Optimizing productive and reproductive performance in the grazing cow

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Abstract

The efficiency of milk production in pasture-based systems is heavily influenced by calving pattern, necessitating excellent reproductive performance in a short breeding season. Where grazed pasture is the major component of the diet, cows are underfed relative to their intake potential. A number of studies have identified body condition score measurements that are related to likelihood of both submission and conception. In general, fertility variables have favourable associations with circulating concentrations of glucose, insulin and insulin-like growth factor-1 and unfavourable associations with non-esterified fatty acids, beta-hydroxybutyrate and endogenous growth hormone. Nutritional strategies to impact these metabolic indicators have been utilised, but effects on herd fertility are inconsistent. Long term selection for improved genetic merit for fertility traits increases the likelihood of pregnancy establishment. This is achieved through more favourable metabolic status, advancing postpartum resumption of cyclicity, improved postpartum uterine health, stronger behavioural oestrous expression and increased luteal phase circulating progesterone concentrations. Use of synchronisation to maximise submission rates can advance the timing of pregnancy establishment and improve calving pattern. Incorporation of sexed semen into the breeding programme can increase the number of female calves born, but at the expense of reduced conception rates. Nevertheless, careful selection of the heifers and cows to be inseminated with sexed semen will minimize the reduction in fertility performance. This review outlines the unique challenges of pasture-based systems, and the roles of nutritional management, genetic improvement of fertility traits, synchronisation and incorporation of sexed semen in the breeding programme in regulating reproductive performance.
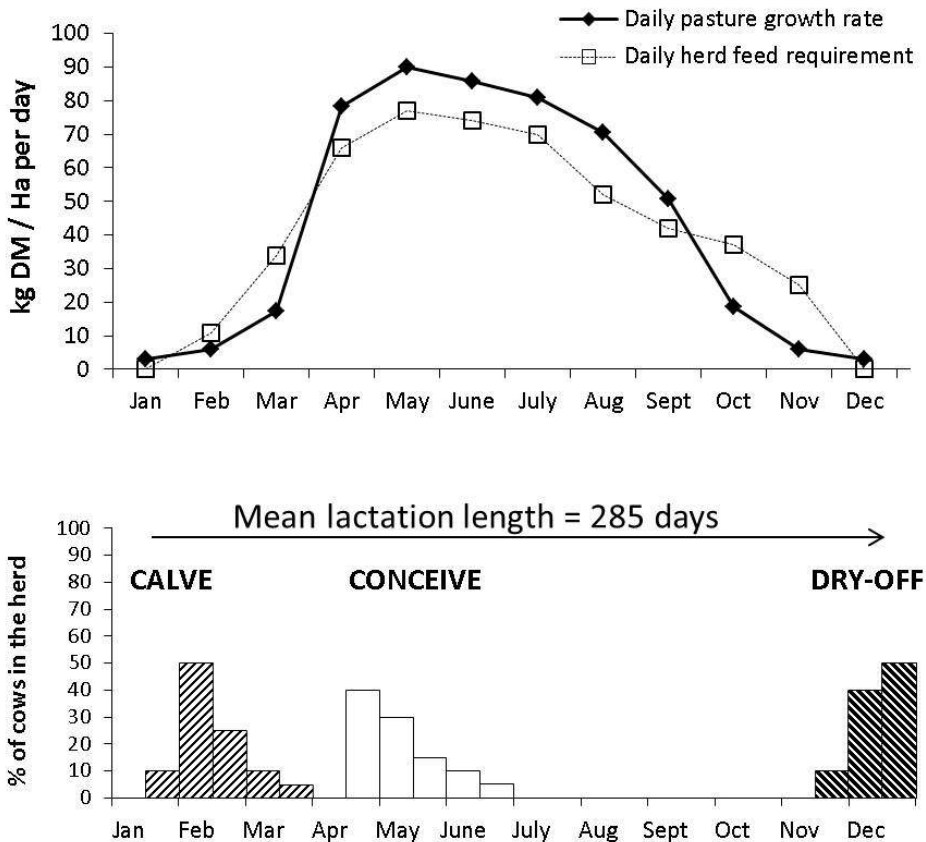
Introduction

The objective of pasture-based milk production systems is to maximise the efficiency with which grazed grass is converted into milk (Dillon *et al.* 1995). Dairy production systems based

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on grazed pasture are primarily located in countries where environmental conditions support long growing seasons. Grass growth follows a seasonal profile; hence, the major challenge for reproductive management is to establish a calving pattern that matches the timing of peak herd feed demand with peak grass growth in late spring/early summer. Ideally, this involves a compact calving pattern in late winter/early spring, a compact breeding period in late spring/early summer, and all cows having a long lactation (mean ~285 days) before dry-off in early to mid-winter. Poor fertility delays peak herd feed demand; the consequences of this include wasted pasture in early spring, inadequate pasture availability in late summer, increased concentrate supplementation, shorter average lactation length and a high proportion of cows with a long dry period (see Fig. 1).

The nutritional management of dairy cows in pasture-based systems is most heavily influenced by the stocking rate on the farm (McCarthy *et al.* 2011). As stocking rate increases, an individual cow is less likely to be able to reach her dry matter intake (DMI) potential, simply as a consequence

Fig. 1. Schematic representation of pasture-based seasonal-calving systems of milk production. Top panel: temporal patterns of pasture growth and herd feed demand. The objective is to match the timing of peak herd feed demand with peak pasture growth rates. Bottom panel: Seasonal pattern of calving, breeding and drying off. A compact calving pattern results in: (i) peak herd feed demand coinciding with peak pasture growth rate; (ii) most cows calved ≥42 days at mating start date; (iii) rapid pregnancy establishment at the start of the breeding period; (iv) most cows having a long lactation on a primarily pasture-based diet; (v) most cows having a dry period of 8 to 10 weeks. Figure courtesy of B. Horan, Teagasc Moorepark and adapted from Holmes *et al.* (2002). Reprinted with permission from Butler (2014) © The Animal Consortium 2014.

of more cows trying to graze a finite amount of available grass. The cow responds by reducing milk yield, but the total milk produced on the farm increases because more cows are being milked. If the stocking rate is excessively high, cows are perpetually underfed and both productivity and fertility are reduced. If the stocking rate is excessively low, pasture is wasted and sward quality deteriorates (Dillon *et al.* 1995, Macdonald *et al.* 2008). The challenge is to identify the optimum stocking rate such that output of milk solids per hectare of land is maximised while individual cow fertility, health and welfare are not compromised. Body conditions score (BCS) is an objective assessment on an animal's available energy reserves, and a large body of evidence exists that underlines the relationship between BCS and reproductive success (Buckley *et al.* 2003, Roche *et al.* 2007). Nutritional management of the pasture-based cow largely revolves around managing BCS through the various phases of the reproductive calendar.

The advent of progeny testing and artificial insemination has markedly improved the production potential of dairy cows in all systems of production and transformed the dairy industry in many countries. Unfortunately, breeding objectives focussed solely on milk production for many years. This resulted in a major decline in genetic merit for fertility traits in most countries. In Scandinavia, however, fertility and health traits (most notably mastitis) have been incorporated into the breeding index for many years. While dairy cow fertility declined in most countries between 1985 and 2005, non-return rates, culling rates due to infertility and calving interval remained relatively constant in the Norwegian Red breed (Refsdal 2007). The incidence of veterinary treatments for reproductive disorders in 503,683 first-lactation daughters of 1,058 Norwegian Red sires was 3.1% for silent heats, 0.9% for metritis, 0.5% for cystic ovaries, and 1.5% for retained placenta (Heringstad 2010). The low incidence of fertility disorders and maintenance of high phenotypic fertility performance provide support for the objective of genetic selection for improved fertility. This review will examine the genetic, nutritional and management strategies that maximise the efficiency of pasture-based systems via improvements in reproductive performance.

Fertility targets for seasonal calving systems

A concentrated calving period necessitates excellent fertility in the preceding breeding season (Fig. 1). Fertility performance targets for the lactating herd in seasonal calving systems have been established (O'Farrell 1994, McDougall 2006, InCalf 2007). These targets are summarized in Table 1. Clearly, it is important that cows have a prompt resumption of cyclicity after calving, exhibit overt behavioural oestrus, and have a strong likelihood of establishing and maintaining pregnancy after insemination. Each of these variables is affected by nutritional status, genetics and herd reproductive management.

Table 1. Fertility targets in seasonal calving systems

Cows calved by MSD[1]	100%
Cows resumed oestrous cyclicity by MSD	≥70%
3 week submission rate[2]	≥90%
6 week pregnancy rate[3]	≥70%
12 week pregnancy rate[4]	≥90%
Breeding season duration	≤12 weeks

[1] Mating Start Date
[2] % of cows bred during the first 3 weeks of the breeding season
[3] % of cows that establish pregnancy during the first 6 weeks of the breeding season
[4] % of cows that establish pregnancy during a 12 week breeding season

Energy Balance, BCS and metabolic indicators

It is generally accepted that energy balance (energy consumed minus energy required for maintenance and milk) is a key regulator of reproductive status (Butler & Smith 1989, Chilliard *et al.* 2000). During early lactation, the energetic cost of milk production can exceed energy consumed, resulting in a prolonged period of negative energy balance (NEB) and consequent mobilization of body tissue reserves. A recent review noted that cows on pasture-based systems are generally thinner than cows on total mixed ration systems (Mee 2012), highlighting that the extent of body fat reserve depletion is likely to be greater. A study on two pasture-based herds in Florida reported that the incidence of elevated non-esterified fatty acid (NEFA) concentrations (≥ 0.70 mM/L) and subclinical ketosis (β-hydroxybutyrate concentration (BHBA) ≥ 0.96 mM/L) in blood samples collected from 771 cows during the early postpartum period was 20% and 35.4%, respectively (Ribeiro *et al.* 2013). In a large survey of cow factors that affect fertility in spring-calving dairy cows in Ireland, both likelihood of submission for AI and likelihood of conception were positively related to nadir BCS, BCS during the breeding season, bodyweight gain during the breeding season and 305-d milk protein concentration (Buckley *et al.* 2003). In addition, it was also noted that 6 week in-calf rate was reduced when cows calved with a BCS > 3.0 and subsequently lost > 0.5 BCS units (Buckley *et al.* 2003). Similarly, the likelihood of pregnancy establishment at first service, following 6 weeks of breeding or following 12 weeks of breeding was positively associated with nadir BCS and negatively associated with post-calving BCS loss and bodyweight loss after the start of the breeding period (Roche *et al.* 2007). Calving at the appropriate BCS (3.00 to 3.25) and minimizing postpartum BCS loss (≤ 0.5 BCS units) are associated with improved reproductive performance (Buckley *et al.* 2003, Roche *et al.* 2007, Ribeiro *et al.* 2013).

Several hormones (insulin, GH, leptin, glucocorticoids), growth factors (IGF1), and metabolites (glucose, NEFA, BHBA) have been identified that are stimulatory or inhibitory to the reproductive axis. In general, these factors tend to increase and decrease in tandem during unfavourable nutritional conditions (Butler *et al.* 2006). Reduced circulating concentrations of insulin, IGF-1, leptin, and glucose, and elevated concentrations of BHBA, NEFA, and glucocorticoids are all associated with impaired reproductive performance. The effects of – and associations between – these different energy metabolites/metabolic hormones on the reproductive axis has recently been reviewed (Butler, 2014).

Nutritional strategies to improve reproduction

At first glance, it would appear that a simple strategy to favourably impact DMI, energy balance, BCS and metabolic indicators linked to reproduction would be to simply provide the grazing cow with additional dry matter via supplementation with high dry matter content concentrate feeds. On well managed pasture-based systems, however, simply supplementing cows with extra concentrate feed (composed of standard ingredients) does not improve fertility performance (Butler 2014). Instead, the additional energy ingested in the form of supplemental concentrate is partitioned to produce more milk. For example, Kennedy *et al.* (2002) reported that the mean milk yield response to additional concentrate in cows stocked at 2.47 cows/ha with high merit for milk production was 0.89 and 1.01 kg milk per kg concentrate DM as annual concentrate input increased from 376 to 810 and 1540 kg/cow, respectively. Corresponding values for cows with medium merit for milk production were 0·66 and 0·74 kg milk per kg concentrate DM, respectively. Similarly, Horan *et al.* (2005) evaluated the milk production response when annual concentrate input was increased from 364 kg/cow to 1452 kg/cow (both treatments stocked at

2.47 cows/ha). The mean milk production response to increased concentrate supplementation in cows of North American ancestry was 1.08 kg of milk/kg of concentrate versus 0.43 kg or milk/kg concentrate for cows of New Zealand ancestry. Clearly, cows with high merit for milk production are genetically disposed towards increasing milk output in response to additional ingested nutrients. This was also noted by Cutullic *et al.* (2011); the milk production response to supplemental concentrate was greater in Holstein cows compared with Normande cows, despite Holstein cows having lower BCS. It can be inferred that when grazed grass is the main or only component of the diet, cows are underfed relative to their milk production potential. The degree that they are underfed is greater in cows with high merit for milk production than in cows with low merit for milk production. Genetic selection for increased milk production potential shifts the hierarchy of nutrient partitioning priorities towards increased milk production at the expense of BCS maintenance/repletion when additional concentrates are supplemented. While this improves day-to-day feed efficiency, it can reduce lifetime efficiency if reproductive failure is an outcome.

The focus of research on supplemental nutrition for pasture based systems in recent years has focussed on specific polyunsaturated fatty acid (PUFA) supplements (McNamara *et al.* 2003, Hutchinson *et al.* 2012a, Hutchinson *et al.* 2012b, Hutchinson *et al.* 2012c). Responses in terms of improved fertility performance have been small or non-existent. This is perhaps not surprising given that grazed grass is high in PUFA throughout the year (Butler 2014). Preliminary investigations have indicated that feeding a supplement composed primarily of non-structural carbohydrates (NSC) in the immediate postpartum period has beneficial implications for resumption of cyclicity and likelihood of pregnancy establishment in pasture-based systems (Burke *et al.* 2010). The improvement in fertility was associated with greater circulating glucose and IGF1. The effect of supplemental NSC feeding on phenotypic fertility needs to be tested in a large scale field trial.

Influence of genetics on fertility

During the latter part of the 20th century, dairy cow breeding objectives in the majority of countries focussed solely on milk production. This inadvertently resulted in a major decline in genetic merit for fertility traits. The recent trends in breeding values for fertility traits and the physiological mechanisms affected by genetic merit for fertility traits have been reviewed (Butler 2013).

Angularity in the dairy cow is a subjective measure of adiposity. In addition to selecting for cows that produced more milk, greater angularity or sharpness was also considered favourable (i.e., cows also *looked* like they produced more milk). It has been well established that BCS is a key driver of cow health and fertility (Berry *et al.* 2003, Buckley *et al.* 2003, Lucy 2003, Weigel 2006, Roche *et al.* 2009, Cummins *et al.* 2012b, Moore *et al.* 2014). Favourable BCS, however, is the opposite of favourable angularity. It is likely that selecting for angularity directly contributed to the decline in phenotypic fertility and increased the incidence of metabolic disorders (Hansen 2000). Selecting for improved BCS has been identified as a strategy to improve health and fertility (Berry *et al.* 2003, Shook 2006, Weigel 2006).

In the US, productive life was incorporated into the index in 1994 and daughter pregnancy rate was added in 2003 (Cole *et al.* 2009). Currently, these two traits account for 33% of the Net Merit index (22% and 11%, respectively). This halted roughly 40 years of a continuous decline in sire and dam breeding values for fertility (Weigel 2006). It has also been reported that the decline in phenotypic fertility performance has similarly been halted and started to improve (Norman *et al.* 2009). In 2003, the mean relative emphasis on production, durability,

and health and reproduction traits across 15 countries was 59.5, 27.9, and 12.6%, respectively (Miglior *et al.* 2005).

In Ireland, during the period from 1990 to 2001, genetic merit for milk yield increased by 25 kg per yr, the proportion of Holstein genes increased from 8% to 63% and the calving rate to first service declined from 55% to 44% (Evans *et al.* 2006). High milk production North American Holstein cows were bred for a confinement based system, where energy dense Total Mixed Ration diets were the standard feeding practice. In a grass based system, the energetic demands associated with milk production could not be met solely by grass DMI, rendering the cows susceptible to excessive tissue mobilisation, negative energy balance, and reproductive failure (Buckley *et al.* 2000b, Horan *et al.* 2004). To address the problem of declining fertility, the Irish national breeding programme introduced a multi-trait selection index called the Economic Breeding Index (EBI) in 2001 (Veerkamp *et al.* 2002). This index included production and non-production traits, thus identifying animals of superior genetic merit for delivering on-farm profit. Each trait is given an economic weighting calculated using the Moorepark Dairy Systems Model (Shalloo *et al.* 2004). As the name 'Economic Breeding Index' suggests, the EBI is designed to identify genetically superior animals for profitability (Veerkamp *et al.* 2002). Currently, the EBI has 6 sub-indexes (relative emphasis in parenthesis); fertility/survival (35%), milk production (33%), calving performance (10%), beef carcase (9%), maintenance (6%), management (4%) and health (3%) (http://www.icbf.com). The fertility sub-index is currently comprised of 2 traits; calving interval (24%) and survival (11%).

Fert+ and Fert- cows

It is desirable to disentangle the effects of high merit for milk yield and poor merit for fertility traits. Cows with high genetic merit for milk production have generally been reported to have poorer fertility than cows with average genetic merit for milk production (Lucy & Crooker 1999, Buckley *et al.* 2000a, Kennedy *et al.* 2003). It is unlikely, however, that high phenotypic milk production *per se* is directly responsible for poor fertility. Indeed, a number of studies have indicated similar or even superior fertility in high yielding cows compared to lower yielding cows (Nebel & McGilliard 1993, Gröhn & Rajala-Schultz 2000, Bello *et al.* 2013). As a result, it is difficult to identify specific mechanisms under genetic control responsible for poor fertility using animal models that differ in phenotypic milk production potential in addition to a wide range of associated phenotypes (milk composition, body weight, feed intake capacity, etc.).

To address this issue, a lactating cow model with similar genetic merit for milk production, but either good (Fert+) or poor (Fert-) genetic merit for fertility traits was recently developed and validated (Cummins *et al.* 2012b). The two groups of cows were managed together under a standard pasture-based system operated in Ireland. This allowed the specific effects of genetic merit for fertility traits to be disentangled from the effects of genetic merit for milk production traits (similar in both genotypes) and environment (similar husbandry and general management). These animals have similar proportions of Holstein genetics, and similar body weight, milk yield and milk composition. Fertility performance, however, is markedly poorer in the Fert- cows compared to the Fert+ cows. The research conducted to date with this animal model has clearly demonstrated that the causes of reduced fertility in the Fert- cows are multifactorial (Butler 2013).

Physiological defects in Fert- cows that occur during the oestrous cycle include a longer oestrous cycle (25.1 vs. 21.0 days; $P = 0.01$) and lesser circulating progesterone (P4) concentrations during the days 5 to 13 of the oestrous cycle (3.84 vs. 5.15 ng/mL; $P < 0.001$).

A large volume of literature supports the pivotal role of P4 from day 5 to 13 of the oestrous cycle in influencing functional changes in histotroph composition (Green *et al.* 2005), structural changes in endometrial glandular duct density (Wang *et al.* 2007), endometrial gene expression (Forde *et al.* 2009), maternal recognition of pregnancy (Mann & Lamming 2001) and likelihood of subsequent pregnancy establishment (Herlihy *et al.* 2013). Inherent differences in circulating P4 concentrations likely represent a key phenotype responsible for fertility differences in these two strains. In addition, the incidence of silent heats (defined as an ovulation event that was not preceded by oestrous behaviour) and the incidence of cows failing to ovulate after expressing oestrus were both increased in Fert- cows (Cummins *et al.* 2012a). Of the oestrus events recorded, 36% fell into the combined categories of silent heats and heats without ovulation in Fert- cows, whereas only 2% fell into the combined categories in Fert+ cows. Interestingly, Cummins *et al.* (2012a) reported that mean circulating oestradiol (E2) concentrations during the period of pre-ovulatory follicle development were similar in both strains. In recent follow-up studies, however, we have observed greater circulating E2 concentrations on the day of oestrus in Fert+ cows (Moore et al. 2014b). It is possible that sub-optimal P4 concentrations in the oestrous cycle pre-breeding interferes with the normal endocrine feedback mechanisms that are required to facilitate appropriately timed oestrous behaviour and ovulation.

Throughout lactation, circulating concentrations of IGF1 are greater in Fert+ cows (Cummins *et al.* 2012b). Despite Fert+ cows having greater circulating IGF1 concentrations, hepatic IGF1 gene expression was greater only in mid to late-lactation. The greater circulating IGF1 concentrations in early lactation appears to be mediated by reduced expression of low molecular weight binding proteins (Cummins *et al.* 2012c), allowing longer IGF1 half-life in the ternary complex (Jones & Clemmons 1995). In addition to greater circulating IGF1 concentrations, Fert+ cows have greater insulin and glucose concentrations during the immediate postpartum period (Cummins *et al.* 2012b, Moore *et al.* 2014). Elevated glucose concentrations in the immediate peripartum period has been linked to likelihood of early ovulation (Butler *et al.* 2006) and likelihood of conception at breeding (Garverick *et al.* 2013). Consistent with their superior metabolic status, Fert+ cows maintained greater BCS during lactation and had reduced BCS loss after calving compared with Fert- cows (Cummins *et al.* 2012b, Moore *et al.* 2014). Maintenance of greater BCS in Fert+ cows during early lactation is facilitated by greater DMI (Moore *et al.* 2014), and requires endocrine signalling to orchestrate appropriate partitioning of nutrients across multiple tissues and organs.

After parturition, the reproductive tract of all cows becomes exposed to microbial pathogens while the cervix remains open after delivery of the fetal-placental unit. The development of uterine disease depends on the type of bacteria involved and on the immune response of the cow, and is associated with reduced subsequent fertility (Sheldon *et al.* 2009). Clinical disease, lower DMI, increased presence of bacteria and greater NEFA and BHBA concentrations during the transition period have been associated with the incidence of endometritis between four and six weeks postpartum (LeBlanc 2012). We examined uterine health in Fert+ and Fert- cows by assessing vaginal mucus scores weekly after calving and also by examining uterine cytology at three and six weeks postpartum (Moore *et al.* 2014). Vaginal mucus score was determined based on the criteria outlined by (Williams *et al.* 2005): (0) clear and translucent mucus; (1) mucus containing flecks of white or off-white pus; (2) < 50% white or off-white mucopurulent material.; or (3) ≥ 50% white or off-white mucopurulent material. Cows were classified as having endometritis if polymorphonuclear neutrophil (PMN) counts were greater than 18% and 10% in uterine cytology samples collected at weeks 3 and 6 postpartum, respectively (Sheldon *et al.* 2006). Both the vaginal mucus scores and uterine cytology results indicated greater incidence of endometritis in the Fert- cows. Despite similar management and housing, Fert+ cows had a

more rapid recovery in uterine health compared with Fert- cows. This likely indicates that the Fert+ cows were capable of mounting a stronger and/or timelier immune response following exposure to microbial pathogens. Endometritis directly affects fertility through the altered local uterine environment, but also indirectly affects fertility through altered follicle development and function (Sheldon *et al.* 2002), delayed resumption of cyclicity (Galvão *et al.* 2010), altered follicle steroidogenesis (Green *et al.* 2011) and development of a smaller corpus luteum (CL) (Williams *et al.* 2007).

Collectively, the findings to date from the Fert+ and Fert- animals underline that genetic progress for fertility traits is possible within the Holstein breed, and that this is possible without any detrimental effect on milk yield. With genomic selection now being routinely used in many countries, progress in identifying sires with good genetic merit for fertility traits will be much quicker than heretofore. The rate of genetic progress at herd level will be further accelerated through genotyping of all replacement heifers as calves, and only keeping those with high genomic proofs to enter the lactating cow herd. It is likely that this will become a common and routine practice within the next few years.

Crossbreeding

In New Zealand, cross-bred cows are now more prevalent than pure-breds, but cross-breeding continues to attract a minority interest in most other countries. The beneficial effects of cross-breeding arise from: (i) introduction of favourable genes from another breed that has been more intensively selected for traits of interest; (ii) removal of the inbreeding depression; and (iii) heterosis (Buckley *et al.* 2014). It is well established that cross-breeding results in hybrid vigour for both production traits (milk yield) and non-production traits (health, fertility). The fertility and survival gains that can be achieved in the F1 cross-bred are remarkable. Under a pasture-based system in Ireland, Prendiville *et al.* (2012) reported that the proportion of cows pregnant to first service (+0.21; P<0.01), in-calf after 6 weeks breeding (+0.19; P<0.05) and in-calf after 13 weeks breeding (+0.08; P<0.05) were greater for the Jersey × Holstein-Friesian compared with Holstein-Friesian and pure Jersey cows.

Synchronisation

In pasture-based systems, AI is generally carried out after spontaneous oestrus (observed or detected with heat detection aids), but targeted or whole-herd synchronisation (+/- timed AI) can be incorporated into the reproductive management to help maximise submission rates. The objective of synchronisation is to control both CL lifespan and the wave-like pattern of follicular growth to ensure that the onset of oestrus and the timing of ovulation are synchronised precisely, allowing a single timed artificial insemination (TAI) without the need for detection of behavioural oestrus (Macmillan 2010). An ideal protocol would result in synchronous ovulation of a dominant follicle with high fertility potential, irrespective of reproductive status or stage of the oestrous cycle at the onset of synchronisation. An injection of prostaglandin $F_{2\alpha}$ ($PGF_{2\alpha}$) causes regression of a responsive CL, whereby P4 concentrations decline rapidly to basal concentrations within 24 hours. This facilitates increased luteinizing hormone (LH) pulse frequency, causing an increase in E2 production by the dominant follicle, induction of an LH surge and ovulation (Diskin *et al.* 2002). Administration of exogenous gonadotropin-releasing hormone (GnRH) also induces an LH surge, and has effects on ovarian follicle development that depend on follicular status at the time of administration. Follicles with a diameter <10 mm

have not acquired ovulatory capacity, whereas follicles ≥ 10 mm can ovulate in response to an LH surge induced by exogenous GnRH (Sartori *et al.* 2001). This results in both the formation of a CL and new follicle wave emergence within two to four days. Progesterone causes a potent suppression of oestrus and ovulation. Consequently, exogenous P4 in the form of intravaginal releasing devices is a powerful tool for the purposes of synchronising oestrus and ovulation in lactating dairy cows (Macmillan *et al.* 1991). Following P4 withdrawal at the end of a treatment period, the rapid drop in circulating P4 concentrations promotes a synchronous oestrus in treated cows, allowing for AI of large numbers of animals (Macmillan & Peterson 1993).

The Ovsynch protocol combines use of GnRH and $PGF_{2\alpha}$ as follows: an injection of GnRH, an injection of $PGF_{2\alpha}$ seven days later, a second injection of GnRH 56h after the $PGF_{2\alpha}$ injection followed by TAI 16 to 20 hours later. In theory, the first GnRH causes an LH surge, ovulation of a dominant follicle and new wave emergence. The $PGF_{2\alpha}$ induces luteolysis 7 days later, and the second GnRH synchronises ovulation of the dominant follicle that arose from the new wave that emerged after the first GnRH (Pursley *et al.* 1995). Since the initial development of Ovsynch, strategies to increase the likelihood of conception after TAI have focussed on development of pre-synchronisation protocols to control the stage of the oestrous cycle when the Ovsynch protocol begins. These include: (i) Presynch-Ovsynch, which utilises two injections of $PGF_{2\alpha}$ given 14 days apart 10 to 12 days before initiating Ovsynch (Moreira *et al.* 2001); (ii) Double-Ovsynch, which utilises one Ovsynch for presynchronisation followed 7 days later by a second Ovsynch for breeding (Souza *et al.* 2008); (iii) G6G, which utilises $PGF_{2\alpha}$ followed 2 d later by GnRH before initiating the Ovsynch protocol 6 days later (Bello *et al.* 2006). These protocols are all quite long; the duration of Presynch-Ovsynch, Double-Ovsynch, and G6G are 34, 27 and 18 days, respectively, from the date of first injection to TAI. This is acceptable in confinement dairy systems with year-round calving. In seasonal-calving systems, long protocols are not practical for "late-calving" cows, but these are the cows that farmers are likely to be interested in synchronizing. Late calving cows (calved < 6 weeks at mating start date) have greater likelihood of being anoestrous and lower likelihood of submission for insemination at the start of the breeding season compared with early calving cows.

The Ovsynch protocol has been evaluated in seasonal calving systems. Fertility results were satisfactory in cows that had a CL on the ovary, had calved >80 days, and were in BCS >3.0 at protocol initiation (Herlihy *et al.* 2011, Herlihy *et al.* 2013). However, these cows are also the least likely to require synchronisation. The Ovsynch protocol is not a suitable protocol for anoestrous cows as it results in low conception rates and high embryo mortality (Herlihy *et al.* 2013). Adding an intravaginal P4 releasing device to an Ovsynch protocol resulted in conception rates that were approximately similar to cows that were not treated, but advanced the timing of insemination and pregnancy establishment (McDougall 2010, Herlihy *et al.* 2011, Herlihy *et al.* 2013). Importantly, the duration of the protocol from start to finish is 10 days, making this a suitable protocol for pasture-based systems. Given that "normal" conception rates can be achieved with a P4-Ovsynch protocol, the calving pattern can be improved by maximising submission rate at the start of the breeding period. The impact on herd calving pattern will be greatest where existing heat detection efficiency is poor.

Sexed semen

Sexed semen is now widely available in dairy industries around the world (Seidel 2012). The process distinguishes X- and Y-chromosome bearing sperm by measuring differences in fluorescence following staining the sperm with a non-toxic, DNA-binding dye (Hoechst 33342) (Johnson *et al.* 1987). Despite reliably producing approximately 90% gender bias, the fertility of the

sexed semen product is compromised (Borchersen & Peacock 2009, DeJarnette *et al.* 2009). The importance of reproductive performance is emphasised in seasonal production systems compared to year-round production systems, and is a key factor in determining profitability on pasture-based dairy farms (Veerkamp *et al.* 2002, Beukes *et al.* 2010). As a result, the uptake and usage of sexed semen to date has been limited in seasonal pasture-based systems. Nevertheless, sexed semen may have a role in seasonal calving systems (Butler *et al.* 2014). The potential advantages of incorporating sexed semen include greater heifer numbers at the start of the calving period, easier management of replacement heifers, more rapid herd expansion, improved biosecurity, elimination of low value male dairy calves and greater output of (higher value) beef crossbreed calves (Butler *et al.* 2014). In Europe, the dismantling of the EU milk quota regime in 2015 will allow farmers to expand herd size and milk output for the first time in a generation. Expansion will be quicker and more profitable if sexed semen is used compared with using conventional semen only (Hutchinson *et al.* 2013a, Hutchinson *et al.* 2013b). Availability of a sexed semen product with minimally impaired fertility would be extremely attractive to dairy farmers. Incremental improvements in the sorting technology will be developed over time, reducing the current gap in fertility performance between sexed semen and conventional semen. Data exists indicating that some bulls have little or no reduction in fertility after sorting (DeJarnette *et al.* 2010). Unfortunately, at this moment, there is no way to identify in advance sires that will maintain similar fertility after sorting. Is it possible to identify cows within a herd that are likely to have better likelihood of conception with sexed semen? Butler *et al.* (2014) reported that lactating cows that were both ≥ 63 days postpartum and were in BCS ≥ 3.00 had conception rates of 51% with sexed semen on a pasture based system. Clearly, sexed semen should be targeted at the higher fertility animals in a herd (i.e., early calving cows in good BCS). Successful integration of sexed semen into herd reproductive management to generate only the required number of heifers could effectively eliminate the unwanted (and low-value) male dairy calf, and completely change the economics of beef production from the dairy herd.

Conclusions

Fertility is the cornerstone of efficient pasture-based systems. Genetically selecting for improved fertility performance will yield dividends over time, but progress is slow. This progress can be accelerated through cross-breeding. Nutritional management should revolve around maintaining appropriate BCS at the various stages of the gestation-lactation cycle and ensuring that any deficiencies in the grazed pasture are compensated in the total diet (e.g., macro- or micro minerals). The key driver of calving pattern is submission rate. If this is unsatisfactory, targeted synchronisation should be adopted as a strategy to achieve maximum submission rates at the start of the breeding season. Sexed semen presents many potential advantages to the management of the seasonal calving dairy herd, but with reduced fertility performance, it's incorporation into breeding programme must be carefully considered and managed.

Acknowledgements

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