregnancy loss		Hazard ratio[2]	95% CI	P
	No. cows[1]	Mean (SD)	No. cows[1]	Mean (SD)			
Australian Breeding Value for daughter fertility (Friesian cows only)	41	103.0 (2.53)	316	102.5 (2.63)	1.07	0.88-1.30	0.52[3]
					[Adjusted for cow age and herd]		
Age at calving (years)	46	6.0 (2.9)	578	5.7 (2.5)	Linear: 1.04	0.95-1.13	0.73[4]
					Quadratic: 1.00	0.95-1.05	0.98[5]
					[Adjusted for herd]		
Cow body condition score on day 1 of mating period	81	4.7 (0.22)	937	4.7 (0.20)	Linear: 1.05	0.30-3.64	0.77[4]
					Quadratic: 0.41	0.02-10.17	0.78[5]
					[Adjusted for cow age and herd][6]		
Peak daily milk litres per cow	90	30.8 (8.41)	1,057	29.9 (6.51)	Linear: 1.01	0.98-1.05	0.005[4]
					Quadratic: 1.00	1.00-1.01	0.007[5]
					[Adjusted for cow age, body condition score and herd]		
Milk protein concentration at peak production (gm/100 mL milk)	89	3.20 (0.30)	1,057	3.24 (0.30)	Linear: 0.94	0.36-2.47	0.98[4]
					Quadratic: 1.11	0.27-4.49	0.89[5]
					[Adjusted for cow age, body condition score and herd]7		
Milk fat concentration at peak production (gm/100 mL milk)	89	4.07 (0.63)	1,057	4.11 (0.54)	Linear: 0.82	0.56-1.20	0.07[4]
					Quadratic: 1.66	1.13-2.42	0.03[5]
					[Adjusted for cow age, body condition score and herd][7]		

[1] Number of cows used in model to estimate total effect of variable

[2] Estimated total effect for a 1 unit increase in potential risk factor; adjusted for covariates as listed

[3] Likelihood ratio test p-value

[4] Likelihood ratio test p-value for linear and quadratic terms jointly

[5] Likelihood ratio test p-value for quadratic term only

[6] Breed and Australian Breeding Value for daughter fertility were also identified from the causal diagram as potential confounders but the effect of body condition score was estimated without adjustment for these as Australian Breeding Values were not comparable between breeds and data were not available for either variable for many cows

[7] Breed was also identified from the causal diagram as a potential confounder but effects reported here were not adjusted for breed because data were not available for many cows

Table 3 Hazard ratio and 95% confidence interval for the total effects of categorical explanatory variables from separate interval-censored Cox proportional hazards models

Potential risk factor	No. cows[1]	No. cows with pregnancy loss	% cows with pregnancy loss	Hazard ratio[2]	95% CI	P[3]
Breed						
Purebreed (Friesian/Jersey)	365	41	9.0	Reference category		
Crossbreed	155	14	11.2	0.75	0.39-1.44	0.37
				[Adjusted for herd]		
Conception was to fixed time AI						
No	774	57	7.4	Reference category		
Yes	375	33	8.8	1.13	0.64-1.99	0.39
				[Adjusted for body condition score and herd][4]		
Calving to conception interval (days)						
1-60	80	8	10.0	Reference category		
61-120	575	40	7.0	0.76	0.24-2.44	0.58
>120	493	42	8.6	0.96	0.30-3.10	
				[Adjusted for cow age, body condition score and herd][4]		
Clinical mastitis[5]						
No	1,106	83	7.5	Reference category		
Yes	43	7	16.3	2.70	1.06-6.92	0.03
				[Adjusted for cow age and herd]		

[1] Numbers of cows used in model to estimate total effect of variable

[2] Estimated total effect; adjusted for covariates as listed

[3] Likelihood ratio test p-value (joint likelihood ratio test p-value for calving to conception interval)

[4] Breed and Australian Breeding Value for daughter fertility were also identified from the causal diagram as a potential confounder but the effect of conception was to fixed time AI and calving to conception interval were estimated without adjustment for these as Australian Breeding Values were not comparable between breeds and data were not available for either variable for many cows

[5] One or more cases of clinical mastitis ('yes') or none ('no') between the cow's first positive pregnancy diagnosis and its final pregnancy test or, for cows losing their pregnancy, to the first pregnancy test where the pregnancy loss was identified

Crossbreeding in Australia – what have we learnt?

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Background

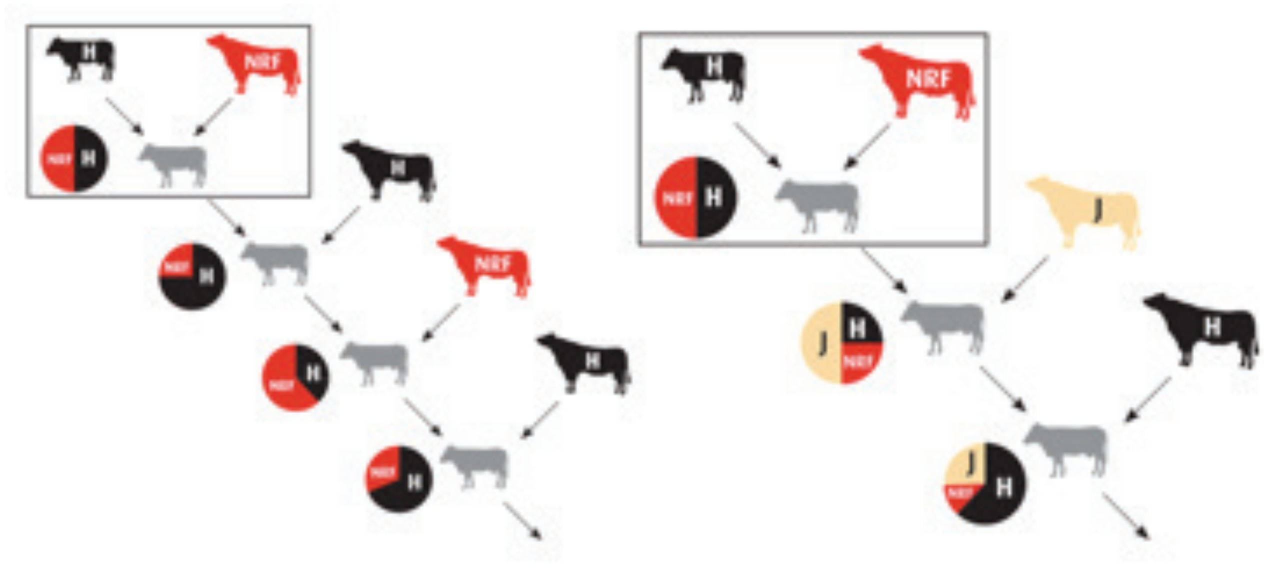
The use of crossbreeding has been suggested as a short-term solution for the decline in fertility in Australian dairy herds, which has been particularly evident in the Holstein Friesian (HF) breed in seasonal calving systems (Woolaston and Shephard, 2011). However, a 2006 survey of 255 Victorian and Tasmanian dairy farmers found that despite many respondents believing that crossbreeding could lead to potential gains in farm production, management, herd profitability and conception rates, very few intended increasing the proportion of crossbreds in their herds in the future (Pyman 2007). One of the main reasons given by these farmers was confusion over what step to take after breeding the first cross. This uncertainty led some farmers to revert back to the use of HF semen with mature HF cows. In fact a major conclusion from the study was that farmers needed more guidance on the management of a crossbreeding program. The review by Wollaston and Shephard (2011) reinforced this view by suggesting that "effective, clear and consistent extension material is needed to allow farmers to assess the benefits and implications of crossbreeding programs within their herds".

In 2015, Dairy Australia funded a two year research project which involved an analysis of the proportion of farmers utilising crossbreeding, including those employing a 3-breed rotational strategy. Additionally, Australian Dairy Herd Improvement Scheme (ADHIS[1]) data on production, cell count, reproduction and survival were used to answer the fundamental questions "where should we go after the first cross?" and "does a backcross or a 3-breed strategy perform better?" A survey of farmers' attitudes towards crossbreeding and an economic model was produced to compare the performance of a purebred herd with a 2-breed or 3-breed crossbreeding herd.

Are farmers utilising crossbreeding?

The breed structures in the Australian dairy industry were historically reported only by numbers of purebred cows or 2-breed (HF and Jersey(J)) crossbreed cows (DataGene, 2016). While these reports have shown a decrease in the use of HF/J cross animals over time (from 24,882 cows in 2008 to 21,964 cows in 2016), reports from reproductive advisers in the industry (S. Snowden; L. Bidevaate pers comm) suggest that an increasing number of farmers are employing crossbreeding, but many of these are now using a systematic 3-breed rotation (as depicted in Fig 1.), rather than 2-breeds (with alternate backcrossing to the parent breeds).

Figure 1 Example of two crossbreeding strategies – a 2-breed Holstein (H) x Norwegian Red (NRF) rotational cross on the left, and a 3-breed Holstein (H) x Norwegian Red (NRF) x Jersey (J) rotational cross on the right. Circles represent the breed makeup of each generation (Source: genoglobal.com/Start/why-crossbreeding/crossbreeding-programs2/3-plus/)



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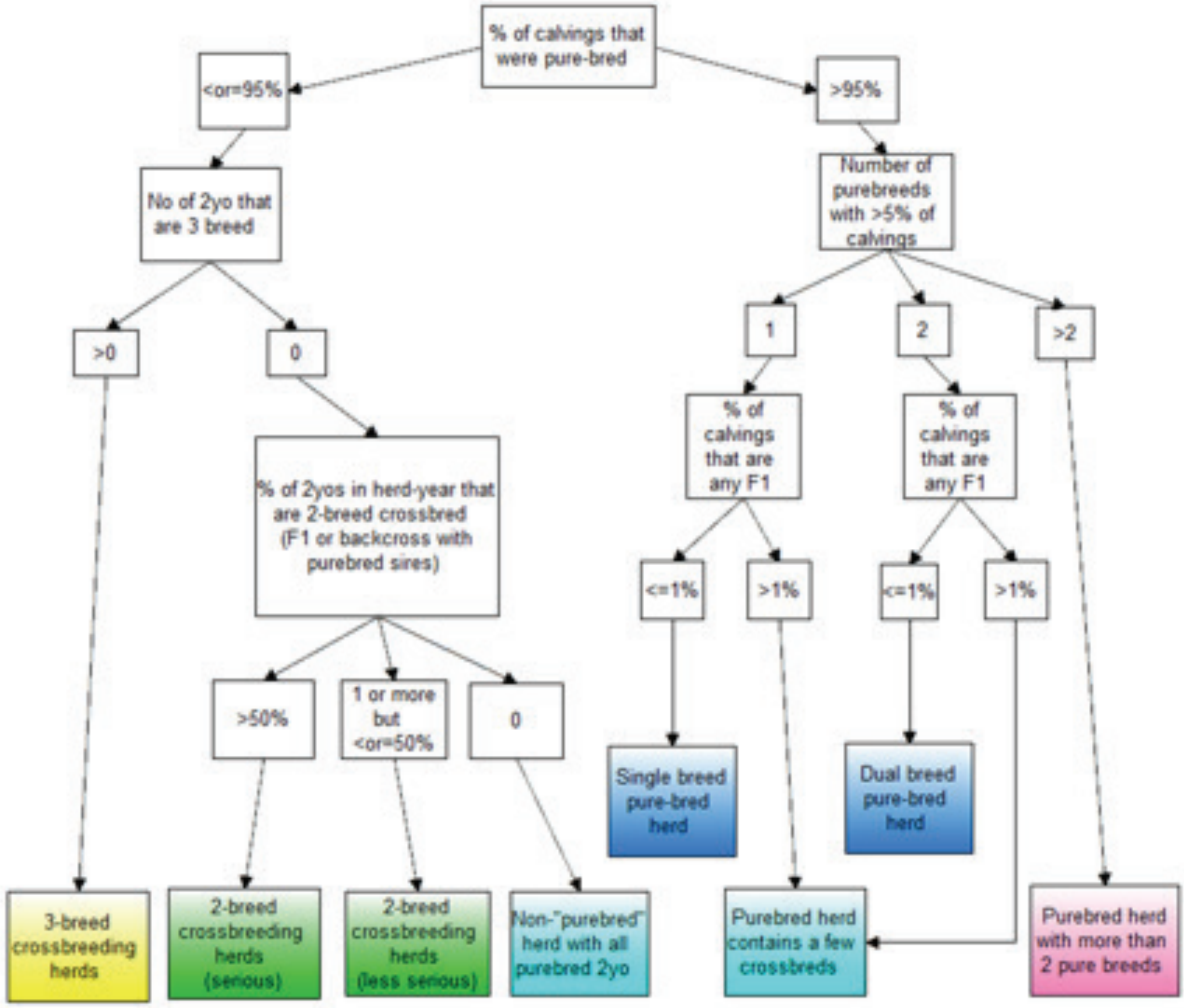
[1] ADHIS was restructured in 2016 is now part of DataGene

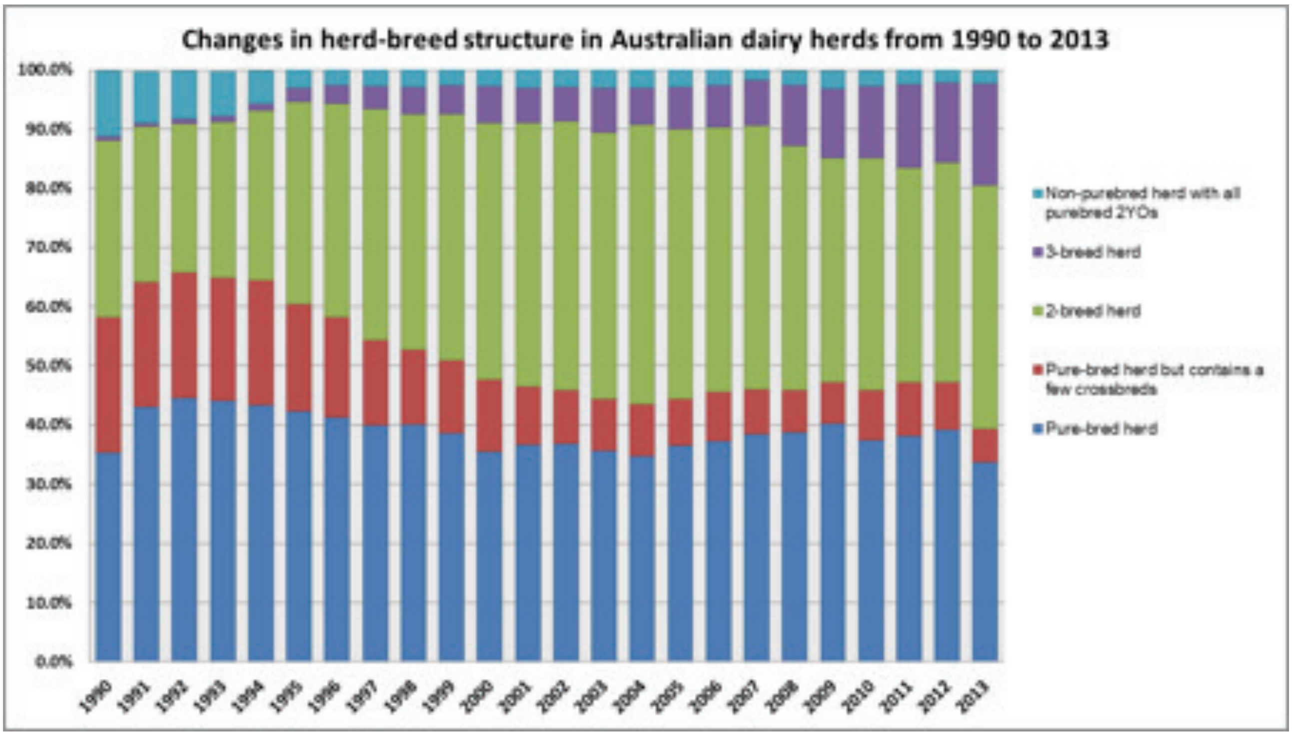
It was important to firstly establish how many farmers in Australia were employing crossbreeding, and of these, how many were choosing to use a 2-breed versus a 3-breed strategy. Additionally, changes over time in the use of the different strategies needed to be explored. Herd data was extracted from the ADHIS dataset (2001-2013) and herds were classified based on their herd-breed structure as shown in Figure 2.

Figure 2 Herd-breed classification system



The major findings were that across the industry, crossbreeding herds outnumbered purebred herds, and the proportion of crossbreeding herds had increased. Also, the proportion of herds employing a 3-breed strategy had increased over the years. The most common herd-breed structure in Australia between 2000 and 2013 was 2-breed crossbreeding herds (39% for less and more serious combined), with the most common breed combinations being the HF/J cross. The next most common type of herd was the purebred herd (35% for single and dual combined); with the most common breed being the HF. Over the period of time studied, the proportion of purebred herds decreased, while the proportion of crossbreeding herds (particularly 3-breed herds) increased. These trends varied with region and with calving system, but the findings indicate that more dairy farmers in Australia have begun to employ systematic crossbreeding strategies (Figure 3).

Figure 3 Changes in herd-breed structure in Australian dairy herds from 1990-2013



Evaluation of the performance, longevity and fertility of crossbred cows

The analysis of crossbred cows' performance in this study was a world first. While previous comparisons between purebred and crossbred cows have been made in various systems around the world, the F2 animal has not been widely studied, and in particular the comparison between a backcross (to one of the F1 parent breeds) with a 3-breed cross. Genetic theory predicts that more heterosis will be preserved with the addition of a third breed to the program but, (particularly in Australia) the gene pool for that third breed may be limited. The implication is that the F2 3-breed cross animal may not perform as well as a backcross that with a sire of good genetic merit.

The study evaluated all the data from the herd-breed classification study, along with NATSCAN[2] reproductive data. Where numbers of cows and lactations were available, comparisons were first made for milk production (and components), longevity, reproductive indices and cell count. The first part of the study made comparisons for these parameters between the F1 cross and the respective purebred parent breeds. The second section of the study made the comparisons at the F2 level between backcross and 3-breed combinations. For both sections, the comparisons were analysed from the actual values, and also with adjustment for sire and maternal grandsire ABV, allowing an evaluation of the potential of the particular cross, were the ABVs optimal.

The results for the F1 comparisons focused mainly on the most common F1 combinations; namely the J-HF cross cows and their performance compared with the parent purebred animals (however comparisons were made for all F1 animals who satisfied the section criteria). The results for production comparisons for the Jersey-HF cross cows are in Table 1.

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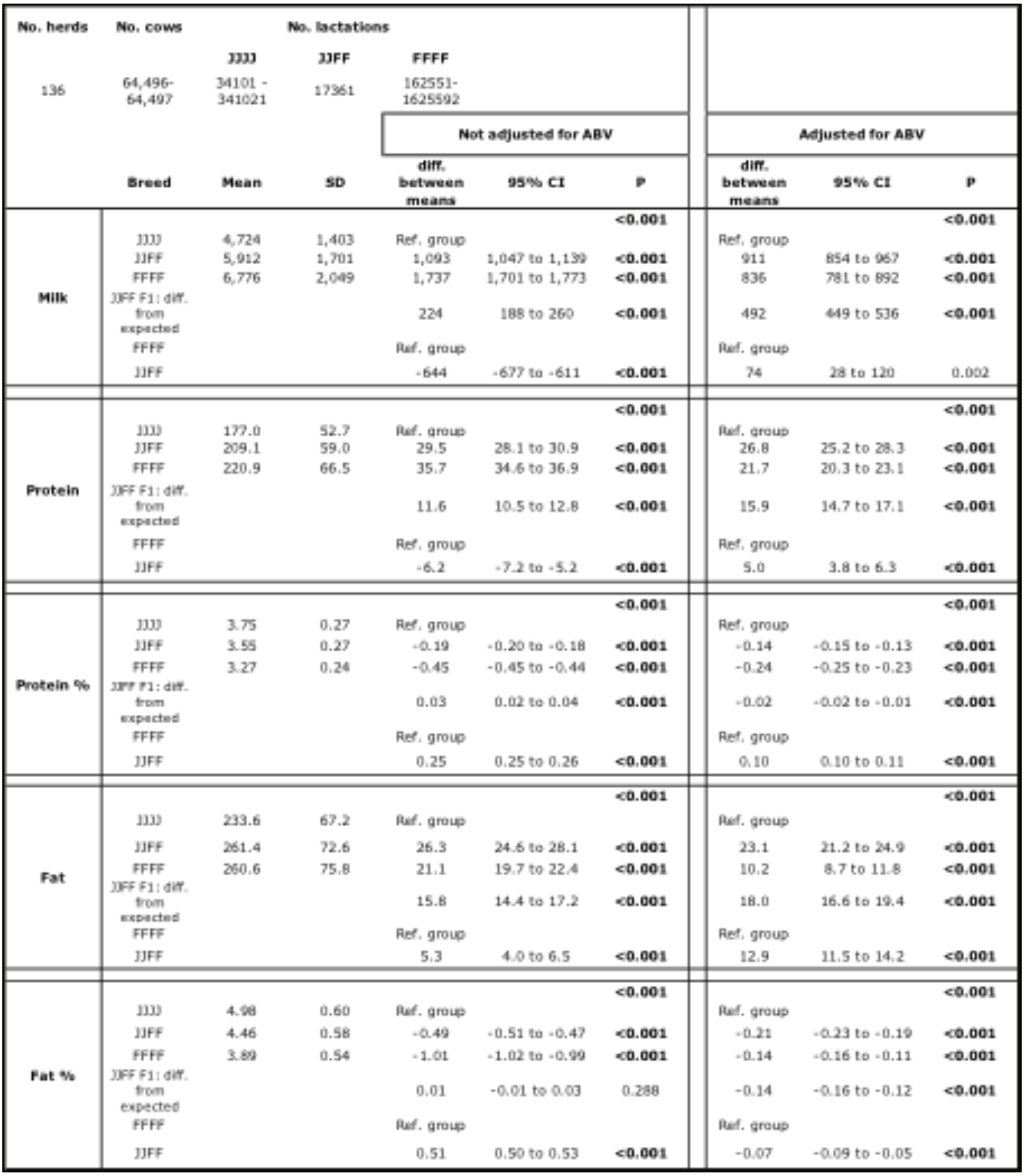
[2] NATSCAN is the national fertility monitoring project where reproductive performance of herds on the national database providing sufficiently complete data to generate a Fertility Focus Report is monitored to identify national averages and trends

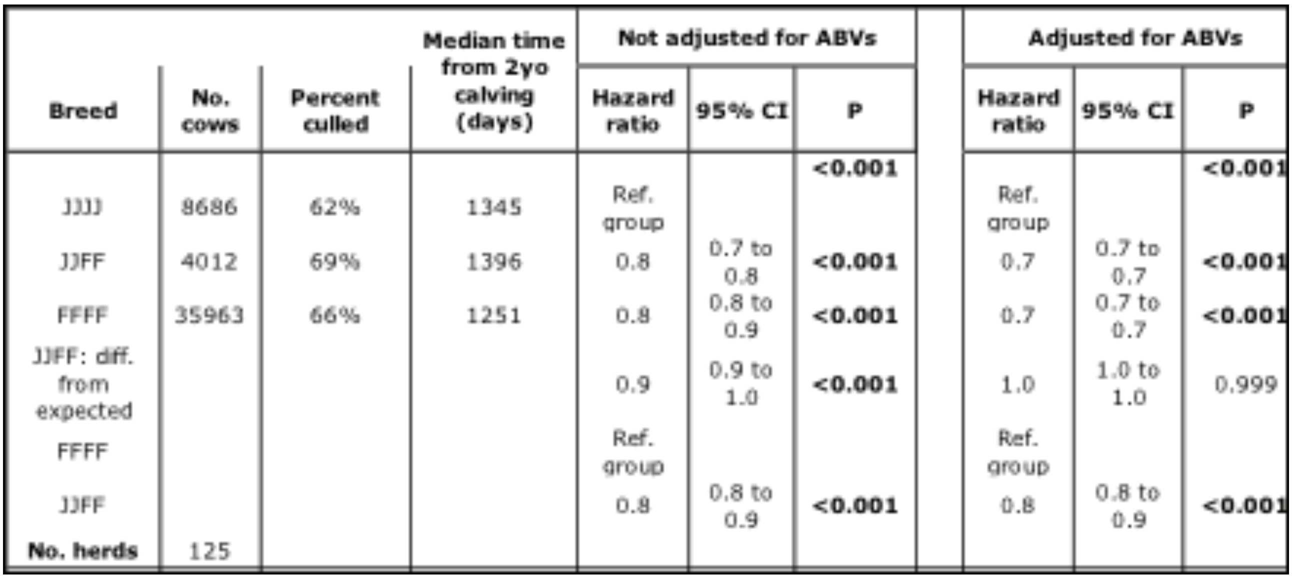
Table 1 Production comparisons between JJFF crossbred cows and their parent breeds



No. herds	**No. cows**	**No. lactations**							
		JJJJ	**JJFF**	**FFFF**					
136	64,496- 64,497	34101 - 341021	17361	162551- 1625592					
				Not adjusted for ABV			**Adjusted for ABV**		
	Breed	**Mean**	**SD**	**diff. between means**	**95% CI**	**P**	**diff. between means**	**95% CI**	**P**
Milk						**<0.001**			**<0.001**
	JJJJ	4,724	1,403	Ref. group			Ref. group		
	JJFF	5,912	1,701	1,093	1,047 to 1,139	**<0.001**	911	854 to 967	**<0.001**
	FFFF	6,776	2,049	1,737	1,701 to 1,773	**<0.001**	836	781 to 892	**<0.001**
	JJFF F1: diff. from expected			224	188 to 260	**<0.001**	492	449 to 536	**<0.001**
	FFFF			Ref. group			Ref. group		
	JJFF			-644	-677 to -611	**<0.001**	74	28 to 120	0.002
Protein						**<0.001**			**<0.001**
	JJJJ	177.0	52.7	Ref. group			Ref. group		
	JJFF	209.1	59.0	29.5	28.1 to 30.9	**<0.001**	26.8	25.2 to 28.3	**<0.001**
	FFFF	220.9	66.5	35.7	34.6 to 36.9	**<0.001**	21.7	20.3 to 23.1	**<0.001**
	JJFF F1: diff. from expected			11.6	10.5 to 12.8	**<0.001**	15.9	14.7 to 17.1	**<0.001**
	FFFF			Ref. group			Ref. group		
	JJFF			-6.2	-7.2 to -5.2	**<0.001**	5.0	3.8 to 6.3	**<0.001**
Protein %						**<0.001**			**<0.001**
	JJJJ	3.75	0.27	Ref. group			Ref. group		
	JJFF	3.55	0.27	-0.19	-0.20 to -0.18	**<0.001**	-0.14	-0.15 to -0.13	**<0.001**
	FFFF	3.27	0.24	-0.45	-0.45 to -0.44	**<0.001**	-0.24	-0.25 to -0.23	**<0.001**
	JJFF F1: diff. from expected			0.03	0.02 to 0.04	**<0.001**	-0.02	-0.02 to -0.01	**<0.001**
	FFFF			Ref. group			Ref. group		
	JJFF			0.25	0.25 to 0.26	**<0.001**	0.10	0.10 to 0.11	**<0.001**
Fat						**<0.001**			**<0.001**
	JJJJ	233.6	67.2	Ref. group			Ref. group		
	JJFF	261.4	72.6	26.3	24.6 to 28.1	**<0.001**	23.1	21.2 to 24.9	**<0.001**
	FFFF	260.6	75.8	21.1	19.7 to 22.4	**<0.001**	10.2	8.7 to 11.8	**<0.001**
	JJFF F1: diff. from expected			15.8	14.4 to 17.2	**<0.001**	18.0	16.6 to 19.4	**<0.001**
	FFFF			Ref. group			Ref. group		
	JJFF			5.3	4.0 to 6.5	**<0.001**	12.9	11.5 to 14.2	**<0.001**
Fat %						**<0.001**			**<0.001**
	JJJJ	4.98	0.60	Ref. group			Ref. group		
	JJFF	4.46	0.58	-0.49	-0.51 to -0.47	**<0.001**	-0.21	-0.23 to -0.19	**<0.001**
	FFFF	3.89	0.54	-1.01	-1.02 to -0.99	**<0.001**	-0.14	-0.16 to -0.11	**<0.001**
	JJFF F1: diff. from expected			0.01	-0.01 to 0.03	0.288	-0.14	-0.16 to -0.12	**<0.001**
	FFFF			Ref. group			Ref. group		
	JJFF			0.51	0.50 to 0.53	**<0.001**	-0.07	-0.09 to -0.05	**<0.001**

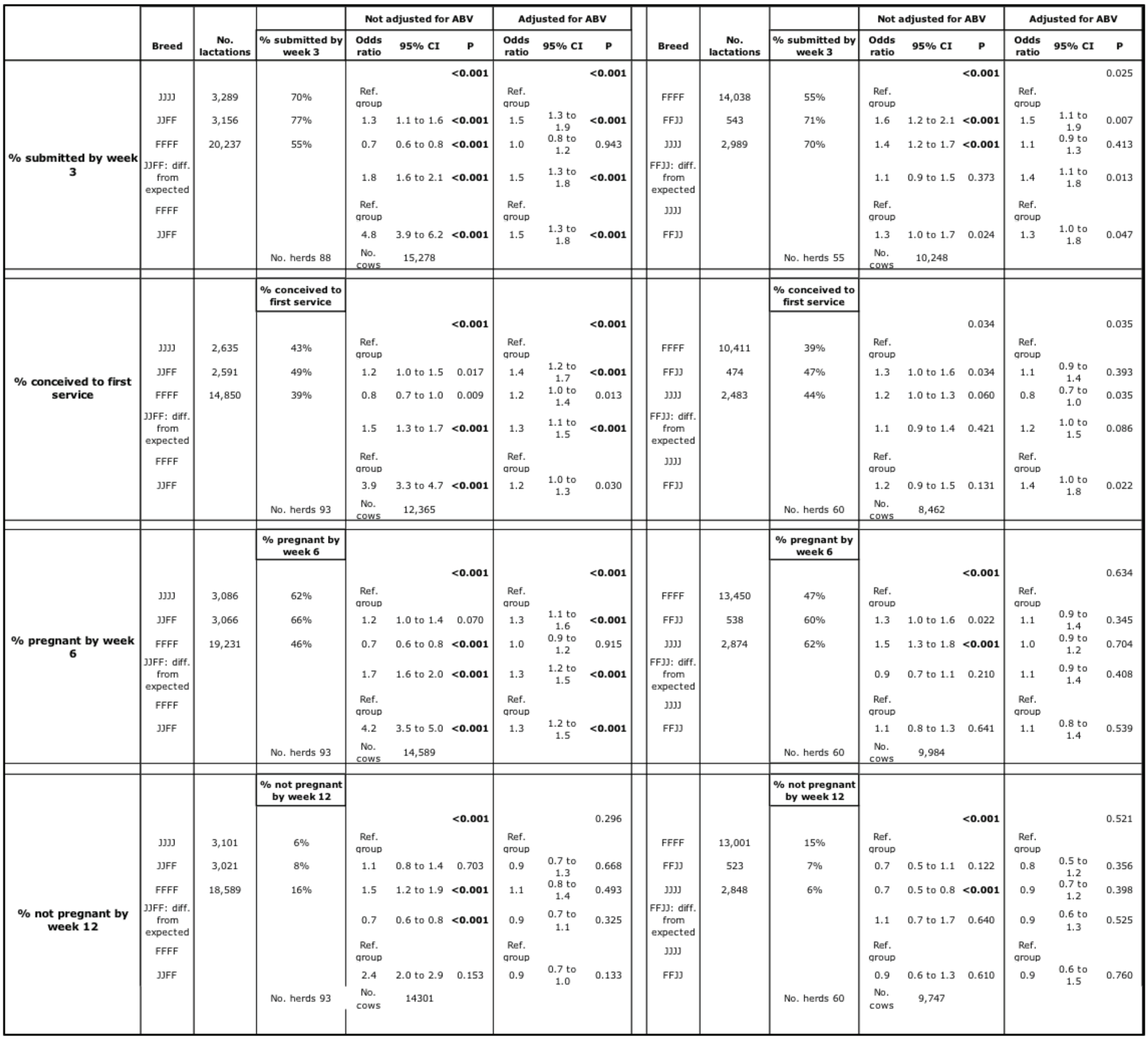
For production, the purebred HF cows produced more milk and protein than the crossbred animals, but the crossbreds produced more fat and had higher milk composition (protein % and fat %) than HF cows. The Jersey-HF crossbred animals also had significantly longer survival than their parent breeds (Table 2), and were better than their parent breeds for some of the reproductive parameters (Table 3). There were no significant differences between the Jersey-HF crosses and their parent breeds in somatic cell counts. Although not shown here, the comparisons between the alternate F1 cross (namely HF-Jersey) and the parent breeds were similar.

Table 2 Survival comparisons between JJFF/FFJJ crossbred cows and their parent breeds



				Not adjusted for ABVs			Adjusted for ABVs		
Breed	**No. cows**	**Percent culled**	**Median time from 2yo calving (days)**	**Hazard ratio**	**95% CI**	**P**	**Hazard ratio**	**95% CI**	**P**
						<0.001			**<0.001**
JJJJ	8686	62%	1345	Ref. group			Ref. group		
JJFF	4012	69%	1396	0.8	0.7 to 0.8	**<0.001**	0.7	0.7 to 0.7	**<0.001**
FFFF	35963	66%	1251	0.8	0.8 to 0.9	**<0.001**	0.7	0.7 to 0.7	**<0.001**
JJFF: diff. from expected				0.9	0.9 to 1.0	**<0.001**	1.0	1.0 to 1.0	0.999
FFFF				Ref. group			Ref. group		
JJFF				0.8	0.8 to 0.9	**<0.001**	0.8	0.8 to 0.9	**<0.001**
No. herds	125								

Table 3 Reproduction comparisons for JJFF and FFJJ F1 cows compared with their parent breeds

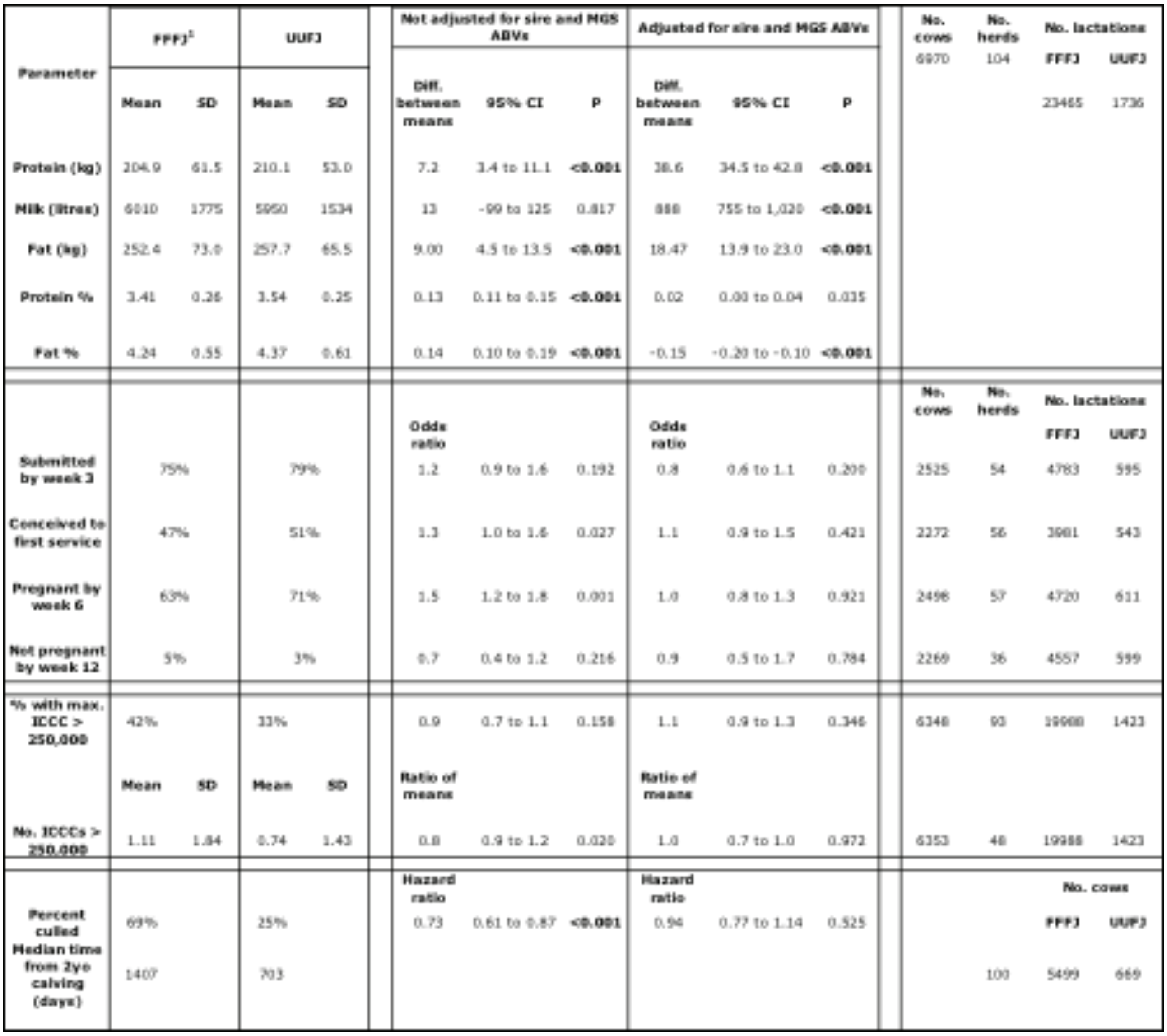


				Not adjusted for ABV			Adjusted for ABV		
	Breed	**No. lactations**	**% submitted by week 3**	**Odds ratio**	**95% CI**	**P**	**Odds ratio**	**95% CI**	**P**
% submitted by week 3						**<0.001**			**<0.001**
	JJJJ	3,289	70%	Ref. group			Ref. group		
	JJFF	3,156	77%	1.3	1.1 to 1.6	**<0.001**	1.5	1.3 to 1.9	**<0.001**
	FFFF	20,237	55%	0.7	0.6 to 0.8	**<0.001**	1.0	0.8 to 1.2	0.943
	JJFF: diff. from expected			1.8	1.6 to 2.1	**<0.001**	1.5	1.3 to 1.8	**<0.001**
	FFFF			Ref. group			Ref. group		
	JJFF			4.8	3.9 to 6.2	**<0.001**	1.5	1.3 to 1.8	**<0.001**
			No. herds 88	No. cows	15,278				
			% conceived to first service						
% conceived to first service						**<0.001**			**<0.001**
	JJJJ	2,635	43%	Ref. group			Ref. group		
	JJFF	2,591	49%	1.2	1.0 to 1.5	0.017	1.4	1.2 to 1.7	**<0.001**
	FFFF	14,850	39%	0.8	0.7 to 1.0	0.009	1.2	1.0 to 1.4	0.013
	JJFF: diff. from expected			1.5	1.3 to 1.7	**<0.001**	1.3	1.1 to 1.5	**<0.001**
	FFFF			Ref. group			Ref. group		
	JJFF			3.9	3.3 to 4.7	**<0.001**	1.2	1.0 to 1.3	0.030
			No. herds 93	No. cows	12,365				
			% pregnant by week 6						
% pregnant by week 6						**<0.001**			**<0.001**
	JJJJ	3,086	62%	Ref. group			Ref. group		
	JJFF	3,066	66%	1.2	1.0 to 1.4	0.070	1.3	1.1 to 1.6	**<0.001**
	FFFF	19,231	46%	0.7	0.6 to 0.8	**<0.001**	1.0	0.9 to 1.2	0.915
	JJFF: diff. from expected			1.7	1.6 to 2.0	**<0.001**	1.3	1.2 to 1.5	**<0.001**
	FFFF			Ref. group			Ref. group		
	JJFF			4.2	3.5 to 5.0	**<0.001**	1.3	1.2 to 1.5	**<0.001**
			No. herds 93	No. cows	14,589				
			% not pregnant by week 12						
% not pregnant by week 12						**<0.001**			0.296
	JJJJ	3,101	6%	Ref. group			Ref. group		
	JJFF	3,021	8%	1.1	0.8 to 1.4	0.703	0.9	0.7 to 1.3	0.668
	FFFF	18,589	16%	1.5	1.2 to 1.9	**<0.001**	1.1	0.8 to 1.4	0.493
	JJFF: diff. from expected			0.7	0.6 to 0.8	**<0.001**	0.9	0.7 to 1.1	0.325
	FFFF			Ref. group			Ref. group		
	JJFF			2.4	2.0 to 2.9	0.153	0.9	0.7 to 1.0	0.133
			No. herds 93	No. cows	14301				

				Not adjusted for ABV			Adjusted for ABV		
	Breed	**No. lactations**	**% submitted by week 3**	**Odds ratio**	**95% CI**	**P**	**Odds ratio**	**95% CI**	**P**
% submitted by week 3						**<0.001**			0.025
	FFFF	14,038	55%	Ref. group			Ref. group		
	FFJJ	543	71%	1.6	1.2 to 2.1	**<0.001**	1.5	1.1 to 1.9	0.007
	JJJJ	2,989	70%	1.4	1.2 to 1.7	**<0.001**	1.1	0.9 to 1.3	0.413
	FFJJ: diff. from expected			1.1	0.9 to 1.5	0.373	1.4	1.1 to 1.8	0.013
	JJJJ			Ref. group			Ref. group		
	FFJJ			1.3	1.0 to 1.7	0.024	1.3	1.0 to 1.8	0.047
			No. herds 55	No. cows	10,248				
			% conceived to first service						
% conceived to first service						0.034			0.035
	FFFF	10,411	39%	Ref. group			Ref. group		
	FFJJ	474	47%	1.3	1.0 to 1.6	0.034	1.1	0.9 to 1.4	0.393
	JJJJ	2,483	44%	1.2	1.0 to 1.3	0.060	0.8	0.7 to 1.0	0.035
	FFJJ: diff. from expected			1.1	0.9 to 1.4	0.421	1.2	1.0 to 1.5	0.086
	JJJJ			Ref. group			Ref. group		
	FFJJ			1.2	0.9 to 1.5	0.131	1.4	1.0 to 1.8	0.022
			No. herds 60	No. cows	8,462				
			% pregnant by week 6						
% pregnant by week 6						**<0.001**			0.634
	FFFF	13,450	47%	Ref. group			Ref. group		
	FFJJ	538	60%	1.3	1.0 to 1.6	0.022	1.1	0.9 to 1.4	0.345
	JJJJ	2,874	62%	1.5	1.3 to 1.8	**<0.001**	1.0	0.9 to 1.2	0.704
	FFJJ: diff. from expected			0.9	0.7 to 1.1	0.210	1.1	0.9 to 1.4	0.408
	JJJJ			Ref. group			Ref. group		
	FFJJ			1.1	0.8 to 1.3	0.641	1.1	0.8 to 1.4	0.539
			No. herds 60	No. cows	9,984				
			% not pregnant by week 12						
% not pregnant by week 12						**<0.001**			0.521
	FFFF	13,001	15%	Ref. group			Ref. group		
	FFJJ	523	7%	0.7	0.5 to 1.1	0.122	0.8	0.5 to 1.2	0.356
	JJJJ	2,848	6%	0.7	0.5 to 0.8	**<0.001**	0.9	0.7 to 1.2	0.398
	FFJJ: diff. from expected			1.1	0.7 to 1.7	0.640	0.9	0.6 to 1.3	0.525
	JJJJ			Ref. group			Ref. group		
	FFJJ			0.9	0.6 to 1.3	0.610	0.9	0.6 to 1.5	0.760
			No. herds 60	No. cows	9,747				

The results for the F2 comparisons varied, depending on the breeds used in the 3-breed cross, but for the most common 3-breed cross, the Australian Red (U) x J-HF, the results were conclusive (Table 4). For this cross, 3-breed cows performed significantly better than both the backcross cows (HF x J-HF or J x J-HF) for most of the parameters examined.

Table 4 Comparisons for HF/HF-J backcross versus U/HF-J 3-breed cross for all parameters



Parameter	FFFJ[1]		UUFJ		Not adjusted for sire and MGS ABVs			Adjusted for sire and MGS ABVs			No. cows	No. herds	No. lactations	
											6970	104	FFFJ	UUFJ
	Mean	SD	Mean	SD	Diff. between means	95% CI	P	Diff. between means	95% CI	P			23465	1736
Protein (kg)	204.9	61.5	210.1	53.0	7.2	3.4 to 11.1	**<0.001**	38.6	34.5 to 42.8	**<0.001**				
Milk (litres)	6010	1775	5950	1534	13	-99 to 125	0.817	888	755 to 1,020	**<0.001**				
Fat (kg)	252.4	73.0	257.7	65.5	9.00	4.5 to 13.5	**<0.001**	18.47	13.9 to 23.0	**<0.001**				
Protein %	3.41	0.26	3.54	0.25	0.13	0.11 to 0.15	**<0.001**	0.02	0.00 to 0.04	0.035				
Fat %	4.24	0.55	4.37	0.61	0.14	0.10 to 0.19	**<0.001**	-0.15	-0.20 to -0.10	**<0.001**				
											No. cows	No. herds	No. lactations	
					Odds ratio			Odds ratio					FFFJ	UUFJ
Submitted by week 3	75%		79%		1.2	0.9 to 1.6	0.192	0.8	0.6 to 1.1	0.200	2525	54	4783	595
Conceived to first service	47%		51%		1.3	1.0 to 1.6	0.027	1.1	0.9 to 1.5	0.421	2272	56	3981	543
Pregnant by week 6	63%		71%		1.5	1.2 to 1.8	0.001	1.0	0.8 to 1.3	0.921	2498	57	4720	611
Not pregnant by week 12	5%		3%		0.7	0.4 to 1.2	0.216	0.9	0.5 to 1.7	0.784	2269	36	4557	599
% with max. ICCC > 250,000	42%		33%		0.9	0.7 to 1.1	0.158	1.1	0.9 to 1.3	0.346	6348	93	19988	1423
	Mean	SD	Mean	SD	Ratio of means			Ratio of means						
No. ICCCs > 250,000	1.11	1.84	0.74	1.43	0.8	0.9 to 1.2	0.020	1.0	0.7 to 1.0	0.972	6353	48	19988	1423
					Hazard ratio			Hazard ratio					No. cows	
Percent culled	69%		25%		0.73	0.61 to 0.87	**<0.001**	0.94	0.77 to 1.14	0.525			FFFJ	UUFJ
Median time from 2yo calving (days)	1407		703									100	5499	669

When the order of this 3-breed combination was changed (for example to J x HF-U or HF x J-U) although less results were significant, in most cases the 3-breed cows still outperformed the backcross animals. This indicates that the order of the cross may not matter, which could assist farmers in simplifying their breeding plans.

Survey of farmer attitudes to crossbreeding

A five-page survey was designed to collect qualitative and quantitative data about Australian dairy farmers' beliefs and attitudes about crossbred cows. Qualitative data was collected on farm composition, farmer demographics, previous or intended changes made to herd composition, comparisons between crossbred and purebred cows in terms of health, production and management parameters and interest in learning more about economic comparisons between purebred and crossbred cows. Quantitative data was collected about previous farmer experience with crossbred cows (including advantages and disadvantages of 3-breed and 2-breed crossbred cows), reasoning behind any changes made to herd composition and information that would be useful in order to make an informed decision on whether to change herd composition in relation to the number of crossbred cows.

The survey was distributed to clientele of the University of Melbourne Veterinary residents clinics. It was also sent to vets in Queensland and South Australia. As the response rate from these sources was very low, another strategy was devised: direct promotion to farmers via the AUSDAIRYL online forum. A total number of 94 responses were received, of which 20 (21.3%) were from pure breeding only herds, 9 (9.6%) were crossbreeding only and 65 (69.1%) had a combination of purebred and crossbred cows in their herd. Of the crossbreeding respondents, 75.5% (71 out of 74) employed a 2-breed strategy, and 39.4% (37 out of 74) had 3-breed crossbred cows.

Major differences between crossbreeding and pure breeding farmers were found in terms of demographics and farm management approaches. Pure breeding farmers tended to be older (38.9% were aged 50-59 years), compared with crossbreeding farmers (31.1% were aged 31-39 years). Farm size and herd size were lower for pure breeding farmers and their stocking rates were higher. Dry land farms were most commonly run by pure breeding farmers, whereas irrigated farms were most commonly run by crossbreeding farmers. Interestingly, 40.3% of crossbreeding farmers were very interested in learning more about economic comparisons between purebred and crossbred herds, whereas 44.4% of pure breeding respondents were not interested at all. Of all farmers surveyed, 67% were interested in learning more about economic, production, health and fertility comparisons between CB and purebred cows, as well as having access to reliable information. This is an increase, compared to the earlier survey (Pyman, 2007) which indicated that 58% of respondents were interested in further information.

The results indicated that most farmers believe that crossbred cows are better than purebred cows with regards to value of milk components, calving ease, fertility (getting back into calf) and general health problems. Factors which farmers rendered as disadvantageous when compared to purebred cows include selling value and access to export markets. No difference was believed to exist when considering milk production, temperament, cell count, availability of semen and cow appearance. Opinions were divided about size, lameness, effect on physical aspects of the farm, longevity in the herd and the simplicity of the breeding program.

Overall, the results indicated that the beliefs and attitudes of crossbreeding farmers are better aligned with the evidence in the literature about crossbreeding than those of pure breeding farmers. Crossbreeding farmers are also more interested in learning more about economic, production, reproductive and health comparisons.

Economic model of crossbred cows

The model used in the Improving Herds project to examine the impact of selection strategies on farm profitability was adapted to examine crossbreeding as a strategy. Three scenarios were compared: the persistence of a pure breed herd, crossbreeding to a 2-breed herd and crossbreeding to a 3-breed herd. This whole-farm simulation modelled individual cow's lives and the discrete but stochastic events in their lives. The model was developed in the R language and environment for statistical computing (R). The individual events were modelled as a combination of management rules overlaying previously-described physiological events (such as the probability of conception following service). The model was stochastic such that a random draw from the physiological event curve determined the result of any particular physiological event. Management rules defined the farming system, such as type of calving pattern, start of mating and calving, type of cow and breeding strategy. The physiological relationships, such as the risk of heat by days after calving, peak lactation milk production, risk of death or disease etc. were defined using mathematical equations obtained from industry data. This effectively means that there were no 'black box' relationships in model construction. Herd size was adjusted to meet pasture consumption targets that were in turn derived from the underlying pasture growth curve. Cow feed demand was estimates as a function of milk production and animal size and herd feed demand by collating individual cow feed demand across all cows. The herd was directed to grow (or shrink) by adjusting the duration the seasonal AI period to produce more (or fewer) replacement heifers according to the balance between total annual farm pasture production and total annual herd feed demand. This approach therefore adjusted stocking rate according to individual cow demand (with the stocking rate increasing as cow size and/or milk production decreased). The replacement rate (and therefore the duration of AI) was adjusted according to the desired herd size and the average longevity of cows.

The model accounts for all variable costs in the production cycle such as the cost of mating, herd health, and milking shed operation. Variable feed costs such as pasture, concentrates and conservation are included. All income streams are accounted for. These are milk, livestock sales, changes to the conserved fodder value and changes to herd inventory. The time line for accrual of costs and income are captured through the sequential progression of the model. This allows the future streams of income and costs to be collated and the net profit at each point in time to be estimated. These future income and expenditure streams are discounted using accepted economic principles and conservative discounting rates and the net present value of these discounted income and costs streams used to compare the gross margins of the three competing management scenarios. No interim product in the production cycle is valued; only saleable items and assumed of value. This avoids the need to estimate the final work of an intervention by multiplying the counts of items against their purported value at that time. The model has been designed to compare the short, medium and long term profitability of competing management strategies.

This model provides the most feasible, realistic and integrated representation of breeding program impacts within a modern Australian dairy farm. The model

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[3] ImProving Herds project is a multi-disciplinary, collaborative research, development and extension program to provide better information to dairy farmers from herd-testing data on cow health, survival and profitability thereby supporting better decision making.

is in general suitable for studying impacts of change in management or composition such as exploring competing breeding objectives, changes to cow culling policy, variation in input and output prices and farming efficiency on overall farm profitability.

Overall the findings were that crossbreeding was consistently more profitable than persisting with a purebred herd in the pasture-based seasonally calving production system that predominates in Australia. Gross margins improvements of between 4–8% pe annum is predicted within a ten-yea horizon (Table 5).

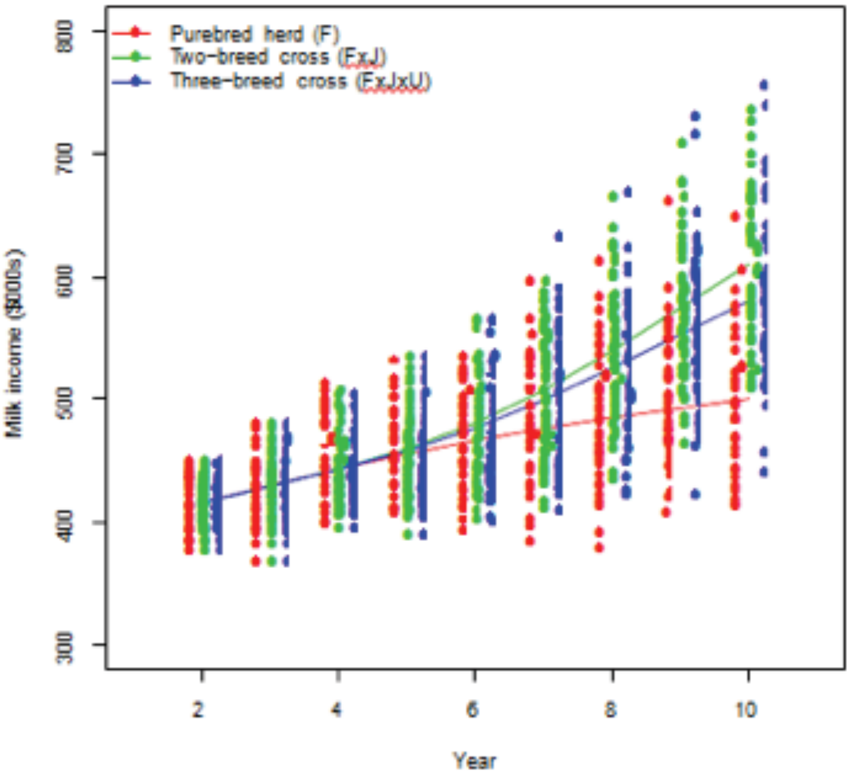
However, crossbreeding needs to be implemented for up to 6 years before differences between the strategies in farm profitability and performance become apparent (Figure 4). This is essentially the time required for the change in breeding strategy to be fully reflected in the milking herd. There is potential for a small reduction in milk production and profitability in the first few years of converting to a crossbreeding strategy. This arises when the bulk of the milking herd remains purebred and when the first few cohorts of crossbred replacements are smaller and less productive.

A key finding is that a crossbreeding strategy requires a concurrent increase in stocking rate. This is essential to ensure that farm pasture consumption is maintained as cow size and cow production decreases with the conversion from purebred to crossbred cows. The crossbreeding strategy resulted in a reduction in cow production per lactation but production per hectare is essentially maintained. This is the key to ensuring total farm milk production and profit is maintained through the transition. However, it should be noted, that the cow reduction in fat production is less than the reduction in protein and litres following the introduction of Jersey genetics.

Table 5 Predicted annual gross margin (discounted), difference from purebred ($ and %) by calving pattern and test scenario

Calving pattern	Test scenario	Net dollars	Difference ($)	Difference (%)
Seasonal	Pure Breed	257,074	0	0.00
Seasonal	Two-Breed Cross	278,152	21,078	7.60
Seasonal	Three-Breed Cross	268,204	11,129	4.10

Figure 4 Annual milk income distribution and trend by test scenario



Improved herd reproductive performance is the major driver of improved profitability. This operates via greater cow longevity providing for reduced annual herd depreciation costs. Cows live and produce for longer and fewer replacements need to be reared each year and these savings directly convert into extra profit. Enhancing reproductive performance is the primary way that crossbreeding improves farm profit in pasture-based dairying. Farms with inadequate reproductive performance can benefit from using sires within breeds that are above average for fertility (and are more fertile than the average cow in the herd). Using crossbreeding can further accelerate the rate of reproductive performance gain. Improved reproductive performance leads to longer cow survival. This not only allows for shorter and less expensive AI mating periods and lower replacement rearing costs but allows provides for an improved (more productive) milking herd age structure. More cows survive to their peak lactations between 5-7 years of age.

Supplementary feeding provides a gearing opportunity for well-managed crossbred herds. The ability to feed more grain to the (larger) herd can provide opportunity to generate even more profit when the milk price:grain price ratio is favourable. Conversely, there is opportunity for larger losses when this ratio is unfavourable. Careful evaluation of milk-to-grain prices and the expected marginal milk response to the feeding of additional grain is required – but this is the case for all grazing systems.

An effective crossbreeding strategy may provide capacity to maintain a true seasonally-calving herd with a short mating period. This strategy has reduced work demands and provides for a better match between farm pasture growth and herd feed demand. One of the benefits from an effective crossbreeding strategy is the provision of a herd more capable of responding to management change thereby providing better ability to manage season/price risks.

Summary

The retrospective analysis of herd-breed structures from 2000-2013 found that the proportion of Australian herds which have crossbred cows has increased over that time, and more farmers have employed systematic crossbreeding strategies, including utilising 3-breed cross systems. The proportions of purebred herds did not change dramatically over the period studied, but the number of purebred herds with some crossbreds declined, indicating that farmers have adopted more strategic crossbreeding systems.

The second part of the study showed that F1 Jersey-HF crossbred cows, although they produced less milk and protein than the HF cows, outperformed purebred HF cows for fat, fat %, protein %, survival and reproductive parameters. These results are supported by other similar studies (Heins et al., 2006; Auldist et al., 2007; Dechow et al., 2007; Prendiville et al., 2009; Heins et al., 2012 and Vance et al., 2013).

The comparisons between the F2 backcross (HF x J-HF or J x J-HF) and the most common 3-breed cross (U x J-HF) resulted in significantly better production, reproduction and survival parameters in favour of the 3-breed cross. This is an extremely important finding, as it will give herd reproductive advisers the ability to use evidence-based knowledge when developing a plan for farmers utilising crossbreeding.

The farmer survey clearly indicated that those farmers who are crossbreeding are seeking more evidence and guidance, and it will be important to disseminate the findings of this study in a targeted way. Interestingly, it appears that are demographic differences between crossbreeding versus pure breeding farmers, with crossbreeding farmers tending to be much younger. This could assist the industry with a targeted approach to educating those farmers most likely to benefit.

The final part of the study, the economic model, demonstrated that in the long term a crossbreeding strategy is likely to be more profitable in a seasonal calving system than pure breeding. However, it may be several years before the benefits are realised, another important message for farmers.

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Fertility and farm financial performance

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'The right cow at the right stage of lactation in the right place at the right time'

Introduction

The Australian Dairy Industry has undergone very significant changes in the past 15 years. This has resulted in a great diversity of production systems within regions; the typical 'single late winter/ spring calving herd which dries off completely, wrongly or rightly, is almost a relic, except in Tasmania (Table 1).

Out of the OMJ Agricultural Consulting client base:

- In 1998, 90% were single calving and 45% dried off completely
- In 2013/2014, 40% were single calving and 2% dried off completely.

It does not matter where you visit in mainland Australia; the issues discussed are nearly always the same:

- The external factors of milk and supplement price, and milk pricing systems
- Volatility of seasonal conditions
- Stocking rate, calving date(s) and calving frequency
- Cost of production
- The optimum level of imported feed
- Seasonality of milk production
- Declining herd fertility.

There is no doubt that the decision making framework has become more complicated, in some cases needlessly. Simple farming systems assist good decision making.

This year highlights the volatility in the industry. If processors are able to hold opening price, at $5.20–$5.80/kg milk solids, it will be considered a 'good' outcome, which is not adequate to grow the industry.

Profitable farms plan and manage to have the right type of cow, at the right stage of lactation, in the right place, at the right time. This involves matching cows' calving time, calving frequency and production per lactation to all the requirements of a particular farm business.

Reproductive performance plays a fundamental role in this outcome but it is difficult to measure – it is not just a simple partial budget of the impact of 10% extra cows not in calf. The effects are more insidious and less noticeable than they were 15 years ago, but equally important.

The marginal curve and law of diminishing returns applies to reproduction as well. There will be some farms where, for a fair bit more effort and cost, the additional return is not significant. Equally, given the average reproductive performance now, there will be some who are on a downward spiral, slowly losing profit but not identifying or addressing the cause.

The common goal: efficient, resilient, low cost, profitable milk production

The common goal, to ensure the long term health and growth of the Australian Dairy Industry, should be the production of milk in a way that is efficient, low cost, profitable and resilient to changes in both the natural and economic environment. Is there a common template in regard to profitable dairy farms?

A general physical and financial profile of a resilient and profitable dairy farm business

Following the Global Financial Crisis in 2008/2009, and the very low opening price in 2009/2010 – $3.50/Kg milk solids (MS), it was evident that there was a set of farm business characteristics that would 'protect' the business in extremely volatile times. This profile is not just about profit or benchmarking; it is the total business picture. It is not just a financial profile but has to incorporate the physical profile of the business as well, given the seasonal variations businesses are exposed to in Australia.

Table 1 State-level feed and cost of production profiles

	VIC	NSW	SA	WA	TAS
% Imported Feed	38%	42%	43%	38%	29%
Cost of Production 13/14 ($/kg MS)	$5.42	$7.11	$6.22	$7.11	$5.11

Table 2 The profitable dairy business tower

Top 40% management skills
Less than 40% imported feed, especially purchased
3.0–4.0 T dry matter/cow home grown milking area feed; no more than 25% of this as silage
TM 200 Rating Total Milker Feed $200/ T DM
Cost of production less than $5.00/kg MS
Equity in total assets 65%; less than 20% debt in short term debt; FMDs used
Debt servicing less than $1.00/kg MS or $500/cow
Significant owner-operator labour; less than 40% paid labour

The 'tower' created (Table 2), incorporating these characteristics as 'bricks', needs to be balanced to be resilient. All dairy businesses can be analyzed via the tower; it very clearly indicates to the business owners the exposure to risk.

A brief explanation of each brick is as follows:

- A top 40% dairy management skill is required, unless there is virtually no debt and no imported feed.
- Once the level of imported feed exceeds 40%, the system is no longer pasture based and would be approaching a semi feedlot model. This is reasonably common in North Victoria and Southern NSW. Clearly, the majority of milk would be marginal milk exposed to risk. (See later section). The 30–40% zone appears to be a balance between maximizing profit, by using supplements to assist in maintaining a higher than average stocking rate, compared to lower or no supplement levels at a lower stocking rate, to reduce the risk of supplement exposure.
- 3.0–4.0 Tonne of dry matter per cow from the milking area, mainly as grazed pasture or crop, reduces dependency on imported feed per cow and also reduces the average feed cost per tonne of dry matter (TDM). This depends upon having the herd's feed requirement matched to the growing pattern on the farm. This does NOT mean the herd must calve in late winter/spring
- TM 200 is an 'ideal' figure for the cost of feed per tonne dry matter to feed a milker. If the balance between pasture at $100/TDM, grain at $280/TDM, and hay or silage, at $200/TDM is correct then $180–$200/TDM will be achieved, so feed costs per kg MS will be low. A combination of high stocking rates, low pasture consumption, high per cow production, and poor matching of pasture growth to feed demands will cause this figure to be unacceptably high.
- A cost of production of $5.00/kg MS reflects a low-cost resilient farm business, and generally a business that has matched herd requirements to pasture/forage growth very well.
- Equity of 65% is desirable, but clearly young farmers encountering first farm purchase will be closer to 40% — the implication is that they have to be even better at other tower characteristics.
- Debt servicing, in many ways, is more important than equity. At less than $1.00/kg MS the business should be resilient, at $2.00 per kg MS the operator needs to be in the top 10% not 40%.
- Less than 40% of total labour as owner operator labour is not necessarily undesirable from a business perspective, but there is no doubt that high levels of employed labour reduces flexibility in tough seasons and increases cash costs.

There is a significant proportion of the Australian Dairy Industry (as evidenced by Dairy Farm Monitor (DFM) and OMJ Consulting data) that, for whatever reason, have 'unbalanced' towers. It is important that future pricing systems assist in ensuring 'bricks' are in the correct position.

There is no 'reproduction brick' but hopefully by the end of this paper there will be one which can be inserted into the tower!

Examples of individual profitable dairy farms

Is the dairy 'tower' supported by hard evidence? Table 3 presents seven farms from ONFARM data for 2011/2012, a generally good season with reasonable milk price. These farms would be within the top 10% of dairy farms; other data sets (Red Sky, DEPI-DFM, TasDairy) would reflect similar performance characteristics in the top 10%.

A fundamental business principle, on which they all operate, is that they will maximize home grown feed consumption (especially direct harvest feed) and have a milk supply pattern which suits their farm, not necessarily their processor.

It is interesting to note that the average cost of production for both OMJ data and DFM-DEPI data in 2011/2012 was $4.79 per kg milk solids, compared to the farms in Table 3, at $4.32, and yet there are autumn calving, spring calving, and split calving herds in this group.

Table 3 OMJ Agricultural Consulting data for high profit farms in 2011/2012 (all very "seasonal")

Location	Calving	COP* $/kg MS	Profit $/kg MS	Return on Asset 2011/2012	Comment
Colac (West)	Single 23/3	$3.84	$2.01	10.7%	Brown soil; harsh Dec–Apr; high winter growth rates; rape and rye.
Milawa (NE)	Split 1/8, 1/3	$4.53	$1.67	10.2%	
Yanakie (Gipps)	Single 8/4	$4.47	$0.99	8.7%	30% of milking area irrigated; split calving enables feed efficiency gains.
Timboon (West)	Single 18/7	$4.68	$1.53	9.3%	Excellent winter growth rates.
Warrnambool (West Vic)	Split 1/3, 20/7	$3.90	$2.61	9.5%	Grey, pugging soil; reasonable summer growth rates.
		$3.83	$2.41		
Corryong (NE)	Split 10/3, 1/8	$3.62	$2.33	14.7%	100 ha coastal sandy dryland; 109 ha irrigated.
Bena (Gipps)	Single 10/7 AV	$4.32	$1.93	9.0 %	20% irrigated. Grey, pugging soil; hill country.

** COP or Cost of Production refers to the total cost of production, which includes farm working expenses (Farm Working Expenses = Herd, Shed, Feed, Overheads, Paid labour), plus imputed operator labour and depreciation.*

In addition, their average profit per kg milk solids was $1.93. Generally, if profit can be in excess of $1.00, it would be acceptable.

Concept of ‘seasonality’

These farms, and many others, highlight the modern meaning of the term ‘seasonal’. In the late 80’s and 90’s, the term referred to herds that predominantly calve once in late winter to spring. It was also established that, in those years, seasonal herds had lower costs than other herds, especially split calving herds. The Ellinbank Research Centre conducted studies in the late 1980’s that confirmed that seasonal, single calving herds had lower costs than autumn calving herds. This belief has continued, but is now once again an unsubstantiated assumption in the dairy industry; the term seasonal needs to be re-defined:

- Seasonal milk production is calving and producing milk to match the pasture/forage production curve on a farm, to enable maximum direct harvest, low-cost feed intakes in cows, which assists in achieving a low cost of production.

It is also important to remember that ‘seasonal’ production is not just about pasture; it refers to the ability of farmers to produce additional platforms of feed, such as ‘autumn start’ crops in northern Victoria, deep rooted crops such as chicory in Western Victoria, or brassicas and cereals in the South, North, and East. There are now some established benchmarks regarding direct harvest feed levels on dairy farms; this is directly linked to lower costs and higher profit per kilogram of milk solids.

Profitable dairy farms generally involve:

- Very efficient people
- Efficient cows (milk solids in proportion to live weight) with 300 day lactations.
- Efficient hectares (high pasture consumption T DM/ha relative to rainfall or irrigation).
- High cost control and financial management.
- An excellent understanding of marginal economics – when the cost of the last unit of input just equals the extra income generated.

The majority of profitable dairy farms are seasonal, but the current payments structures are, in some cases, encouraging them to be non-seasonal; in other cases, very efficient seasonal farmers are being paid premiums that cannot be justified.

Of particular concern is the fact that the observed variation in milk price between farms, of $1.00 per kilogram milk solids, is in fact the same figure as a reasonable profit on a dairy farm. In many cases, this variation is negating the chance of profit, which can only shrink the industry long term.

Too often, high cost of production farms believe the cost issue is related to seasonality, when, in fact, it might be simply an inherent high cost of production system — the current payment structures encourage both problems!

Group data

As described above, the characteristics of the most profitable dairy farms usually involve efficient people, efficient cows and efficient hectares. Another description is that the top operators manage to get 20% more output from 20% less input.

The top 25% consistently produce milk at a cost of production of $0.50 per kg MS less than the average, and have an earnings before interest and tax (EBIT) – or profit – at least $0.65 per kg MS above the average.

The most profitable farms averaged 37% home grown feed.

Table 4 represents a summary of the average of the top 25% of the DFM data and the OMJ data in 2011/2012 and 2012/2013, compared to the average of the data set, noting that the data sets represent the top 30%.

D-ARM conducted a detailed analysis of OMJ Agricultural Consulting data from 1998–2012 and produced the following results (Figure 1).

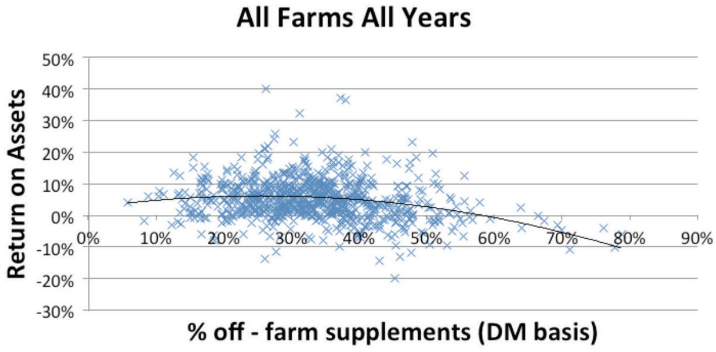

Figure 1 Relationship between return on assets and use of off-farm supplement

Table 4 Characteristics of profitable dairy farms (OMJ/ DFM data)

	% Imported Feed		Cost of production $/kg MS		EBIT (Profit) $/kg MS		Return on Assets %	
	13/14	12/13	13/14	12/13	13/14	12/13	13/14	12/13
OMJ Clients Top 25%	34	39	$4.59	$4.19	$2.65	$1.55	14.3%	8.2%
OMJ Clients Av.	36	37	$5.09	$4.77	$2.15	$0.98	9.9%	3.5%
West Vic (DFM) Top 25%	34	40	$4.58	$4.66	$3.03	$1.93	12.1%	3.7%
West Vic (DFM) Av.	38	42	$5.21	$5.28	$2.03	$0.03	7.9%	0.2%

Note: These two years contrast the extreme variability of the Victorian Dairy Industry in both milk price and seasonal conditions.

There seems to be a high prevalence of high profit farms between 20 and 40% re off farm supplements and a low prevalence of high profit farms above 50%. Note: Return on Assets above 20% will normally involve a lessee rather than a farm owner.

There appears to be a high prevalence of low profit farms below 3 T DM/cow pasture consumption (Figure 2 and Figure 3).

There appears to be a trend for higher pasture consumed per hectare to be associated with higher profit, but given the spread of rainfall and irrigation water applied there is unlikely to be a clear picture.

There appears to be a trend for higher labour efficiency to be associated with higher profit. This trend appears to be unclear when more than 60,000 kg milk solids are harvested per labour unit (figure 4).

In addition to the above analysis, Dairy Australia commissioned independent consultants Jon Hauser and Neil Lane to analyse 416 annual sets of Dairy Farm Monitor data, to investigate the drivers of farm profit and the impact of seasonality on farm operating costs.

Their key findings relevant to farm profit were:

- Total operating cost is strongly negatively correlated with the proportion of grazed pasture in a cow's diet. The more pasture the lower the operating cost/kg MS.
- Farms with less than 40% of grazed pasture in the diet have a high risk exposure to milk price and feed price.
- As farms increase pasture consumption, climate risk becomes more significant. Pasture based farmers do, however, have many options to mitigate risk, including varying feed purchases, the use of fodder reserves, and an appropriate stocking rate.
- The higher pasture intake farms have lower operating costs, but do require higher capital input to purchase the land on which to grow the pasture. However, despite the lower capital requirements, the operating cost burden puts farms with low grazed pasture consumption below average in terms of return on capital.

The Hauser and Lane study strongly supports the OMJ and DFM data. If one was to review TasDairy DPI data, or Red Sky data, the same correlations of characteristics, of farms with lower operating costs and higher profit having high levels of home grown feed, would be found.

It should also be noted that attempts to link per cow production and profit have generally been difficult to correlate although the 'gut feel' and observation is between 500–580 kgs of solids per cow.

Good farmers have been fully aware of these key indicators and have simply adjusted annual milk supply patterns and stocking rates to maximize home grown feed supply (particularly direct grazed pasture), while exploiting supplements to a moderate degree, to maximize/ optimise profit.

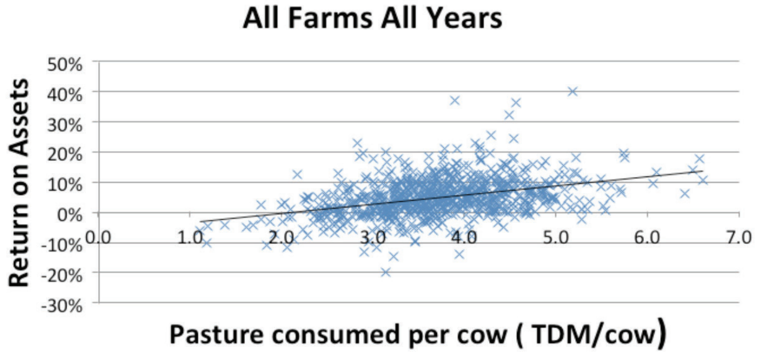

Figure 2 Relationship between return on assets and pasture consumption/cow

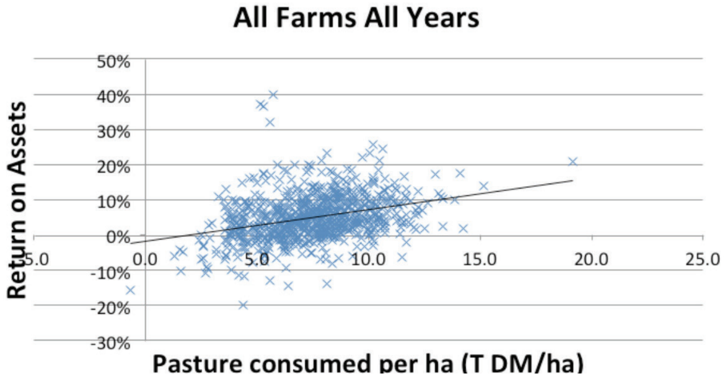

Figure 3 Relationship between return on asset and pasture consumed per hectare

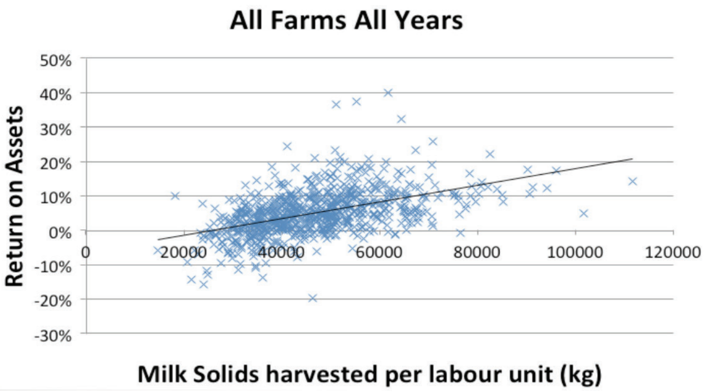

Figure 4 Relationship between return on assets and labour efficiency

Changes to the dairy production landscape over the past 15 years affecting pattern of milk production

When reviewing the drivers of profitable milk production, to suit both the processor and the farmer, there are some changes to the dairy production landscape that need to be considered.

The Dairy Industry has changed very dramatically over the past 15 years, yet milk payment incentive months have not changed significantly. The 'on farm' changes include both decisions to change by dairy farmers, plus imposed changes, in particular changes to pasture/forage growing environments.

Changes in the use of supplement

Both the ONFARM and DFM-DEPI data confirm the general observation that, currently, dairy farms import substantially more supplement than 14 years ago (Table 5). This impacts on both profit volatility, with a greater dependence on marginal (supplement) generated milk, and risk exposure to external factors.

Fortunately, there has also been a 22% increase in pasture consumed on better performing dairy farms. But, in some cases no doubt, especially in Western Victoria, the supplement usage increase has not been matched with proportional increased pasture consumed, which means that extra production is totally supplement dependent.

The direct impact of these changes is that there are many more decisions centered on supplement cost as related to milk price on a daily basis than previously. If decisions are to be kept simple, then a daily value of milk and a daily cost of supplement assist in simplicity, and this, together with other longer term factors, can be considered in the overall decision making. If milk pricing is complex and months are connected, the decision making is far more complex.

Pasture production profile

The pattern of pasture growth throughout the year across the regions has changed very significantly in the past 15 years. As an example, figure 5 presents the relative change in pasture growth across a season on a Dryland region on 'well managed farms' between the 1990's and more recent years.

These changes have been due to:

- Improved cultivars designed to have lower spring growth rates but higher 'shoulder' and winter growth rates.
- The use of annuals and bi-annuals, particularly in lower rainfall areas.
- Nitrogen (N) usage has increased from approximately 38 Kg of N/ha/Year to 200 Kg of N/ha/year. This has meant that nitrogen is constantly used to exploit those periods when there is effective growth, even in spring, to enhance fodder conservation, and obviously in winter, to enhance directly harvested pasture. This has also occurred at a time when stocking rate increased significantly as well as per cow production on many farms.
- Improved grazing management techniques have assisted in higher growth rates outside spring.
- The use of fodder crops and cereals both in winter and summer to increase early and late direct harvest feed sources.
- A close monitor on soil fertility.

The 'old' concept, of winter milk production being difficult, has been replaced on many farms with greater difficulty in summer. Traditional, spring calving herds can now be under severe summer feed pressure, while autumn calving herds, depending upon winter rainfall and soil type, can in fact encounter less feed pressure.

This means that the selecting a milk production pattern suitable to a particular farm is even more important now, in regard to production costs per kilogram of milk solids.

Calving timing and frequency

In 1998, 90% of OMJ Consulting Bench marking herds were single calving 'seasonal' dairy farms. Of total client numbers in 2012/2013, based on 145 herds, this number had decreased to 48%; split calving herds had increased from 10% to 52%. Admittedly, it is not exactly the same group of farms but the trend is clear. In addition, very few single calving herds would completely dry off now. They will 'batch' dry off and end up milking a minimum number of 'in calf' stale cows and some empties.

This situation has become even more dramatic in recent years as

Table 5 Changes to supplement use and pasture consumed

	Grain/ cow	% Imported Feed	Pasture consumed
ONFARM client data (Av.1995–99)	1.04	25%	7.1 T DM/ha
ONFARM client data (Av. 08/09 to 13/14)	1.90	33%	9.1 T DM/ha
Dairy Farm Monitor data (DFM) 13/14	1.70	38%*	8.8 T DM/ha

**In 2012/2013 statewide in Victoria the average was 42%.*

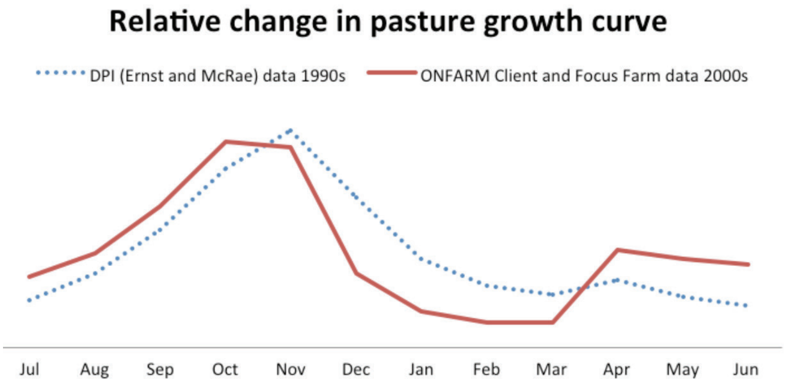

Figure 5 Relative changes to the pasture growth curve since the 1990s

indicated by Figure 6. This data indicates that between 2006/2007 and 2011/2012 the proportion of split calving (in what is a very similar group each year) increased from 28% to 58%, a figure similar to OMJ clients.

It's interesting to note that this coincides with the period of the payments structures paying premiums for flatter curves. It almost provides an excuse not to be too concerned about poorer reproductive performance.

The reasons for this change over time include:

- Lower success rates with reproductive performance, which is anecdotally linked to many factors, but one obvious one is cow type.
- The changing feed profile has meant that even farmers who had good reproductive performance may have been able to make feed utilization gains, by decreasing milking numbers in summer and winter, and grazing dry cows in lower mob numbers on out paddocks.

On large farms with supposedly fixed labour costs, the multiple calving periods have spread the labour demands and costs.

Milk payment systems have definitely accelerated the change.

There is a perception that split calving increases cost of production. There is no industry evidence to support this perception. There is no doubt that, on farms with pre-dominantly owner operator labour, split calving requires more labour on an annual basis. Management has to be better and monitored more carefully, but many split calving farms do this very well. In such cases, the greater complexity of repeating activities and possibly higher labour costs, are offset by the feed efficiency gains, so profit can be higher than with a single calving herd. This highlights once again that it depends upon the 'mix' of factors on a particular farm. It also means that if 300-day lactations are still a target then milking numbers will be more consistent throughout the year (and hence a flatter milk production curve) than a single calve situation. However the costs may be no different.

In summary, and of relevance to any milk processor planning a pricing structure:

- Dairy farms use significantly higher levels of supplements than 10–15 years ago. This usage is all year round. This means that decisions linking milk price and supplement usage must be easy to analyse by farmers.
- The pasture and forage growth pattern is significantly different; therefore the costs involved in producing milk outside spring will be different, but linked directly to the ability to grow feed at other times than spring. Summer has now become a high risk period for milk production, particularly in the east and west where there is less irrigation.
- The majority of herds now split calve for a variety of reasons. This means that the milk production pattern will be more even than previously occurred. In some cases, this will hold constant, or even reduce overall costs, while in other cases it may increase costs.
- Farms have lower equity and higher debt servicing. Therefore, there will be greater interest in milk payment structures that pay a premium for certain supply patterns. The cost analysis on a changed supply pattern is far more complex than the income analysis.

The majority of the industry is exposed to more physical and financial risk in a more complex farm environment. Transparency and simplicity at all levels will assist.

Annual cost of production

When discussing the milk payment systems, supply patterns and efficient dairy production, a vital consideration is 'Cost of Production' (COP). Any change to a payment system which causes an increase in the cost of production is counterproductive unless the processor can show a significant gain in processing costs, but normally a higher farm gate price will be demanded.

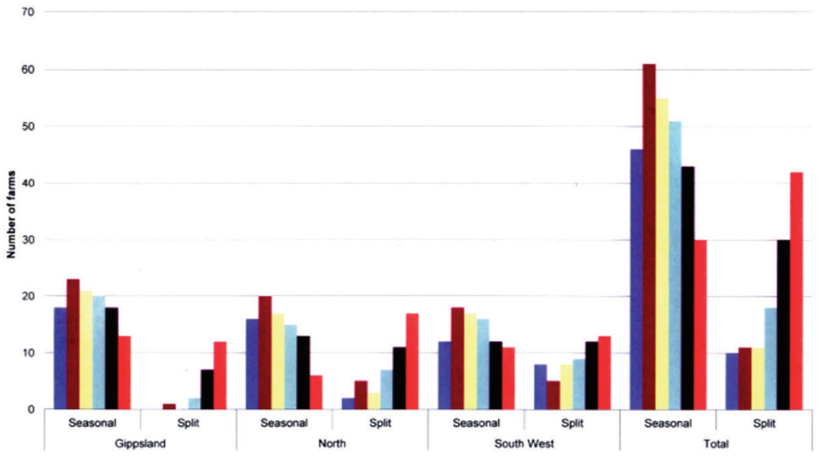

Figure 6 DEPI Dairy Farm Monitor data by calving pattern

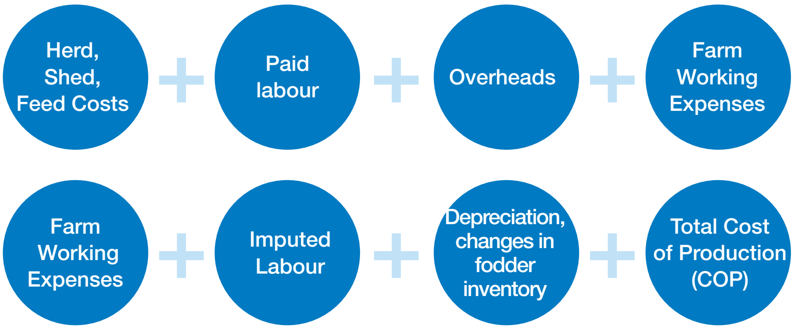

Figure 7 Cost of production schematic

Definition and range

The Dairy Industry frequently uses terminology which means different things to different people. The appendix to this report contains an article 'Talking the Same Language Always Helps' which clarifies some of the terminology, but the following diagram explains the term 'Cost of Production', commonly quoted, and often misunderstood (Figure 7).

Cost of production diagram

Total Cost of Production does not Include debt, personals or capital expenditure

While low COP is not always highest profit (earnings before interest and tax — EBIT), as was previously stated, the most profitable dairy farms will tend to have below average costs per unit of output, and lower costs provide a resilience to volatility.

Specific data always needs to be related to a particular year, but OMJ and DFMI data would indicate that if COP can be in the range of $4.50–$5.50 per kilogram milk solids, then there should be a degree of business resilience.

It is always the broad range between farms that creates interest. Table 6 presents OMJ data from three years indicating the range of COP within each year.

The range in individual farm Cost of Production over the four-year period averaged $2.24/kg MS between all data farms.

The real question becomes: what causes a variation in COP in excess of $2.00 per kilogram milk solids?

Factors affecting cost of production

Cost of production is the end point of a myriad of variables, many of which are controllable. Milk and supplement prices, and seasonal conditions especially the absence of a spring in Western Victoria are clearly significant and difficult to control.

The greatest source of variation is within the business itself, which is partly related to the type of production system and very significantly related to management. On a typical better performing dairy farm the cost structure will be as follows (figure 8).

Obviously, the categories that will impact very significantly on COP will be feed and labour.

As farm size increases above 500 cows, overheads can impact very significantly in both repairs and maintenance and general administration. These areas, together with labour, explain why large farms often do not exhibit the economies of scale expected.

Variables that impact on COP will to some extent be different between farms, but, from observation, the most significant are:

- Management. Some operators have a natural cost control and marginal decision making skill in all areas of the business. Others spend more to get the same production because they lack the inherent skill.
- Calving date (s) and stocking rate. If these are inappropriate for the natural resource base of the farm, then costs will be high, even under good management — but expect that a good manager will alter these settings.
- Cost, amount, and efficiency of supplements. Often, at the same stocking rate in the same area, one operator will feed an extra tonne of grain to have the same per cow production.
- Labour cost and efficiency, particularly as farm size increases. An industry guide to labour is $500 per cow, or $1.10 per kg MS. It is common on large farms to find labour at $700 per cow, or $1.54 per kg MS.
- Overheads can rapidly increase into what can be described as 'overhead hemorrhage' or 'pretty farm syndrome'.
- System: some dairy production systems have inherently high COP but require lower capital investment. Semi and full feedlot operations, even if well managed, are unlikely to have a COP within $1.00 per kg MS of pasture based farms. There is limited data available on the cost of production on feed lots, but, to date, it indicates that this milk is unlikely to be produced at less than $6.50 per kg MS, even when best practice management exists.
- Frequently, a high proportion of non-spring production is blamed for a high annual cost of production, when, in fact, it is often other variables within the farm business.

Effect of calving date on annual cost of production

As suggested in the previous section it is possible that seasonality of calving date has been unjustly associated with high annual cost of production.

To investigate this further, D-ARM Consulting analyzed 156 sets of farm

Table 6 Cost of production ($/kg MS). From OMJ data

	Top 10%	Average	Range
2010/2011	$4.00	$4.40	$3.35–$5.82 ($2.47)
2011/2012	$4.05	$4.43	$3.40–$5.74 ($2.34)
2012/2013	$4.19	$4.77	$3.83–$5.72 ($1.89)
2013/2014	$4.48	$5.09	$3.92–$6.20 ($2.28)
4 Yr. Average	$4.18	$4.67	Av Range $2.24)

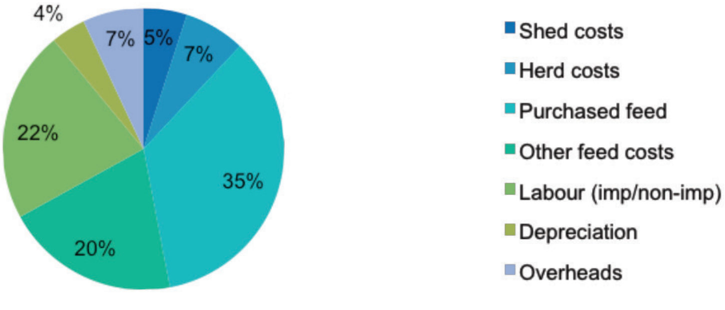

Figure 8 Cost structure example from a better performing dairy farm

data from a 3 year period with years reflecting a range of seasonal conditions and milk/supplement prices (09/10–11/12). The groups were sorted into three calving patterns with approximately 50 farms in each calving group for each year.

The calving groups were defined as:

- Spring/winter: Single calving and start of calving between June 1 and October (53 data sets).
- Autumn: Single calving and start of calving between Feb 1 and May 31 (52 data sets).
- Split (51 data sets).

The 'spring' and 'autumn' groups tended to have a lower herd size and lower milk production than the 'split' group. The 'autumn' group appeared to have a lower average rainfall, and possibly included more farms in NE Victoria. The 'spring' group appeared to feed slightly less off-farm supplements and have a higher stocking rate on the milking area. The labour efficiency (kg milk solids harvested per labour unit) appeared to be similar between groups.

Table 7 provides a summary of this statistical analysis, with full details presented as an appendix to this report.

Critical findings from this analysis are:

- There is no statistical difference in feed costs of well managed seasonal herds which calve in autumn, winter/spring or split calve. They can all be efficient, resilient, profitable businesses.
- There is no significant difference in COP across these three calving periods, once non-cash costs such as imputed labour are included.
- There is minimal difference in levels of imported feed.
- An interesting observation is that per cow production in the winter /spring herds was, on average, 61 kg MS less than the autumn calving group, which is often the observation, because autumn calved cows have a more secure period of very high quality pasture under good management conditions, whereas spring calved herds are under more quality pressure, then summer low pasture growth pressure.
- The 'spring' group has a milk price about $0.35 to $0.40/kg MS lower than the other groups and EBIT about $0.40/kg MS lower. The difference in EBIT per kg MS was statistically significant at a 95% confidence level.
- The average Return on Assets of the 'spring' group also appeared substantially lower than other groups.
- The vast majority of the profit difference is attributable to the difference in milk price received rather than any difference in costs.

Table 7 Calving pattern variation

	Winter/Spring	Autumn	Split
Milk Solids kg	135,709 kg	149,714	174,610
% Imported Supplement	31%	35%	35%
Total Cost of Production (cash costs plus imputed labour and inventory changes)	$4.48	$4.59	$4.69
EBIT $/kg MS	$1.09	$1.49	$1.46

(ONFARM data 2010–2013 analysed by D-ARM Consulting)

In addition to this analysis, Hauser and Lane's Dairy Australia's Study also found that:

> '…The more surprising outcome is that operating cost, total capital employed, and return on capital do not show any particular trend as off peak milk % increases…'
>
> '...not all farmers have used more intensive supplementary feeding systems to shift a highly spring milk production curve to more off peak milk…there are many examples of farms that have made the transition with relatively high levels of grazed pasture in the cow diet…'

In summary, good dairy farm businesses that have supply curves maximising the direct harvest feed from the milking area, are fully aware, in many cases, that the seasonal premiums they have been receiving are not justified.

Cost of production variation within a year

As is clear in the breakdown of COP, feed costs are a major contributor to cost of production. This discussion relates to the accrual based feed cost variation during the year which is different to the cash flow impact of feed costs. For example in Western Victoria farmers will conserve silage in October and pay for that conservation in November. The silage is perhaps not fed until January. The cost of producing milk in summer must include the silage (accrual based), but from a cash flow perspective the cost was incurred in November.

On a pasture based (greater than 55% home grown feed) dairy farm, it is clear that the 'spring' period is the time of greatest pasture growth, is a period of lower feed costs per kg MS compared to other times of the year. Spring will vary between regions and also within regions.

For the period external to spring, or 'off peak', there should be a range of total feed costs between efficient farms. There may be monthly variations but these must even out to a greater extent – otherwise there would be a significant difference in the annual costs, which is not the case.

In practical terms:

- A cow, calving on September 1st in a herd which commences calving on July 1st, in a dry summer area, will have 90 days of cheap pasture intake, in addition to some marginal milk supplement. Then the diet for the next 150–200 days will be silage, grain, and limited pasture.
- A cow calving on March 1st in a January calving herd will have limited pasture for 60 days and then potentially high quality pasture for the next 180 days.

This suggests that, if most cows average 300 day lactations, there will be 100 days in spring at low cost and 200 days out of spring at higher cost. Generally, the 'shoulder' months, either side of spring, will be slightly higher, and further from spring higher again. Summer has become the period when all herds are under feeding and there is feed cost pressure, except, in irrigation areas to some extent. However the cost of irrigated pasture is often underestimated.

To highlight this impact, the Table 8 presents the relationship between feed cost and season or time of year.

A dairy farmer's ability to manipulate milk production to minimize cost or maximize resilient profit (hopefully both) without simply constantly entering the capital cow market is directly linked to reproductive performance. This is both in terms of herd turnover rates but also matching efficient cows with high quality cheap feed.

Reproduction and profit: principles, theory versus practice

The introduction of multiple calving periods and extended lactations in the eastern states has made the 'water murky' in assessing the impacts of reproductive performance on profit. I have no client who deliberately extends lactations in cows, unless they are changing calving dates. It is still only done when there has been reproductive failure. This is despite the comment '… I don't worry too much if a cow doesn't get in calf; she just rolls over to the next mating period…' The principles of depreciation and a 'profitable cow' are consistent irrespective of changes to the calving landscape.

Principles of a profitable cow

My 'principles' for a profitable cow are presented in Table 9.

If my profitable cow either starts to lose efficiency which means production relative to feeding level, or does not last very long, then both of these impact on profit. It is a pity that she has to have a dry period, which costs me $126 or 22 kilograms of milk solids equivalent.

Depreciation is the real cost of holding inventory.

The implications of this are:

- A cow needs to last more than two years or equivalent, or produce a bucket load of extra milk
- If a large proportion (say > 50%) of cows is turned over in two years, profit can easily reduce by 30%.

There are three types of cows within a year that can be identified: efficient and profitable, cost covering, and dry (table 11). The latter two do not generate profit. If we have to many of either group these for too long profit is reduced dramatically.

It may appear obvious but the implications of this are:

- Covering costs is a lot different to optimum in lactating cows, and yet so often the question is asked: what's the cut-off for my empties when they are no longer covering their variable costs. The focus is on this rather than emphasizing that the inefficient cow is occupying the place of a more efficient cow.
- Dry cows cost money and dry cows off early has to evaluated carefully.
- Pregnancy status makes decisions much harder. Once a cow is in calf she's likely to be given more opportunity to 'sit' in the herd. Careful evaluation of empties at MSD is critical.
- It is accepted that in early lactation milk responses will be higher to expensive concentrate supplements than in later lactation.
- Lack of replacements and/or money just continue the less than optimum merry go round.

These principles can be applied to all herds. The economic impact in single calving herds that completely dry off are very clear and well established. However it is less obvious in multiple or all year round calving herds, especially since 'extended lactation has become more acceptable and encouraged, that is a cow milking longer than 365 days.

Extended lactation: theory versus practice

Table 12 presents the research findings regarding declines in production for various periods beyond a normal lactation.

This research ensured that all cows, even at relative low production

Table 8 Feed cost as $/kg MS on a greater than 40% pasture-based dairy farm

	Summer	Autumn (dry)	Autumn/ Winter	Spring
Pasture in diet	Irrig D'land 8 kg 2 kg	2 kg	9 kg	16 kg
Feed cost in $/kg MS	$2.60 $3.30	$3.20	$1.90	$1.30

But cows have a 300+ day lactation so everyone shares in more expensive milk

Table 9 My profitable cow (OMJ)

Description	Income and costs *(If in the right place, at the right time, at the right stage of lactation)*
550 kg Liveweight Producing 585 kg MS in 8,028 L (peaks at 2.3 kg MS and dries off at 1.5 kg MS) Consumes 6 T dry matter, 1.9 kg grain, 0.14 kg canola, 0.4 kg vetch, 0.2 kg cereal hay and 3.4 kg home grown pasture and silage	Income (milk and stock): › $3,475 › $5.94/kg MS Costs (as $/kg MS): › Herd $0.42 › Shed $0.20 › Feed $2.33 › Labour (paid) $0.46 › Overheads $0.41 › Labour (imputed) $0.67 › Deprec. (plant/equip) $0.26/ $4.75 Profit: $1.20/kg MS or $702/cow Note: Buried in feed and herd is $70,000 ($229/cow) to hold my stock inventory.

received 165 MJME per day of a well-balanced diet.

In addition, the economic modeling, as part of the extended lactation research, suggested:

> '…The conclusion is that, after allowing for risk affects, the EL system produced greater net financial benefit than the 300 day lactation system over the 3 years of operation…'

If the information presented above is correct, then one would expect profiles of herds to indicate that there are significant numbers of extended lactation cows in herds and that this should enable dairy farmers to require less replacements. The actual number of cows in an extended lactation in herds is presented in Table 13. This indicates that for whatever reason the number of extended lactation cows is not as great as the research indicates is possible.

In addition to this, there is no indication that there has been a reduction in the number of replacements required in multiple calving herds.

This requires further investigation.

Profitable farmers and reproduction

It would appear that the most profitable farmers can be grouped into the following categories regarding their reproduction, with the appropriate level of performance for their type of cow:

- Those farms that milk large (550kg +) Holstein type cows and supply milk all year target 30% heifers of peak milker numbers to enter the herd. This means rearing 32%, to allow for losses. Any less than this means that it is difficult to have discretionary culling, and too many low producing empties are kept. This group has indicated that any greater than 30% empty would significantly impact on profit. A constantly monitored herd profile

Table 10 Replacement cost to hold herd inventory (i.e. herd depreciation)

- Milker purchase value: $1,500.
- A good milker will make a profit of $702/yr
- Chopper sale value: $800
- Depreciation: $700
- This can be incurred in one year or spread over several years and production periods

At $5.78/kg MS

Depr. period	1 Yr	2 Yr	3 Yr	4 Yr	5 Yr
Depr. $/cow	$700	$350	$233	$175	$140
Depr. as % profit	100%	50%	33%	25%	20%
Depr. as kg MS	121 kg	60 kg	40 kg	30 kg	24 kg

Table 11 Three cows within one year

	Cow 1 Profitable Mid lactation	Cow 2 Lower producing But covering her feed cost (+$1.00)	Cow 3 Dry cow
Production (kg MS)	1.9 kg	0.80 kg	0
Income at $ $5.78/kg MS	$11.00	$4.50	0
Daily Total Feed Cost ($)	$4.03	$3.50	$2.25
Margin Over Feed ($)	$6.97	$1.00	- $2.25
Feed Cost ($/kg MS)	$2.12	$4.37	(0.4 kg MS)

Table 12 Effect of lactation length on "annual" milk yields when fed 160-180 MJME/day diet @ 1.0 kg MS/day dry off (Auldist, O'Brien, Cole, McMillan and Grainger DPI)

Lactation length (Months)	Milk solids (kg F & Pr) All cows	Difference c.w 10 months
10	496	0
13	494	- 3%
16	482	- 6%
19	466	- 10%
22	444	

Table 13 Extended lactation cows — what is really happening?

Twenty profitable farms NSW and Vic*		HICO data – Macalister irrigation District herds#	
Lactation length (days)	**% Peak milkers**	**Lactation length (days)**	**% Peak milkers**
356 – 465	5.6%	0 – 300	82.5
466 – 600	1,7%	350 – 400	3.3
600 +	< 1%	400 – 500	3.9
		500 – 600	1.5
		600 +	1.3

** Six farms all year round calving*

 # Obtained from MISTRO herd recording herds. Analysis by Richard Shephard

Table 14 Observed/implied advantages or disadvantages of single vs multiple calving systems

	Risks	Opportunities
Multiple Calving	› Not transparent › More compromise › Harder to have the finger on the pulses of all animals › Stage of lactation feeding › Challenge on dryland	› Fewer replacements (5%?) › Manipulation of feed profile to maximise direct grazed feed/cow › Spread pressure on staff and facilities
Single Calving	› Feed pressure points › Repro management must be good › Minimum requirement – all cows calved by MSD	› Very, very transparent with all groups at all stages › Focus on doing one task at a time

is a necessary concept in herds that milk all year round:

- Greater than 10% of peak milker numbers above 365 days is a concern that needs investigation, for both reproduction performance and 'optimum cow.
- Greater than 10% of cows above 488 days is a worry.
- Both categories above 10% is a concerning worry.
- These type of characteristics can be included as a reproductive brick in the resilient dairy tower described earlier in Table 2.

Those farms milking a more fertile type of cow, and that possibly dry off completely, target 20–25% replacements of peak milker numbers. This group believes a 10% empty rate is an achievable target and would regard 20% as significantly impacting on profit.

The observed or implied advantages of single calving versus multiple calving systems has been summarised in Table 14.

In regard to what the more profitable dairy farmers measure and quote:

- 90% can quote empty rate. In an all year round calving herd, 70% could quote average days in milk.
- 50% can quote conception rate and, even then, in many cases it is not the correct figure – suggesting a lack of uniformity in understanding of conception rate by farmers.
- 20–30 % can quote submission rate, 6 week in calf rate, and average days from calving to conception.

This has a significant impact on extension programs and selecting the appropriate information to discuss and focus on with a particular farmer. This also requires further investigation.

Appendix: Putting all this together in one farm visit

Information known before the visit:

The farm

- 128 ha
- 2.5 cows/ha
- Dryland
- 517 kg solids/cow
- 1.8 T grain
- Soil type: pugs when wet
- Facilities: All good with primitive feed pad/stand off area

Pasture Growth Rate Pattern

- See Figure 9

Reproductive performance

- Historically single calving, gradually spread
- Now split – ended up there after high empty rate two years ago (30% +)
- Start of calving 25/7 and 24/4

People

- Late 50s, employ labour, like their black and whites

Situation on the date of the visit (3/8/2015)

- 181 cows milking (160 in the vat): 62 fresh, 40 autumn calvers, 79 empties (milked 300 – 360 days)
- Producing 18 L @ 4.00% BF/3.77% Pr = 1.4 kg MS
- Flat feeding rate: 6 kg grain and additive at $2.28/hd and pasture at $1.20/hd
- Average cover: 2,150 kg/ha
- Growth rate: 22 kg/ha/day
- Eat rate: 14 kg/hd/day
- Heaps of pasture and its growing well.

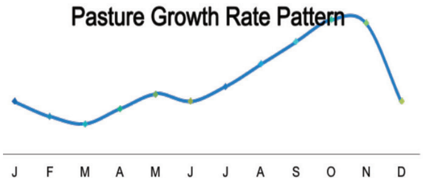

Figure 9 Example pasture growth rate curve

Table 15

	Spring (9–10 weeks)	Winter (3–4 weeks)
MSD Calving	15/10–23/12 25/7–39/9	18/7–8/8 24/4–15/5 (PG)
Preg tests – 14/10 and 10/7. Look very closely at empties 1.5 kg MS and below		

Short term situation

- Milk value/cow: $4.90/kg MS (36.3 cents/std L)
- Daily cost/cow:
  - Supplement: $2.28 (Equiv. to 0.46 kg MS)
  - Pasture: $1.20 (Equiv. to 0.24 kg MS)
  - Shed: $0.16 (Equiv. to 0.03 kg MS)
  - Labour: $1.50 (Equiv. to 1.04 kg MS)
  - **Total: $5.14 (Equiv. to 1.04 kg MS)**

(If grass gets really scarce and residuals low, then charge a similar price for pasture and supplement)

- The more empties and the more calvings, the more this needs to be monitored.

Long term

- Clarity!
- A clear annual repro program (Table 15)
- Not all empties are joined
- All cows are milking Sept, Oct, Nov (spring)

Reproduction is critically linked to profit, but the effect of poor reproduction manifests itself in a myriad of areas so is difficult to identify. However, it can be summarised in terms of:

- The right type of cow: A cow that can be easily managed, without complexity, to get in calf. This does not necessarily mean a cross bred – just the right type of cow!
- The right stage of lactation: Management so that a cow at the right stage of lactation or efficiency is being fed appropriately.
- The right place: The stage and place are combined so that a very efficient cow fits in with the highest feed quality profile of the farm.
- The right time: Bringing the reproduction and agronomy together to achieve as low a cost of production as possible, while exploiting the margins in supplements.

The simpler the farming system is, then the easier it is to achieve all of the above.

InCalf Symposium October 2017 addendum paper

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A paper was presented in the proceedings of the 2015 Symposium which discussed the "changed" dairy industry compared with the 1990s. As pointed out then, the changes that have occurred have created implications for dairy farmers trying to navigate their way through their volatile industry. The same applies to their advisors, who are trying to assist their clients in what has become a complex industry with a myriad of hybrid production systems.

All the issues raised in the 2015 paper are still relevant today, for example the physical and financial parameters that make some dairy businesses more profitable and resilient than others, and the relevance of cost of production on dairy farms.

The relevance of reproductive performance was also considered, particularly in regard to the research on the biological and economic effects of extended lactation.

The increased use of extended lactation on farms has created more confusion and to some extent justified poor reproductive performance. The use of "extended lactation cows" has become a "management tool", leading some to question the importance of reproductive performance on a profitable dairy farm in the Australian Dairy Industry. This prompted more work in this area using a group of highly profitable dairy farms to gauge the importance of reproduction in their systems.

A key area worth revisiting since the publication of the 2015 paper is the upheaval created by the actions of some processors.

Processor "antics", from April 2015 until recently, highlight the insecure pricing environment in which most dairy farmers operate, especially within south eastern Australia.

In a recent review of the dairy industry as an investment, Bell Potter highlighted the "...vagaries of seasonal factors and global pricing dynamics in dairy markets in addition to currency fluctuations..." as key risks to investment in the dairy industry. The review almost implied "Why invest in dairy?" Forget the external investor — what about as an owner of a dairy business?

Yet despite the volatility and concerns regarding dairy as an investment, the 2016/2017 Dairy Farm Monitor results in Victoria and Tasmania have indicated a significant number of farms achieved very acceptable rates of return on their assets and profits per kilogram of milk solids.

This seems at odds with the common perception of the dairy industry over the past 18 months. It simply highlights that there is a group of dairy farm business owners who have manipulated their business profile, both physical and financial, to optimise profit while not exposing the business to excessive risk. The principles noted in the 2015 paper are ingrained in many of these farms.

The characteristics which have been particularly relevant:

- A **production system** appropriate to the price being received. Flexibility of production system is often touted as the key to resilience. This is actually a misconception. If you examined the farm businesses that have survived very well in the past 18 months you would likely find that in fact they do NOT have flexible production systems. They have developed a reasonably fixed system which is resilient to the level of volatility encountered. The critical settings of stocking rate and calving date(s) have been established and "tested"; even levels of supplements don't change unless the industry settings reach extremes. This proven resilience provides enormous confidence to the operator during volatile times. In many ways it can be described as "business as usual".
- **Cost of production (COP)** is becoming increasingly important in resilience. However, interpretation of the figure needs to be used in context and with caution. The easiest way to have a low cost of production is to spend very little and produce very little. The lack of production might have serious viability implications. For a marginal increase in cost of production per unit of output there might be a very significant increase in total profit even if there is a small decrease in profit per unit of output.

  The industry data base, DairyBase, is now providing consistent language regarding dairy business performance analysis across a broad range of production systems, and there are useful guides as to the "best practice" cost of production in various productions systems. A low input pasture based system at $4.20/kg milk solids COP, a moderate input pasture based system at $4.50/ kg MS COP and a feedlot at $6.00/kg MS COP would all be considered operating in the best practice zone for their system. If a profit of at least $1.00/kg MS is a target then there is a clear guide as to the milk price required by the three systems.

  Within each system COP can be lower than expected; it often comes down to the intrinsic characteristic of the business owner.

- It is becoming clear that in a predominantly pasture based system the **perceived link between when milk is produced and the cost of production** is weak. If farms produce milk to suit the individual characteristics of their farm and implement a high level of cost control and marginal thinking then a low cost of production for their system is achieved. The lack of evidence supporting cost of production and seasonality has challenged the justification for variations in milk price between farmers supplying the same processor. This has been an issue since 2007 but recent low prices has exposed this even further and has been the cause for significant numbers of farmers to shift their supply to either a higher paying or more equitable paying processor-preferably both... It often comes down to the intrinsic characteristic of the business owner.
- The investigation involving the **reproductive performance** of several highly profitable dairy farms with a broad range of production systems is reported in other areas of this symposium, but it has highlighted that reproductive performance is still important despite the changes to the dairy production system. However the reproductive performance does not have to be excellent. When it's not, the highly profitable farmer mitigates the impact and manipulates the business accordingly.

The broad based advisor, as distinct from the more specific technical advisor, often attempts to identify the characteristics of the highly profitable dairy farm, manipulated into that position by the highly skilled farm owner.

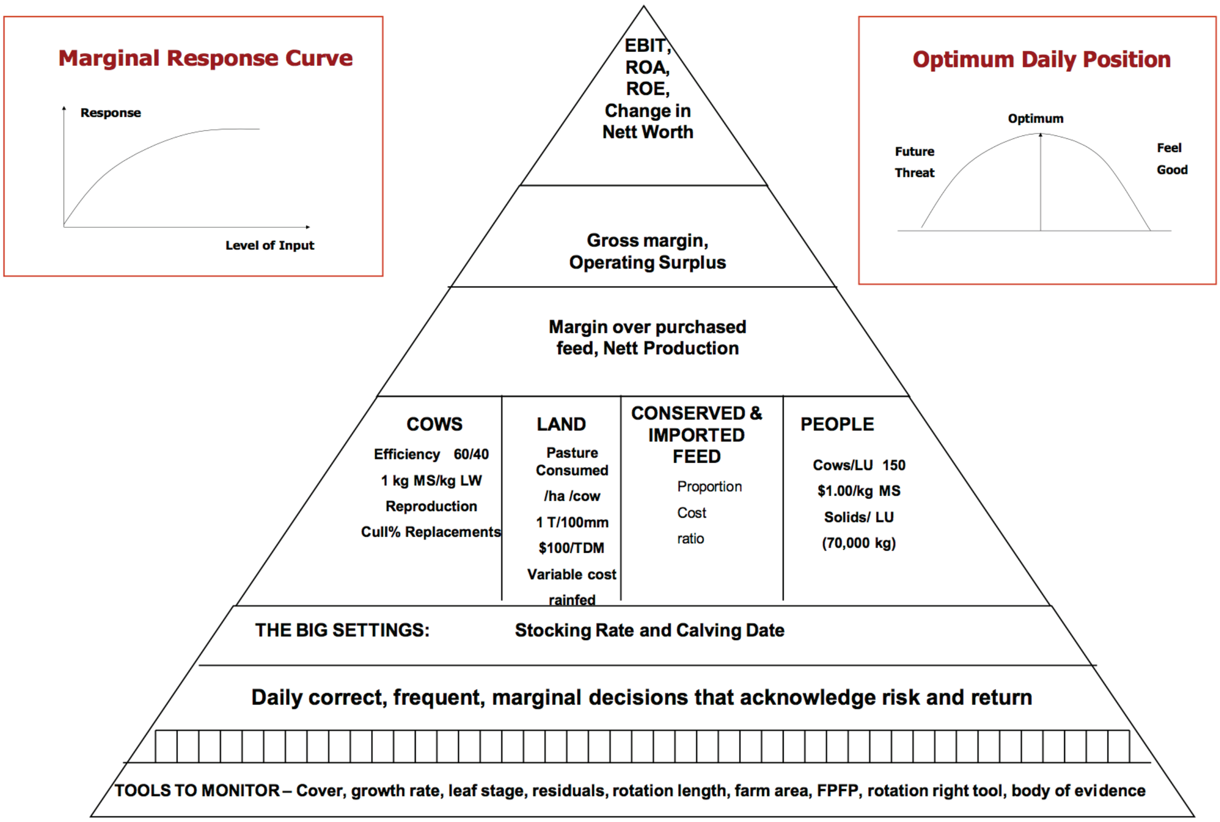
The below "profit pyramid" attempts to identify the physical guides, the principles applied, and the tools to measure on these highly profitable farms.

These individuals are highly skilled. Key features are:

- They have an ability to process complex decisions quickly and assess risk.
- Most aspects of the business remain simple. If complexity is introduced it must be justifiable and profitable.
- There is a degree of quantitative assessment used for most areas of the business — both daily and annually. They do measure but do not over analyse.
- They are rarely excellent in any one area of dairying, but tend to be very good in all areas.
- Once they have settled into their resilient steady state position then the level of annual analysis often decreases. Progress will be gauged by the increase in equity each year which is the ultimate measure of creating and holding profit.

It becomes very clear that the generation of profit on a dairy farm is less about technology and more about the individual; the role of an effective advisor is the same.

Profit Pyramid



Turning capital, labour, management, administrative, feed, herd and shed inputs, and time into milk solids and profit.

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Abstract

A concern of this paper is the soundness of understanding of dairy systems and of advice given to dairy farmers by people in extension and consulting, service providers and in the R&D system. In this paper, the reasons are set out why the whole farm approach based on sound understanding of the technology, economics, finance, risk, human and beYOnd farm gate elements is the only way to understand and provide sound advice about the operation of a dairy farm system. The first aim of this paper is to (i) explain that the result of a dairy farmers efforts is the result of the combination of all things; and (ii) point out (again!) the folly of using average technical ratios to 'inform' advice and decisions in lieu of drawing on the long-established principles of farm production economics. The way these principles of farm economics work — which have been around since the 1940s — is explained. The culmination of the whole farm approach incorporating principles of production economics is applying the principle of equi-marginal returns to decisions about combining inputs into the dairy system, whilst taking care to account for all the likely costs and benefits that will occur when a change is made to a farm system. Making a good job of dairy farming requires making a good job of combining all inputs. Bad advice is prevented and good advice is possible when the blinkered focus on a single input is eschewed. This leads to the second aim of this paper which is to demonstrate how to avoid some common mistakes using the whole farm approach. An example is given, seeing the cow as a lump of capital, with 'hidden' annual depreciation costs which come to the fore when she departs the herd prematurely, say, as a result of not getting in calf or from applying high selection pressure in the pursuit of genetic improvement of the herd. The way herd reproduction performance affects the hidden costs of the cow as a lump of capital, is demonstrated. The proposition that solutions to parts are not solutions to wholes is put forward.

Introduction

A dairy farm business consists of fixed inputs of capital such as land, cattle and plant and equipment, permanent labour and management, administrative inputs, and variable inputs of feed, herd and shed inputs, all combined over time to produce income from the physical output of milk solids plus output of a livestock nature. The output of a livestock nature has several dimensions, being livestock output in the form of (i) new animals that embody technological change (genetic gain) and (ii) animal income produced as animals in the herd progress through age groups, from birth until they incur an annual depreciation cost and decline in value. There are also animal outputs that are meat such as cull cows and calves destined for beef production.

The dairy whole farm production function is:

Annual outputs of milk and livestock = f(land, cattle, plant, labour, management, administrative, feed, herd, shed, soil moisture, temperatures, time)

Within a production year, decision-makers make decisions about the quantities of the variable inputs to use, aiming to make the most farm total gross margin (total income minus total variable costs), all subject to the constraints of the fixed assets of land, cows, plant, permanent labour and management and administrative inputs with which they have to work, and the soil moisture and temperatures that prevail.

Over a longer time, farmers strive to achieve their goals by making decisions about all inputs, as, over time, all inputs are variable. The extent to which farmers manage to make the most farm gross margin in a production year and to achieve their goals over a run of years depends on (i) the way they combine the inputs to production over which they have control, for the time period relevant to their decisions, and (ii) the effects of external influences such as prices, costs, exchange rates, market access, processor performance, interest rates, seasonal conditions which interact with the on-farm inputs, and together determine the performance of a business in a year and over a run of years.

Production Economic Principles and the Technologist's Dilemma

In 1958 the UNE's Professor Jack Lewis's in his Inaugural Professorial Lecture, 'Confessions of a Farm Economist' (Lewis 1958) talked about 'the kind of problems with which the farm economist is concerned' … 'to show the usefulness of economic principles and methods of analysis in decision-making on the individual farm, in the industry, and in the affairs of the nation' (p.1). Tellingly, Lewis said 'Without doubt we still have a long way to go before farm economics is as meaningful to the man [sic] on the land and has the same acknowledged application in his [sic] everyday affairs as the physical and biological sciences' (p.2). Lewis bewailed the unscientific approach of agricultural scientists who were either oblivious to, or rejected, economic theory; economists who were too preoccupied with aggregate economic theory to concern themselves with the refinement and application of their principles to the problems of individual farms; and the 'naïve empiricism' that underlay the fruitless search of records for empirical 'laws of successful farming'. The folly of comparative analysis was noted, along with the inappropriateness of inferences drawn from average cost of production findings. He concluded with a contention — 'confession if you like — …that much of what passes for farm management work is little better than a placebo — a medicine to humour the patient rather than cure the illness' (p.11). Further 'Farmers are so conscious of the economic nature of their problem and remain so hopeful of receiving useful information that they often tolerate this treatment for surprisingly long periods' (p.11). Jack Lewis extolled the virtues of the whole farm approach, budgeting and the need for knowledge of input-output relationships, while pointing out that farm economics has a 'vital role at the individual farm level or industry level' (p18). The fact that Lewis in 1958 could have been describing the farm economics/farm management economics situation of Australia in 2017 is a worry (Malcolm and Wright 2016).

Unsound Advice Based on Average Technical ratios

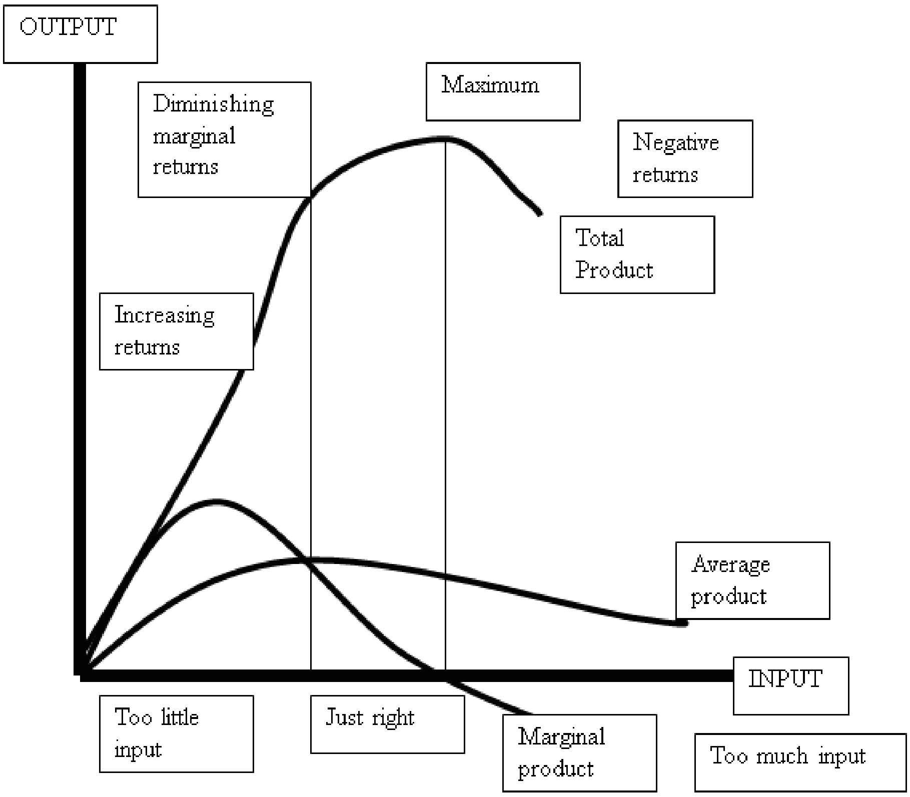
The term 'Technologist's Dilemma' refers to the challenge technologists have in deciding on the best way to combine the inputs of a dairy business to make the most farm gross margin in a year and to contribute most to achieving farmers' goals in that year and over time. The dilemma arises because the technologists' information about technical efficiency, which is physical output divided by physical input, is insufficient information on which to formulate sound advice. Indeed, advice based on increasing or maximizing technical efficiency ratios, such as production per cow or production per hectare, or maximum milk solids per unit of feed input per cow (feed conversion efficiency) will, if followed by the farmer, lead to making the farmer worse off economically than can be achieved using advice based on sound farm economic methods and analysis.

For example, feeding to maximize the average feed conversion efficiency (kg MS output/kg feed input) will mean the cow is being fed less than is necessary to maximize profit. Stocking to maximize total production per cow, or per hectare also means profit is not maximized. Worse, depending on which technical ratio is being maximized, the information leads to logically opposite conclusions. To increase production per cow leads to the decision to reduce the number of cows per hectare. To increase the production per hectare leads to the decision to increase the number of cows per hectare. Such confusion — and bad advice — follows from any attempts to maximize the technical efficiency ratio of any of the inputs that make up the whole farm production function. The farm economist's critique of agricultural scientist's advice is that when such advice violates basic principles of production economic. The operation of the principles of farm production economics is shown in the following diagrams.

Diminishing Marginal Returns

First, the Law of Diminishing Marginal Returns (or Law of Variable Proportions), shown in Figure below. This principle is called a Law for good reason; advisors and decision-makers in agriculture ignore this at their peril.

Figure 1 Total, average and marginal product resulting from adding a variable input, all other inputs held constant



The key idea is that as more of a variable input is added to all the other inputs that go into production, the extra output resulting from extra input initially increases, then the rate of increase diminishes until eventually an added variable input adds nothing to total production and continuing to add inputs will reduce total output, to less output than could be achieved with less inputs. The focus for decision makers is thus the marginal (extra) response from each extra unit of input. Note that total product and marginal product are actual physical quantities of output. The average output however is a made-up number, not an actual physical quantity of output (except for the one case where the added input produces a marginal output that equals the average output). In the diagram above, and regardless of the costs and returns of the input and output, the sensible stage of inputs to use is in stage 2, between where the average product has reached a maximum and the total product is maximum and where marginal product becomes zero. The profit maximizing rule is — with no constraint on capital available to buy variable inputs — to use variable inputs within stage two and to the level where the extra cost of the extra input just equals the extra revenue from the extra output that results.

Figure 2 Marginal Analysis: the actual change in output from one extra unit of input

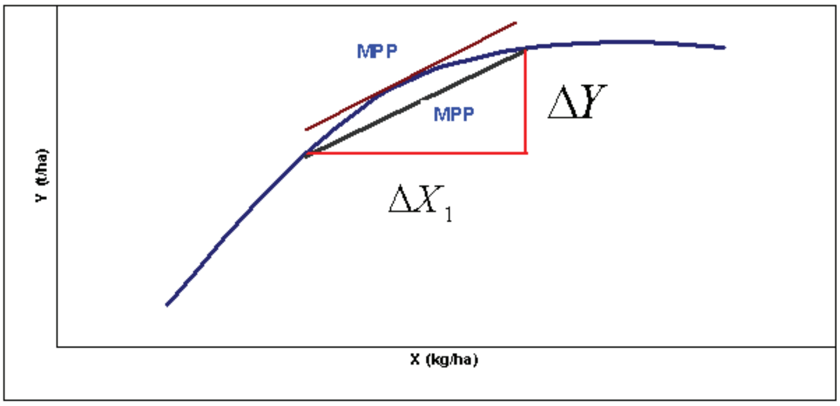


Figure 3 Average analysis: the mythical average output of all the quantity of an input used

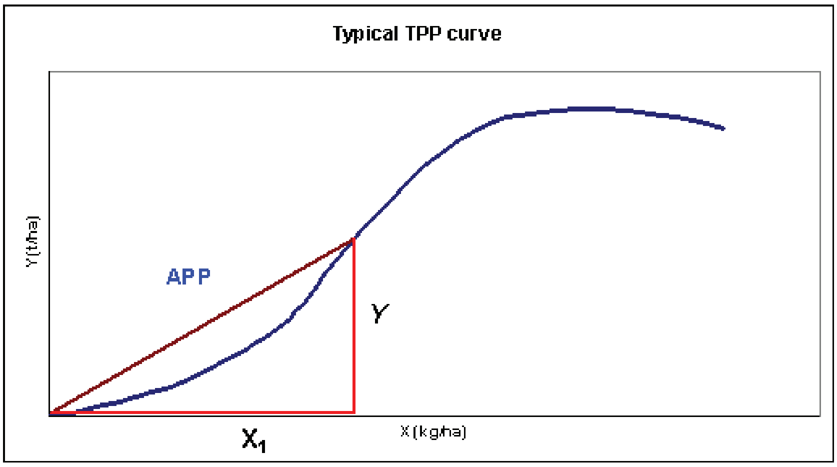
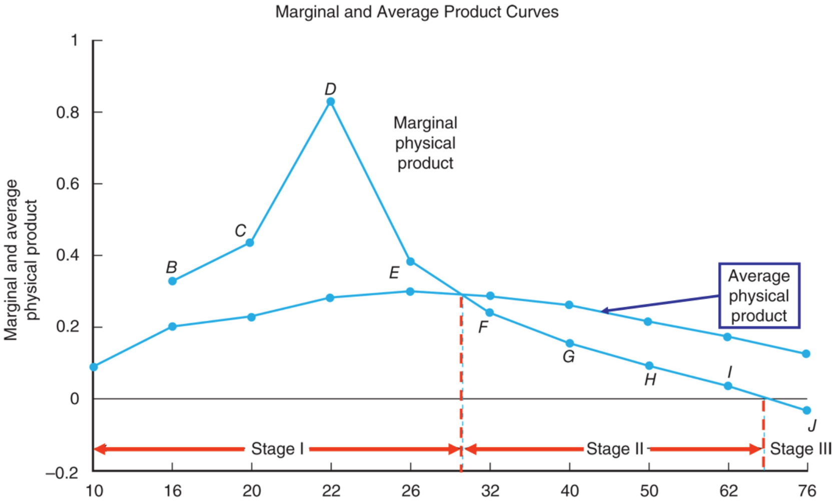


Figure 4 Rational (Zone 2) and Irrational (Zones 1 and 3) zones of production



Relation between physical production and costs

The marginal and average costs of production for variable levels of input use are a mirror image of the physical relationships between the variable input and the total product. This is shown in the four panels below.

In Figure 5 is shown the relationship between physical production responses as more variable inputs are added and the corresponding effects on costs of production. Total, average and marginal costs mirror the total, average and marginal product as more variable inputs are added.

Sound Advice Based on Marginal Revenue vs Marginal Cost

In figure 6 the price of the product being produced is introduced; shown as marginal (extra) revenue. This is the physical quantity of the extra unit of output multiplied by the price of it. The critical lesson to draw from the 4 diagrams in Figures 5 and 6 is that the cost in a farm system that matters to decision-makers is the extra (marginal) cost of a change, whether this is an additional unit of feed to a dairy cow, or an additional dairy cow, with all other inputs held constant.

The extra cost is compared to the extra revenue that results. If extra cost exceeds extra revenue, extra profit is added to all the previous additions to profit produced from all the inputs added previously. When the marginal revenue from an additional unit of input just equals the marginal cost of that unit of input, total farm profit is maximized. This principle is demonstrated in the figure opposite.

Figure 5 Production and cost relationships

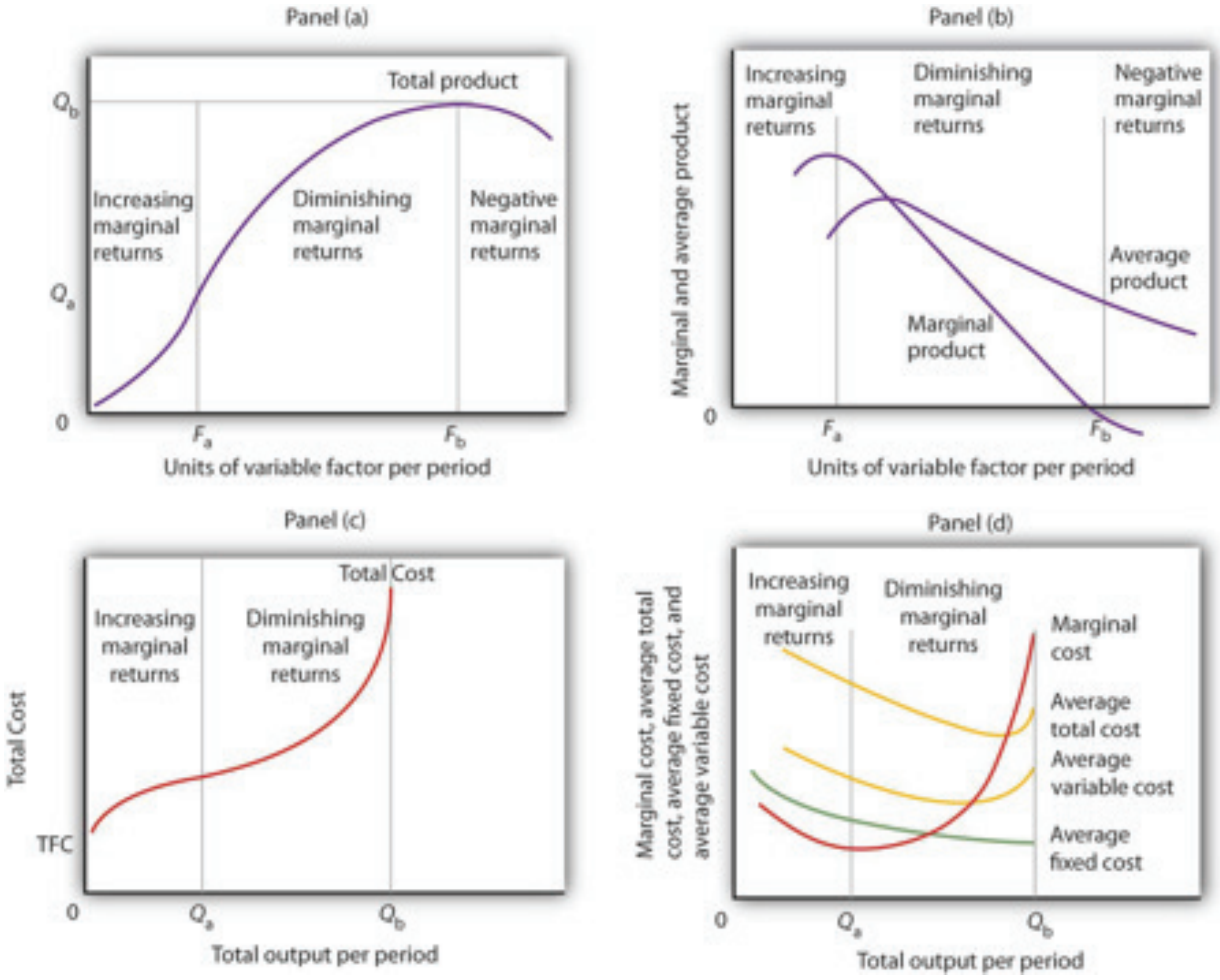
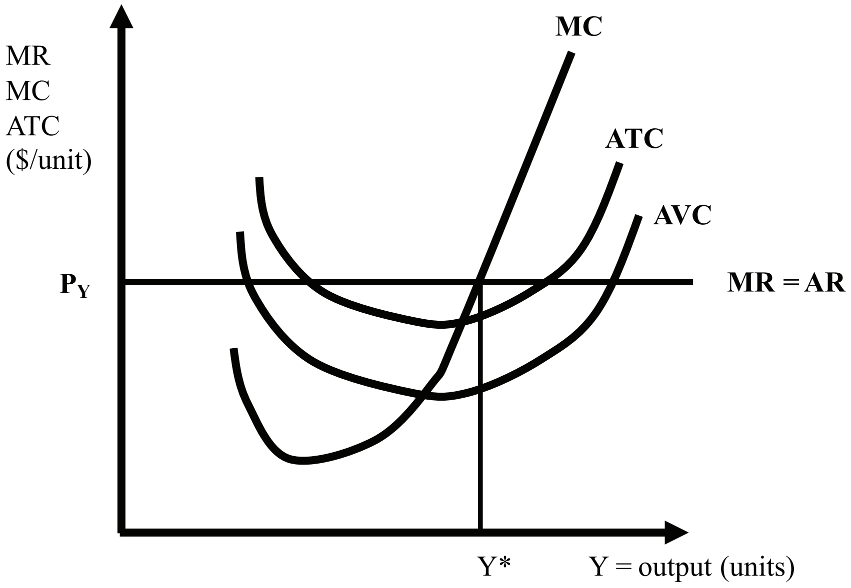


Figure 6 Profit maximizing using marginal principles



The diagram above shows:

- AVC – average variable cost curve as output increases
- ATC – average total cost curve as output increases
- MC – marginal cost curve as output increases
- MR – marginal revenue from each extra unit of output, as output increases (as price received per unit does not change with quantity supplied, MR equals average revenue equals price).

A further point demonstrated in Figure 6 is that minimizing average cost (maximizing average product) does not maximize profit. In figure 6, maximum profit occurs when input level Y* is used and marginal revenue equals marginal cost. This is at a greater level of output than the level of input which maximizes average product and minimizes average cost. This simple notion is often a revelation to accountants and technologists alike.

Equi-marginal marginal returns and maximum profit

Sound advice is thus based on the addition to farm income, called marginal revenue, and addition to farm costs, marginal cost, of an extra unit of any of the inputs in the whole farm production function that are variable in the relevant production period. For example, in the very short run, say a day to day basis, the only variable input over which a dairy farmer might have control over will be feed allocated to the cows. Regardless, the profit maximizing rule is, if working capital was not limited, to use inputs to the farm system up to the level where the marginal revenue of each input just equals its marginal cost. This leads to one further principle — called the principle of equi-marginal returns — which derives from the profit maximizing principles that apply to each input used in the farm system. This principle of equi-marginal returns about how to combine all inputs to make the maximum profit from the whole farm system applies to all the variable inputs in a production year, and to all inputs over a longer time when all inputs can be varied.

As working capital is always limited, the equi-marginal returns profit maximizing rule is modified to:

Profit is maximized over the relevant production period when all inputs are combined such that the ratio of extra income to extra cost of an extra unit of each input are equal. That is, not MR=MC for each input, but MR/MC of input 1 = MR/MC of input 2 and so on, to = MR/MC of input n.

An imperative in applying the principles of production economics to analyse soundly the implications of a change to a dairy system is that all the extra costs and extra benefits of a change are considered. Some of the extra costs and benefits are not obvious, such as the annual depreciation cost of a capital asset.

The cow as capital input

Capital

In economics, the term ‘capital’ has several meanings.

Capital refers to things that can be used in the production of other things (this is what makes capital a factor of production), e.g. a tractor, a cow, permanent pasture.

Capital refers to things made by humans such as dairy, fences, yards, shed, water system, in contrast to ‘land,’ which refers to naturally occurring resources.

Capital refers to physical inputs that not used up immediately in the process of production, that have a life more than one cycle of production, such as breeding animals, unlike raw materials or intermediate goods such as maintenance fertilizer, pasture dry matter consumed. Long-lived livestock in the balance sheet are just like other appreciable and depreciable farm assets.

Capital can refer to funds invested or available, such as an overdraft facility.

Long-lived livestock play a role in production just like the role played by other forms of capital. Dairy cattle require investment early in their life and do not produce output for a couple of years. Then, when they are mature, they produce output for a number of years, having anything from another 2- 3 years to 8-10 years of further productive life. The difference with livestock capital and other farm capital is that livestock capital is a farm input that not only produces output, such as a dairy cow that produces milk and meat, but as well, a cow produces additional livestock which also become part of farm livestock capital. Capital of long-lived livestock is both a farm input that supplies services to the farm system and also an output of the farm system.

Sometimes the term fixed capital is used for the long-lived inputs to production, and variable capital is used for raw materials and intermediate inputs to production that are consumed within a production cycle. In dairy farming cows are fixed capital, supplying an input service over a number of production cycles. If cows were bought into the production system and disposed from the system within a year they would be an intermediate input, like pasture grown and consumed.

The fixed capital that is dairy cows supply several streams of inputs to the farm system: (i) an input to milk solid production, (ii) an input to genetic material of offspring and (iii) an input to replacement of fixed capital and (iv) an input to meat production.

Costs of Capital

As a fixed input to the system, the annual costs of owning — not running — a dairy cow is the same form as the annual cost of owning a tractor or other capital equipment. The ownership costs of capital equipment are:

1. annual depreciation as a result of the asset losing value because of obsolescence or wearing out. This is estimated as (Start of year value - expected salvage value in current dollars at end of life in the system)/(no. of years of expected life remaining in the system). For example, a tractor worth $200,000 at the start of the year, which has an expected 5 years life left at which point it will be worth $50,000 current dollars, has an annual depreciation cost of $150,000/5=$30,000.
2. annual opportunity interest cost of the capital tied up in the machinery. (This is considered when weighing up whether to own a machine or obtain its services in some other way, but in a whole of farm analysis, the capital tied up in the machinery is included in whole farm capital invested, against which an overall opportunity cost is relevant).
3. annual overhead costs such as registration, insurances associated with owning a machine
4. annual shedding costs incurred as a result of owning a machine.

The relevant dairy cow ownership cost is the annual depreciation of the start of year capital value and lifetime depreciation as a result of wearing out or obsolescence. The annual depreciation cost of a dairy cow depends on the value at the start of the year minus the value at the end of the year. The value at the start of the year is determined by the expected profit from the cow over the rest of her life, thus expected milk production, milk prices and feed costs help determine cow value. The salvage value of a dairy cow is determined by the cow-beef price, which has been between $2-$3/kg cwt ($1-$2/lwt) over the past 20 years, with prices only being above this trend in the past couple of years. A 500kg lwt/275kg cwt cow at $2.75/kg cwt would sell for $750. A $1500 investment (a cow) with a life of 5 years and a salvage value of $750 has an annual average depreciation cost of ($1500–$750)/5=$150/cow/year. If the average time of a cow in the herd was 4 years, annual average depreciation cost per cow would be $187.50. If a cow lasted 3 years in the herd, average annual depreciation per cow would be $250.

Years in herd	Annual average depreciation
1	$750
2	$375
3	$250
4	$188
5	$150
6	$125
7	$107
8	$94
9	$83
10	$75

Another way to estimate annual herd depreciation cost is shown in the following example. Suppose we have 500 cow herd, with 100 cows in each of the age groups 2, 3, 4, 5, 6 years old. Suppose the 2-year-old (YO) cows are each worth $1800/head, giving $180,000 capital as 2-year-old cows. Suppose there are no deaths and the 100 six-year-old cows are culled at the end of their 6th year, for $750 each, giving a total of $75,000. The annual herd depreciation is estimated as $180,000-$75,000=$105,000, or $210 per cow per year.

Value of Cow Capital

Annual animal trading profit or loss takes account of all income and costs of the herd during a year. Early in a cow's life she increases in value (income) as she grows from a new born calf to a 1 year old heifer to a springing 2YO heifer to a 2YO cow in milk, then declines in value as her expected life left in the herd declines each year as she becomes a 3YO cow then a 4, 5, 6+ YO cow. Provided the cow continues in the herd, she eventually reaches a salvage value when she is culled from the herd. The salvage value is set by the meat value at the end of her life.

The expected life of the cow in the herd is determined by the management of herd health and critically by the reproduction performance of the cow, as well as the selection pressure imposed to increase the genetic potential of the animals in the herd. Reproduction performance matters because if she does not get in calf she will eventually cease to lactate. Depending on the system, the need for the cow to reproduce may be on an annual cycle, or longer. Regardless, in part, annual herd depreciation cost is a function of the length of life of cows in the herd which is in part a function of cow fertility and reproduction performance and selection pressure applied to pursue genetic improvement. The result is that cow and herd fertility and rate of genetic gain are determinants of the annual depreciation cost of the capital invested in the herd.

The three critical numbers in determining the value of a cow of each age group in a herd, (as well as the annual depreciation of the capital of a dairy cow), is (i) the expected stream of annual future net benefits, (ii) the expected life and (iii) the expected salvage value of the cow.

The stream of annual future net benefits is determined by all the other inputs to the system, both fixed and variable inputs and including management. In the example below, if a capital asset of any form was purchased for $1800 and had a life of 5 years with a salvage value of $750, the asset has to earn a net income each year of $296 to earn 7% return (real not nominal) on the initial capital investment. Another way to put it is that the value of an asset is the present value of the stream of net benefits it will produce, discounted at the required rate of return.

If dairy farmers pay $1800 for a 2 YO heifer to bring into the herd to calve and commence lactating; they expect to get 5 lactations and 5 calves out of her; they expect her to produce 85% of the milk she will produce as a 4 YO; and they expect that at the end of her sixth year (5th lactation) the cow will be culled for $750. If the required rate of return on capital was 7% real p.a., then the cow (capital asset) must be expected to produce net returns to the cow-capital of $252, $267, $296, $296 and $296 over the five years of life in the herd. Note: real risk-free returns to capital in the economy have ranged from 2% to 6% over the past half century. In this example, a real risk-free return to capital of 4% is assumed, plus a 3% risk premium. Now, what follows from this is that this cow capital asset will be valued at the start of each year differently as she passes through each of the age groups in the herd. A 3YO cow that is expected to produce 4 more calves and lactations, amounting to $267 plus 3 further annual streams of net income to the cow capital of $296, at 7% required return on capital, is worth $1656. A 4YO cow generating $296, $296 and $296 is worth $1487; a 5YO cow promising $296, $296 is worth $1274; and a 6YO cow with one lactation left giving $296 is worth $997. Interestingly, even though a 2YO heifer produces only 85% and a 3YO produces 90% of the milk they will produce as a 4+YO cow, the value of the cow declines each year from 2YO as life left in herd declines.

Years	2	3	4	5	Annual average depreciation
Net income*	296**	296	296	296	296
Salvage value					750
Capital investment	1800				
NCF	-1548	267	296	296	1046
NPC	0				
Return on capital	Net Annual Income/cow before depreciation				

* Whole-of-life depreciation is captured by the difference between initial capital invested and salvage value

** This sum is the net return to the cow-capital. Further net returns from the cow are required to give the return to the other capital inputs to the farm system such as land and plant.

Example of Annual Livestock Trading Profit or Loss and Herd Depreciation

The income produced by the fixed asset, the cow, as she increases in value through time, and the cost of the fixed capital of the cow as she loses value from aging and leaving the herd, are all encapsulated in the annual livestock trading profit of the herd.

Effective life of herd capital is determined by the annual average herd cull rate. If, typically, 25% of cows in a steady state herd are culled, the average life of cows in the herd (the herd capital) would be 4 years. If culls are 33% of a steady state herd, the average life of the herd capital is 3 years. If 20% of cows are culled each year from a steady state herd, average length of life of cows in the herd is 5 years. Livestock trading profit accounts for all increase in value and decreases in value of cows through age and remaining life, and cost caused by deaths, as well as annual income produced by the cows producing calves. An example is shown below.

In this simplified example, the milking herd is 500 cows. The timing of the production year is that all cows calve on day 1 of the year and culls occur at the end of lactation. To make the point clear about depreciation cost, the herd, unrealistically, has equal numbers of cows in each age group from 2-6 years old. In the first case, all culls are the 6YO's which are not in calf and are culled for age. All deaths occur in this age group. All cows culled for health reasons come from the 6YO group. All cows from 2-6YO group calve on day one of the production year and lactate and all cows mated — the 2,3,4,5YO age group, get in calf. There are no culls for cows being not-in-calf, other than the cull cows that start the year as 6YO and end the year about to turn 7YO. The 400 cows in the 2-5YO age group of cows are mated and 400 calves born, half male, half female. For the purposes of this analysis, these are valued as if all are sold and the required number of heifer replacements are purchased back as freshly calved 2 year olds. This is the same financial effect as for the typical case where replacement heifers are reared on farm. In this example, 100 6YO cows (20% of the herd) are not mated and are culled each year at the end of lactation. Twenty per cent replacement 2YO heifers are purchased, to commence lactating at the start of the production year. For the values chosen for the cows in the herd in different age groups and the calving performance and cull values, the annual livestock trading loss is $48,750. This is the net effect of all animals produced, capital appreciation and depreciation that occurs in the herd through the year. The depreciation comes from 100 4YO cows worth $1487 at the start of year becoming 5YO cows worth $1274 at the end of the year, and 100 5YO cows worth $1274 becoming 6YO cows worth $997 by the end of the year. The 6YO cows at the start of the year are culled $750/hd for at the end of the year when they are just about to turn 7YO. The 5 cow deaths all occur from the 6YO age group. Reasons for culling are for age and health, amounting to a cull rate of (20%). In this scenario, no cows are culled for poor reproduction performance. If this herd is in a steady state, with the reproduction performance as defined (100% mated 2-5YO cows get in calf), the depreciation cost of this herd each year is $103,764. (See Tables 1&2 below).

Table 1 Livestock Trading Schedule

Class	Opening Number	Opening Value	Total Value	Sales	Number	Closing Value	Total Value
				Culls age/health	95	$750	$71,250
2yo	100	$1,800	$180,000				
3yo	100	$1,657	$165,651				
4yo	100	$1,487	$148,712				
5yo	100	$1,274	$127,417	Males calves	200	$50	$10,000
6yo+	100	$997	$99,724	Excess female calves	200	$250	$50,000
Births	400			Deaths-cows	5		
				On hand at End			
Purchases							
Purchases	100	$1,800	$180,000	2yo	100	$1,800	$180,000
2yo to replace 6yo aged and health culls				3yo	100	$1,657	$165,651
				4yo	100	$1,487	$148,712
				5yo	100	$1,274	$127,417
				6yo	100	$997	$99,724
Total	1000		$901,504	Total	1000		$852,754

Bought in replacements same as if retained the 100 replacements needed and sold all excess as 5-day-old calves.

Trading profit -$48,750

What is changing on this farm business throughout the year?

Table 2 Herd depreciation

Income	Number	Increase in value	Income
calves (bull)	200	50	$10,000.00
calves (heifer)	200	250	$50,000.00
		Total income	$60,000.00

Depreciation	Number	Decrease in value/hd	Cost
Deaths	5	997	$4,986.21
2 to 3	100	143	$14,349.24
3 to 4	100	169	$16,938.94
4 to 5	100	213	$21,295.16
5 to 6	100	277	$27,692.37
6+	95	247	$23,488.08
		Total costs	$108,750.00
		Trading loss	**-$48,750.00**

Herd Fertility and Annual Depreciation Cost

Fertility as an input to a dairy system and a determinant of the annual depreciation cost of herd capital and of herd livestock trading loss

Suppose in a different scenario, total cows culled was made up of the 20% 6YO (with the same 20% for age and for health as in the first case). In this case as well though only 75% of the 400 2-5YO groups mated get in calf. Further, assume the 25% (100) not-in-calf cows are all in the 5YO age group. The Livestock Trading Loss becomes $88,750, a $40,000 increase compared with the case where there was 100% of mated cows in calf and only the 6YO group all were culled for age and health. The increase in livestock trading loss comes from less calves produced and less calf income, more 2YO replacements required, and more annual herd depreciation cost. In this case, the herd annual depreciation cost is $128,488, an increase of $40,000 in livestock trading loss. This comes from $15,000 less calves produced and sold, plus the increase in depreciation. The increase in depreciation comes from the 100 5YO cows that are not-in-calf and thus instead of becoming a 6YO cow worth $997, they are culled for $750, creating the added depreciation: 100*($997-$750) = $24,770, or $247 per 5YO cow not in calf. If one more of the 5YO cows mated got in calf, and had a heifer calf worth $250, this would avoid a depreciation cost of $247 in that year and reduce total herd livestock trading loss by $247+$250=$497. (If the additional cow in calf had a male calf this would reduce livestock trading loss by $297).

For the case where 87.5% of the 400 2,3,4,5 YO cows get in calf — 50 of the 5 YO cows are not in calf — the depreciation is $116,126 and the livestock trading loss is $68,612. in this case, the extra herd depreciation, above the 20% in-calf case, is $13,000 ($260/cow) and extra herd trading loss is $20,000. That is, in this scenario, getting in calf one more of the 50 cows not in calf, with her having a female calf, reduces livestock trading loss by $260+$250=$510/cow ($310/cow for a male calf).

The effects of fertility performance on herd depreciation and trading profit/loss for this example are shown below.

Implications of herd depreciation costs for the whole system

The example above was somewhat stylized in that using a steady state herd with hypothetical conditions to isolate the effects of herd depreciation and livestock trading loss and highlight how herd fertility performance and cull rate affects livestock trading loss. Being such, the example does not reveal the full effects of the reproduction performance on the whole farm system.

Feed System

While the bought-in costs of replacement heifers reflect the actual costs of rearing them on farm in a self-replacing system, the herd reproduction rate achieved has practical management implications throughout the whole system. In practice, with the usual self-replacing system of herd replacement, reproduction performance affects the year-round feed demand that has to be managed by determining the number of replacements to be reared.

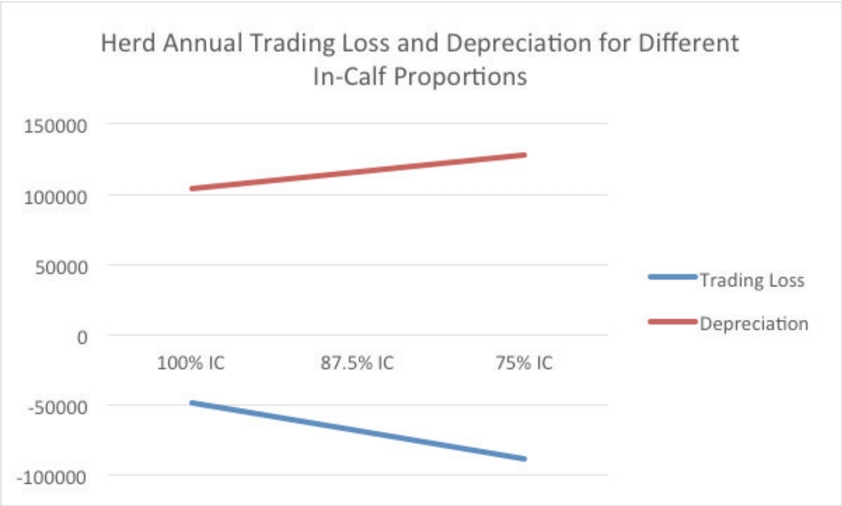
Fertility, genetic gain, selection pressure and herd replacement rates

Herd fertility and reproduction performance and herd replacement rates are intricately entangled, with effects on a steady state herd that simultaneously increase and reduce farm profit. As shown, fertility performance affects herd depreciation and livestock trading profit through animal income produced. Other effects are described below.

Replacement rates of a dairy herd determines the age structure of the herd, which makes relevant the fact that heifers produce 85% the milk solids a 4-7YO cow does, and a 3YO produces 90% the milk solids 4-7YO cow does. High reproduction performance makes it possible to retain relatively more 4-7YO cows in the herd and to introduce fewer replacement heifers. Introducing fewer replacements has the effect of allowing more of the 4-7YO cows to provide their productive services over a longer life span, and saving on AI costs and heifer rearing costs.

Fertility and herd replacement rate affects the degree of selection pressure that can be applied, in turn affecting the rate of genetic gain achieved. Culling can enhance the rate of genetic gain by removing more of the poorer animals from the herd but high culling offsets some of the economic benefit of the genetic gain.

Figure 7 Herd depreciation and In-Calf rates



It is often unrecognized the extent to which the high replacement rates, that can apply when in pursuit of high rates of genetic gain and profits, also has off-setting effects of increasing herd depreciation costs and reducing profit. In addition, high herd replacement rates in pursuit of high genetic gain changes the relative proportions of lower producing 2YO and 3YO cows to higher producing 4-7YO cows, imposing a cost on the business in the short term at least.

At least for a steady state herd size, an approach of containing herd replacement rates has the possibility of generating greater profit than an accelerated culling situation which could results from poor reproduction performance. The same logic, and implications for herd profit would apply to applying unduly high rates of selection pressure in pursuit of genetic gain.

How can you know farming if only finance (or genetics, or animal health or agronomy etc etc) you know? Some implications of applying the whole farm approach for farm management analysis and advice.

What is the whole farm approach? New Zealand's Wilfred Candler sets this out:

Let me first define what I mean by the Whole Farm Approach to management advice. This merely 'refers to advice which has been budgeted to ensure that it really does result in an improved farm plan, from the farmer's point of view'.

'Budgeting allows the best proposal from a number of alternatives to be selected. Unbudgeted advice, on the other hand, is simply bad advice. A soil test alone cannot, repeat cannot, tell you whether it would be profitable for a farmer to put on more or less fertilizer, since profitability depends, inter alia, upon the number of stock run'.

Thus, the Whole Farm Approach is obviously an integral part of a farm management analysis and planning. Occasionally one hears a rather peculiar phrase 'the whole farm approach to farm management'. I say peculiar because this statement implies there is another approach to farm management.

Applying the whole farm approach means recognising that sound economic advice can only come from sound scientific understanding. It also means recognizing that a farm system/farm business is made up of many parts which the farmers fit together into a whole farm — the combination of all things, combined according to the principle of equi-marginal returns. The parts that comprise a farm system can be described in broad categories as being: human; technical; economic; financial; risk and beyond the farm gate. Each part of the farm system affects other parts of the system, which means you cannot identify and solve a problem in a farm system by only looking at one or a few parts of it. To identify and solve a problem it is necessary to first look for and identify all parts of the business and then consider how the parts that seem to be 'the problem' relate to all the other parts that make up the rest of the system. Understanding well how the farm system works is not just the physical operational side but also the financial detail. The best farm managers and their advisors are masters of the human, technical, economic, financial, risk and beyond the farm gate factors. Still, it is surprising how often very good operators who are the absolute masters of the operational side of their business, are at a loss when queried about the finances and the economics of the business. (The same can be said about the 'Captains' of industry and science and R&D and their too often tenuous grasp of commercial realities and whole of industry understanding. We know the idiotype. They operate on a 'I just know' or 'I don't need to know that' basis: the 'Often wrong but never in doubt' brigade. Understanding the essential numbers in the 'books' properly, along with everything else, is critical. Too often identifying all the potential economic consequences of actions and inactions is thought too hard or beyond an advisor's or operator's understanding and so is assumed away or delegated! Economic and financial realities are not so simply dealt with.

If the whole farm approach is the only way to do farm management analysis and planning, what does this mean for the advice of disciplinary specialists, such as soil scientists, agronomists, veterinarians, geneticists who find themselves 'conscripted' unavoidably into trying to answer whole farm questions, solve whole farm problems and develop strategies for growth of whole farm businesses. First, it means recognizing, and respecting, all the disciplinary fields involved in the situation, and then assembling all the key bits of disciplinary knowledge relevant to solving the problem at hand. Then, knowledge and intuition (knowledge from experience) are combined into reasonable expectations and judgements about causes, effects, alternative solutions and possible outcomes.

The whole farm, equi-marginal returns way of thinking about how a farm operates and how it could operate with change, is the very antithesis of the single input focus on Average technical efficiency of inputs. The whole farm approach rules out having a narrow focus on one dimension of the system at the expense of equally important other parts. Another example: the way the benefits of animal genetic gain is promoted combining estimated Breeding Values into $Indices for animals, representing the $Index of animals with combinations of particular genetic traits as being a measure of the addition to farm profit of these extra units of traits in an animal is simplistic – and wrong. This happens, despite the fact that the information about the particular genetic traits of an animal is immensely valuable. Or, equally erroneous, common 'free lunch', 'magic pudding' claims about economic benefits of investments in genetic improvement without counting the necessary costs of lifting the environmental constraints in order to allow the superior genetic potential to be expressed. Also assumed away are the practical matters of time and the effects on the herd performance via effect on dynamics, depreciation and structure. Equi-marginal returns thinking – where is the next investment dollar best spent, and counting all the benefits and costs, is the way to go.

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