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A preliminary study on the feasibility of two different cow-calf contact systems in a pasture-based, seasonal calving dairy system: effects on cow production and health

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Internationally, consumer dissatisfaction with cow-calf separation at birth has led to increased interest in alternative calf−rearing methods, specifically cow-calf contact (**CCC**) systems. The objectives of this preliminary study were to estimate whether CCC could be incorporated into an Irish spring-calving, pasture-based system, and to investigate the effects on cow milk production and health. Three systems were compared: the conventional Irish system (**CONV**;18 cows), cow and calf were separated < 1 h postbirth, cows were pasture-based and milked twice-a-day; a full-time access system (**FT**;14 cows), cow and calf were allowed constant, unrestricted access, were pasture-based, and cows were milked twice-a-day; and a part-time access system (**PT**;18 cows), cow and calf had unrestricted access when indoors at night, cows grazed outdoors by day while calves remained indoors, and cows were milked once-a-day in the morning. Cows were blocked and balanced across the three systems by previous lactation machine milk yield (**MMY**), BW, and body condition score (**BCS**). Following an 8-week CCC period, all calves were weaned (FT and PT underwent a 7-d gradual weaning and separation process) and all cows were milked twice-a-day. Cow MMY was recorded daily and milk composition was recorded weekly; milk data were analysed from weeks 1 to 8 (CCC period), weeks 9 to 35 (post-CCC period), and weeks 1 to 35 (cumulative lactation). Cow BW and BCS were taken weekly for weeks 1–12, and at the end of the lactation. During the CCC period, all systems differed (P < 0.001) in MMY (mean ± SEM; 24.0, 13.6, and 10.3 ± 0.50 kg/d for CONV, FT, and PT cows, respectively). After the CCC period, CONV MMY (20.2 ± 0.48 kg/d) remained higher (P < 0.001) than the FT (16.6 kg/d) and PT cows (15.7 kg/d). The FT and PT cows yielded 24 and 31% less in cumulative lactation MMY and 26 and 35% less in cumulative lactation milk solids yield, respectively, compared to CONV (5 072 ± 97.0 kg and 450 ± 8.7 kg). During the CCC period, somatic cell score was higher (P = 0.030) in PT cows (5.15 ± 0.118) compared to FT cows (4.70 ± 0.118), while CONV (4.9 4 ± 0.118) were inconclusive to both. The PT cows (523 ± 4.9 and 520 ± 6.8 kg) were heavier than the CONV (474 ± 4.9 and 479 ± 6.8 kg) and FT (488 ± 4.9 and 487 ± 6.8 kg) cows at week 4 and week 8 (both P < 0.001). The PT cows had higher BCS than CONV and FT at all observed times. This preliminary research suggests that although CCC was incorporated without impacting cow health, the two CCC systems investigated negatively affected cow production.

Implications

In this preliminary study investigating cow production and health, we compared three different calf−rearing systems that differed in cow-calf contact and milking frequency, applied within the Irish seasonal-calving, pasture-based dairy system. We found that cow production was lower for cow-calf contact cows both during the cow-calf contact period and after the calves were weaned. Cow health did not appear to be affected by cow-calf contact. This research identifies issues with cow production within pasture-based cow-calf contact systems, which will help to direct future pasture-based cow-calf contact research; successfully achieving cow-calf contact will require modification of management in these systems.

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Introduction

Pasture-based dairy systems are predominant in certain temperate countries, such as Ireland and New Zealand, where grass grows nearly year round (Hurtado-Uria et al., 2014) and thus provides a nutritious, economic feed source for dairy cattle (Shalloo and Hanrahan, 2020). To ensure that the cows' nutritional demands match the seasonal fluctuation of grass growth (Dillon et al., 2005; Horan et al., 2005), the majority of dairy farmers in these countries utilise seasonal (i.e. spring) calving. In Ireland a compact, spring-calving dairy system is generally applied, meaning 90% of the cows calve within a 6-week window, centred on mid-February (Shalloo and Hanrahan, 2020). Although consumers consider pasture-based dairy systems more desirable than indoor systems (Schuppli et al., 2014; Ventura et al., 2016), consumers still have welfare concerns about cow-calf separation soon after birth (Sweeney et al., 2022). Separating cow and calf soon (< 2 h) after birth is a common management practice and has been used for many reasons, including increasing saleable milk and reducing calf health risk. However, consumers, researchers, and farmers are conflicted on whether the practice is beneficial or harmful for animal welfare. In contrast to this, cow-calf contact (**CCC**) systems are a type of management system that allow calves to have some contact with either their dam, or a foster cow, for a period of time (Sirovnik et al., 2020). A recent scientific opinion paper from the European Food Safety Authority Panel on Animal Health and Animal Welfare (2023) has recommended that dairy farmers keep cows and calves together for at least 24 h, and has stated that longer periods of contact between cow and calf should be implemented in future. However, most international CCC research has been conducted on indoor housing systems with year-round calving (i.e. Barth, 2020; Wenker, et al., 2022; Neave et al., 2024). For CCC to be implemented in Ireland, it is preferred to integrate it into the pre-existing pasture-based, compact calving system, and it should increase animal welfare without decreasing human welfare or majorly affecting productivity.

Cows in CCC systems have a decreased machine milk yield (**MMY**) during the nursing period (Barth, 2020; Johnsen et al., 2021; Ospina-Rios et al., 2023). After this time period, research varies on whether or not the cow's cumulative lactation MMY and daily milk yield after weaning and separation are impacted. Although a review (Meagher et al., 2019) concluded that CCC did not have a negative impact on cumulative lactation MMY, the research described within their review was variable, both in the CCC systems investigated and the results they provided, and the majority of included studies were indoor systems. The impact of CCC on milk components (fat, protein, and lactose concentration), and thus milk solids yield (**MSY**), should also be considered as calf nursing has been shown to reduce milk fat concentration of machine-harvested milk (Bar-Peled et al., 1995; Barth, 2020; Wenker et al., 2022). Dairy farmers are also concerned with the risk of mastitis in CCC cows (Neave et al., 2022). Although two reviews (Johnsen et al., 2016; Beaver et al., 2019) concluded that suckling was beneficial in reducing the risk of mastitis, the majority of studies were not performed on pasture-based dairy farms with spring-calving. Monitoring the udder and teats is another important aspect, as the risk of udder damage during CCC was noted as a concern for dairy farmers (Neave et al., 2022), teat damage has been observed previously (Ospina-Rios et al., 2023), and udder conformation can impact the calf's ability to nurse (Edwards and Broom, 1979; Edwards, 1982; Ventorp and Michanek, 1992). Other than udder-based concerns, the health of cows has often been considered to not be impacted by the CCC system. However, regular health-related scoring, including measurements of BW, body condition score (**BCS**), injury status, locomotion score (lameness), and clinical health scoring, should be used to monitor cow health status when comparing systems.

This preliminary study aimed to investigate whether dam-calf CCC rearing could be incorporated into the pre-existing Irish spring-calving, pasture-based dairy system and estimate the effects on cow production and health. We implemented two different CCC rearing systems that varied in housing environment and milking frequency and compared them to the conventional dairy and rearing system in Ireland (cow and calf separated at birth and milked twice a day). We were specifically interested in the differences between the systems regarding cow performance (cumulative and average MMY, MSY, and milk composition) and cow health, both in terms of overall health (BW, body condition score, clinical health, and locomotion) and udder health (mastitis incidence, somatic cell score (**SCS**), and udder conformation).

Material and methods

Animals, management, and study design

This preliminary study was conducted from 20 January 2021 to 14 November 2021 at Teagasc Moorepark Research Farm, County Cork, Ireland. Calf-associated measurements can be found in Sinnott et al. (2024). The three systems compared were the conventional dairy and rearing system in Ireland (**CONV**), where dam and calf are separated < 1 h postbirth, cows were pasture-based (24 h/d) and milked twice a day; a full-time access (**FT**) system, where dam and calf had constant, unrestricted access to each other, the pairs were pasture-based, and cows were milked twice a day; and a part-time access (**PT**) system, where cows went outdoors during the day to graze while their calves remained indoors, and to ensure cows had sufficient milk for calves when they returned indoors at 1500 h PT cows were not milked in the afternoon (milking occurred once-a-day (**OAD**) in the morning at 0800 h). All multiparous cows enrolled in the study had no previous experience raising a calf in their previous lactations; thus, cow-calf contact was novel to all experimental cows. As the research farm was 100% spring-calving (January to March), all trial cows were selected before the start of the calving season (early January). Fifty-four cows of the following characteristics were blocked and balanced equally across the three different systems (CONV, FT, and PT) by (mean ± SD, where applicable): cow breed (70% Holstein-Friesian and 30% Holstein-Friesian × Jersey (> 25% Jersey)), parity (mean = 2.4; range 1–5; 16 parity 1, 19 parity 2, 19 parity 3 +), previous 35-week lactation cumulative milk yield (4 677 ± 1 047.4 kg; in the case of primiparous animals this was based on their dams first lactation milk yield), previous lactation SCS (4.9 ± 0.44; in the case of primiparous animals this was based on their dam's first lactation SCS), precalving BW (599 ± 65.8 kg), precalving BCS (3.22 ± 0.173; 5-point scale; Edmonson et al., 1989), expected calving date (16 February 2021 ± 15 d), expected calf sex and breed (sexed semen artificial insemination – dairy bull, conventional artificial insemination – dairy bull, natural insemination – beef bull), and Economic Breeding Index (€176 ± €33.9; see Berry et al., 2005 for more details). Trial cows entered the systems once they had calved, which occurred over an 8−week period (a typical distribution for the Irish system). The randomised complete block design was completed by an individual independent of the study using Microsoft Excel. Sample size calculations were completed, based on previous experimental results, using cow daily MMY and calf plasma immunoglobulin G, and gave a group size of 18. Eighteen cow-calf pairs were enrolled per system, but four pairs from the FT group had to be removed early in their lactation and were not replaced due to lack of additional cow availability.

One FT cow (parity 1) was removed at 3 days in milk due to failure to bond with her calf. Three FT cows (one parity 3 and two parity 4) were removed due to their calves becoming sick and requiring intervention (i.e. removal from dam to be placed into a hospital pen in the calf shed for treatment and monitoring; done at the discretion of the farm manager and veterinarian) at 10, 11, and 14 days in milk. One PT pair (parity 2) was removed from the system at 11 days in milk due to calf illness, but this occurred early enough in the calving season that we were able to replace the pair with a similar cow yet to calve. One PT cow (parity 3 +) was culled from the herd at week 11 of lactation for reasons unrelated to this experiment, so was retained in all analyses where appropriate (included in all CCC period analyses but not included in milk data analysis of weeks 13–35 or weeks 1–35). Final cow numbers per system for analysis were: CONV system, 18 cow-calf pairs (13 female dairy calves and five male beef calves); FT system, 14 cow-calf pairs (10 female dairy calves, two female beef calves, and two male beef calves); PT system, 18 cow-calf pairs (10 female dairy calves, one male dairy calf, two female beef calves, and four male beef calves). Caretakers and researchers were not blind to the systems due to the highly differentiable attributes of each system. Measurements were performed using each individual cow as the experimental unit. This trial consisted of two phases: the active experimental phase (calving to week 12 of lactation; including the CCC period and weaning and separation) and the rest of the lactation (weeks 13–35).

Management of different systems

Conventional cows and calves were separated within 1 h post-birth. After separation, colostrum was collected from the CONV cows; following which they joined a grazing herd where they were managed independently following typical Moorepark grazing management practices (see below for more details). Conventional cows were offered a predominantly grazed grass diet (> 85%), did not come into contact with any calves, and were milked twice-a-day (0700 and 1500 h).

The FT cows were allowed continuous (24 h/d), unrestricted access to their calves, apart from milking times, until weaning and separation, which occurred during their 9th week of lactation (more information on weaning and separation can be found below). The FT pairs were kept together primarily outside on grass, but were housed indoors depending on weather and grass availability (see grazing management section for more details). When the FT pairs were housed, they had access to identical but adjacent facilities to the PT pairs, as described below (and in Fig. 1). The FT cows were milked twice-a-day (0800 and 1600 h); during milking times calves were left at pasture, separated outside the collecting yard, or, in the straw-bedded pen, if indoors, and were reunited immediately after milking.

The PT cows were allowed part-time (17 h/d), unrestricted access to their calves until weaning and separation, which occurred during their 9th week of lactation. During the night (1500–0800 h), the PT cows were housed indoors in the cubicle area (Fig. 1) and the gates that connected the calf pen and cubicle area (creep area) were open, allowing calves to enter the cubicle area. Cows could not access the straw−bedded calf pen. When indoors, cows were provided with *ad libitum* grass silage; PT calves were also able to access the grass silage during contact times once they were tall enough to reach over the feed bunk. The PT cows were milked OAD in the morning (0800 h). Part-time cows were not milked in the afternoon to ensure that they would have milk when they returned to their calves in the afternoon and to reduce the labour associated with the system. The PT calves were not supplemented with any milk. If calves were in the cubicle area at the time of milking, they were moved to the calf pen and the gates were closed, preventing calf access to the cubicle area during the day. After morning milking, cows went outside to grass (a separate paddock to the FT pairs) where they stayed until 1500 h, when they

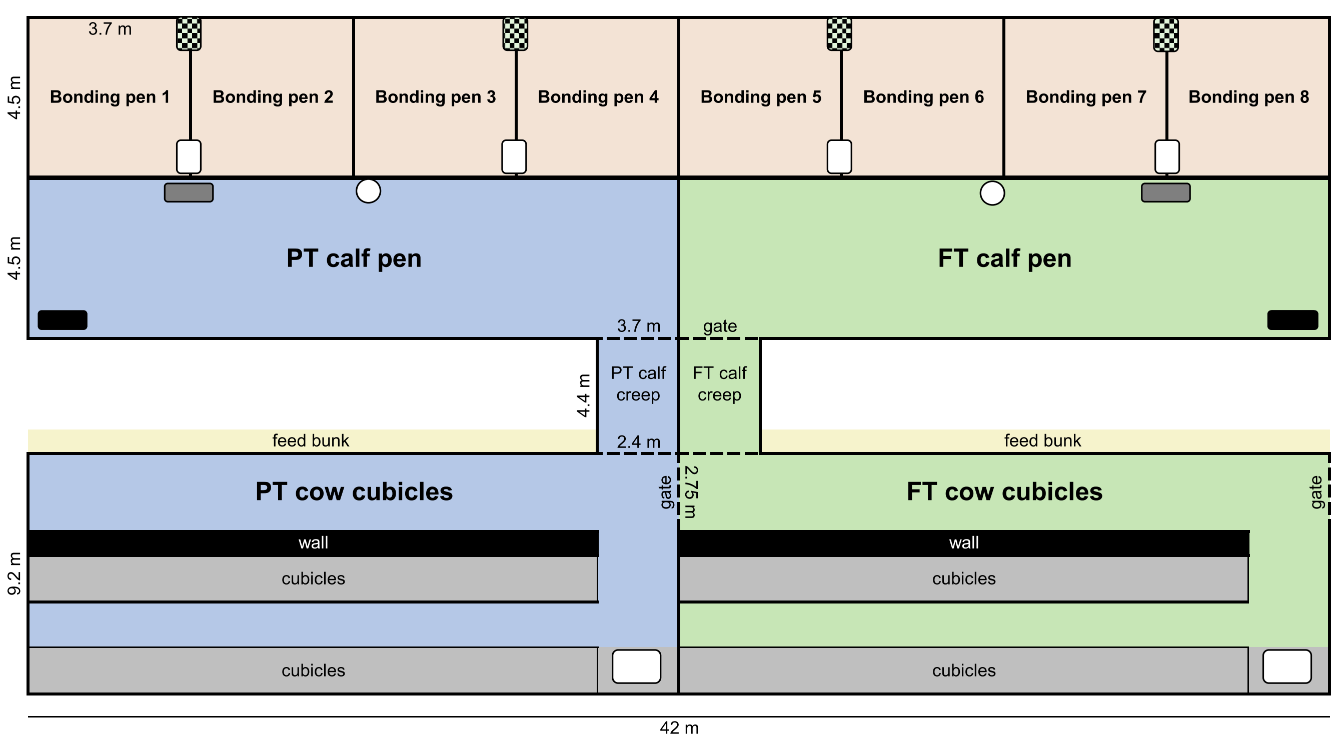

Fig. 1. Indoor housing and pens, including the bonding pens, for cow-calf pairs in the full-time access (FT) and part-time access (PT) cow-calf contact systems. White-filled boxes and circles represent water troughs, black-filled boxes represent concentrate feeders, grey-filled boxes represent forage (hay) feeders, and black and white boxes represent grass silage feeders. The gates separating the FT and PT calf pens from the bonding pens were solid and did not enable any contact between groups. The gate between the FT and PT calf pens, creep areas, and cubicle areas did allow for physical contact between groups. The diagram represents a portion of a shed.

returned directly inside to be reunited with their calves. The PT cows returned to twice-a-day milking as soon as weaning commenced (start of week 9 of lactation). During periods of inclement weather when it was deemed unsuitable to let cows out to grass by day, PT cows remained housed indoors, where they could see and hear their calves but had no access (gates separating the calf pen from the cubicle area were closed).

Selection of different systems

As the success of pasture-based dairy production systems relies on maximising the number of grazing days and amount of grass that can be utilised (Kennedy et al., 2005), it was necessary for this preliminary study to choose CCC systems that would work in tandem with the pre-existing system (CONV). The FT system was chosen as it mimicked the conventional, pasture-based system in Ireland, with the addition of keeping calves with their dam at grass (as well as indoors). However, as we thought that the FT system may not be feasible in non-experimental settings for various reasons (i.e. concerns about calf health during inclement weather and cold temperatures at pasture, additional labour requirements, and health and safety issues associated with the systems, such as separating cows from calves at milking times), we also chose to include the PT system. We thought that the PT system, which allowed calves to be kept indoors, would eliminate the pasture-related calf health concerns. To ensure that cows had milk when returning to their calves (lowering the risk of teat damage), we decided that the PT cows would only be milked OAD in the morning. Early lactation OAD milking is a common strategy on seasonal calving dairy farms to reduce labour (Deming et al., 2018; Edwards et al., 2020; Kennedy et al., 2021). We acknowledge that there were several other iterations of the CCC systems that we could have implemented, however, we chose these two CCC systems as we felt they would be the most feasible within an Irish context.

Precalving (dry period) management

During the dry period, prior to the experiment, all cows were managed similarly. Target dry-off BCS was 2.75 (5-point scale; Edmonson et al., 1989), to allow for a target calving BCS of 3.25. Cows were housed indoors in a cubicle shed, provided with access to *ad libitum* grass silage and water, and supplemented with concentrates (1 kg/d) and prepartum minerals. Cows were closely monitored and when calving was imminent (within 3–5 days) cows were moved from a cubicle shed to a straw-bedded pen located adjacent to the calf house. None of the trial cows calved in the cubicle shed.

Calving management and the bonding period

Immediately before calving, cows were brought into individual maternity pens. Conventional system cows and calves were separated within 1-h postbirth and treated as described in the above section. For CONV cows, cow-calf separation was performed by farm staff or a researcher during the day (0630–1830 h) and by a night-watchman during the night (1830–0630 h). Full-time and PT pairs were not separated at birth but moved to an individual bonding pen (Fig. 1; approx. 17 m^2) in a separate shed postcalving, where they stayed for a minimum of 48 h to allow for bonding. The pairs were not disturbed or removed during this period, except for the calf being removed for < 5 min for a blood sample taken 24 h postbirth (to test for immunoglobulin G levels, data not included here). The pen had a water bowl and the cow was provided with *ad libitum* grass silage. The calf was not artificially fed colostrum, but rather nursed colostrum from its mother. Calves were not assisted in suckling, but the pairs were frequently monitored by researchers and farm staff to ensure bonding and nursing was occurring (approximately once every 1–2 h during the day; if lack of bonding was suspected, the night-watchperson was asked to check the pair 1–2 times during the night). Only on one occasion (described above) did a cow reject her calf (cow and calf stayed on separate ends of pen, farm staff intervened to provide colostrum) and thus was removed from the trial. Failure to bond was suspected in another pair (disinterest from cow, but no violence detected towards the calf), but after being given an extra bonding day, were determined to have bonded sufficiently (cow appeared interested in calf and multiple nursing events were observed). Both instances occurred in parity one cows. Cows were milked for the first time in the milking parlour at the next scheduled milking after the 48 h bonding period was complete, and cows and calves joined the rest of the pairs in their respective system at this time.

Milking management

All cows were milked using a mid-line, 30 unit side-by-side parlour (Dairymaster, Ireland). The automatic cluster removers had a milk flowrate cut-off point of 0.2 kg/min with a 3 s time delay. Unless the specific system required it, the standard farm milking times were 0700–0900 h (morning milking) and 1430–1630 h (afternoon milking).

Grazing management

The experimental paddocks consisted of a permanent grassland site, which was approximately 7 years old at the time of the experiment; the pasture primarily consisted of perennial ryegrass (*Lolium perenne* L.) and white clover (*Trifolium repens*). Pastures were rotationally grazed, with a target postheight of 3.5–4 cm during the first grazing rotation and 4–4.5 cm from the second rotation onwards. Fresh pasture was allocated, using a single−strand temporary electric fence, after every milking during the first grazing rotation (start 30 January 2021; 62 d long); from the second rotation onwards pasture was allocated on a 24 h basis. Calves in the FT system were able to walk under the temporary electric fence and access the fresh pasture. Each system was allocated an individual farmlet that was grazed rotationally. Pastures were of similar age, composition and soil type for each system. While all systems grazed individually, they were located in adjacent paddocks to ensure pastures of similar composition were offered simultaneously.

In the CONV and FT systems, a total daily allowance (pasture and concentrate) of 18 kg DM/d was offered to each cow. The rate of concentrate supplementation ranged from 1 to 4 kg/d and was dependent on grass availability (i.e. if 16 kg DM/d of grass was available, 2 kg/d of concentrates was provided). Concentrate supplementation was common across all systems and was provided in the parlour during milking by an automatic concentrate feeder (CONV and FT cows split evenly between the morning and afternoon milkings; PT cows received all at morning milking). If the feed deficit (i.e. low grass availability) was so large that more than 4 kg concentrate/cow per d was required, grass silage was offered to meet the remainder of the deficit. Conventional and FT cows grazed fulltime (day and night) from 26 February to the end of the study period (14 November), except during periods of inclement weather or low grass availability, and during weaning and separation for the FT cows.

In the PT system, pasture was allocated to achieve a postgrazing height of 3.5–4 cm during their 6 h grazing window; they were offered *ad libitum* grass silage when indoors at night. Part-time cows grazed by day until after weaning and separation (described in more detail below). After weaning and separation, PT cows grazed fulltime until the end of the study.

During periods of moderate inclement weather, restricted access to pasture was practised (on/off grazing), to minimise the risk of poaching/pugging damage (Kennedy et al., 2009; Kennedy et al., 2011). During on/off grazing periods, the cows grazed for 3 h periods after each milking (6 h/d total). When removed from the paddock, they returned to their respective housing (see above for more details). The same management strategy for the CONV and FT cows was used during periods of low grass availability (30 January 2021 to 26 February 2021) during the first rotation. As the PT cows only ever grazed by day (6–7 h/d) during the CCC period and could not graze after the afternoon milking due to their system requirements (indoors by night with calf), they never practised on–off grazing. During periods of severe inclement weather, when cows needed to be housed fulltime (8 d total; 13–15 February, 19–21 February, and 23–24 February), they were housed by their respective system and kept fully indoors and were provided with grass silage (14 kg DM/cow silage and 4 kg concentrates).

Weaning and separation

Conventional cows were separated from their calf at birth and thus did not go through the same weaning and separation process as the PT and FT pairs. Full-time and PT pairs were weaned based on calf age (mean ± SD; 58 ± 3.9 d) over a 7 d period using a gradual, three-stage process initiated by moving the FT and PT pairs to a different, separate shed. This was done on a system basis; the FT and PT pairs were kept separately until the end of the weaning and separation process (see Fig. 2). To prevent unnecessary distress, pairs were not individually weaned; a minimum of two pairs underwent the process each time. The weaning and separation process was also only initiated twice a week (Monday or Thursday), to better allow small groups to be created based on calf age. As a result, two weaning and separation groups might have been housed together at once.

To initiate the weaning process, cows and calves were separated and placed in adjacent straw-bedded pens equipped with gates that allowed for the exchange of visual, auditory, and tactile cues, but prevented suckling (Fig. 2). Both cow and calf pens were

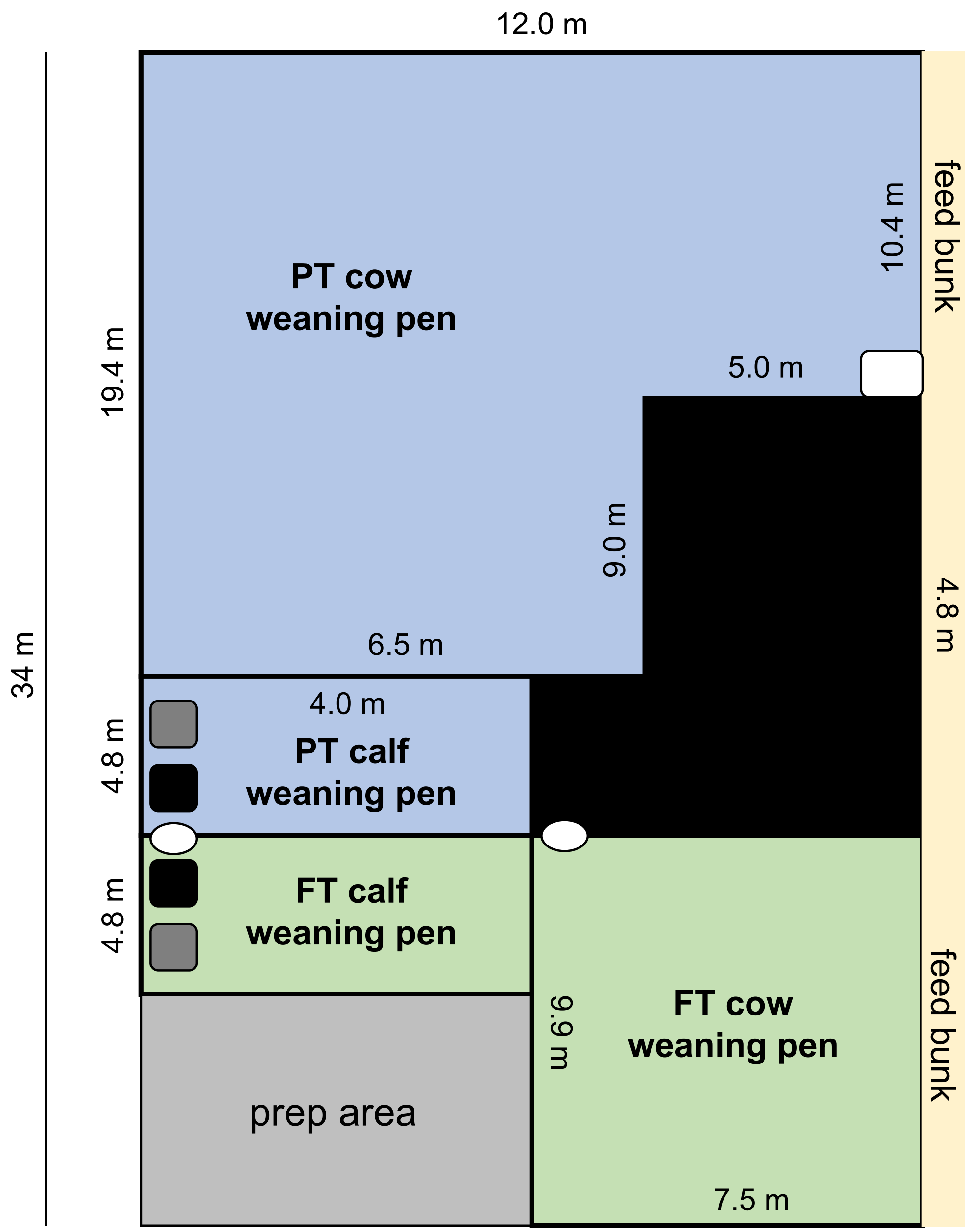

Fig. 2. Indoor weaning and separation areas for cow-calf pairs in the full-time access (FT) and part-time access (PT) cow-calf contact systems. All areas were separated by gates that allowed for some degree of physical contact. The black area represents other pens not used for the weaning and separation process. The prep area (grey area) was not an animal-housing area. White-filled boxes and ovals represent water troughs, black-filled boxes represent concentrate feeders, and grey-filled boxes represent forage (hay) feeders.

equipped with water bowls. Cows had access to *ad libitum* grass silage in the pen and were fed concentrates (3 kg/d) in the milking parlour. Calves had *ad libitum* access to concentrates, grass silage, and hay. During the first stage (3 d period), cows and calves were allowed 1 h of unrestricted contact around 1 h after the morning milking (milking finished from 0900–0930 h, contact was allowed from approximately 1030–1130 h) and calves could suckle. For the rest of the day, the pairs could interact through the gate (restricted access) but no suckling could occur. The pairs were temporarily separated for the morning and afternoon milkings, where cows were removed from the shed and then were returned to their pens immediately after milking. During the second stage (2 d period), pairs were not allowed direct contact: pairs could interact through the gate but no suckling could occur. At the start of the third stage (2 d period), the pairs were fully separated. Calves remained in their pens during this period. Cows did not return to the shed after morning milking; they joined the general herd of cows at pasture and remained there for the rest of their lactation, where they were managed similarly to the CONV cows.

Measurements

Cow production measurements

Machine milk yield (kg/d) was recorded daily for each cow for their entire lactation (Dairymaster). Milk samples (1 composite sample/week) were obtained from each cow weekly on a consecutive evening and morning milking, meaning that the PT cows' samples during the CCC period were only collected during the morning milking. Milk composition (milk fat, protein, and lactose concentrations) and somatic cell count were determined using a Milkoscan FT6000 (Foss Electric DK). Each week, daily MMY was averaged across all 7 d to give an average daily MMY for each cow for that week. Milk fat and protein concentrations were used for calculating average and cumulative MSY (average daily MSY = (daily MMY * milk fat concentration of corresponding week) + (daily MMY * milk protein concentration of corresponding week); cumulative = average daily MSY * 7) for each week of lactation.

Cow health and welfare measurements

BW and BCS were recorded following morning milking weekly for the first 12 weeks of the lactation and for 2 consecutive weeks at approximately 35 -weeks of lactation (i.e. weeks 35 and 36). After exiting the parlour, cows entered a race that ended in a crush with a sliding backing gate. An electronic portable weigh-scale with Winweigh software package (Tru-test Limited) was placed at the end of the crush, and body condition was scored by a single observer (intra-observer reliability; weighted kappa = 0.9589) when the cow was on the scales (BCS scale from 1 = emaciated to 5 = extremely fat, with 0.25 increments; Edmonson et al., 1989).

Weekly somatic cell counts (obtained using the method described above) were converted to SCS (log10 of somatic cell count) for further analysis. Incidence of mastitis was considered to have occurred when a teat was treated with an antibiotic; all incidences of mastitis were recorded throughout the entire lactation by the farm staff.

Cow clinical health scoring was performed twice a week (Tuesdays and Fridays) over the first 12 weeks of lactation. Nine aspects of cow health were scored (demeanour, ocular discharge, ear position, nasal discharge, cough, dehydration, mobility, interest in surroundings, and faecal hygiene) using a health scoring method (Supplementary Table S1), adapted from Barry et al. (2019) and used in cows by Crossley et al. (2022). Health scoring was performed by two observers (inter-observer reliability: 89% agreement first attempt, 97% agreement second attempt). A total clinical health score was calculated by summing the nine aspects of clinical health (see Supplementary Table S1 for more details), where a higher score indicates a less healthy cow.

Locomotion was scored by a single independent observer (intra-observer reliability; weighted kappa = 0.9367) over the 11-week scoring period. After morning milking, cows individually exited a race and walked past the observer on a clean, level, open concrete surface heading towards pasture. Five aspects of cow locomotion (spine curvature, tracking, ab/adduction, speed, and head bob) were scored from 1 to 5 (where 1 = perfect; 5 = most impaired) using a system described and adapted by O'Driscoll et al. (2010). A total score for each cow was calculated by summing the five aspects of locomotion, where a higher score indicates poorer locomotion.

Udder measurements

Milk leakage and udder firmness were assessed immediately prior to morning milking by the same observer on a weekly basis during the first 12 weeks of lactation. General monitoring of the state of the teats (i.e. if there was any damage to the teat) was observed weekly at this time but was not scored; however, no damage, from nursing was observed in any cows. Observations were performed once cows had entered the milking parlour and were standing in the milking stall, but before teat preparation, as this is the time when intramammary pressure is assumed to be highest (Gleeson et al., 2007). Milk leakage was scored as positive (i.e. milk leakage from one or more teats) or negative (i.e. no milk leakage), further described in Kennedy et al. (2021). Udder firmness was assessed by manually palpating both rear quarters of the udder between the cows' hind legs and assigning a score on a 3-point scoring system described by Gleeson et al. (2007), where: score 1 = soft, udder yields significantly to gentle pressure from the fingers; score 2 = firm, udder yields slightly to gentle pressure from the fingers; score 3 = hard, the udder tissue does not yield to gentle pressure from the finger tips. If there was a significant difference between quarters (e.g. score of 3 on left rear quarter and score of 1 on right rear quarter), the score on both sides was recorded. For the purpose of analysis, only the higher score was used in the statistical analysis. Milk leakage was scored before udder firmness to prevent potential milk let-down caused by palpation of the udder. Both milk leakage and udder firmness were scored by a single observer.

Udder characteristics were scored during each cow's first appearance in the milking parlour (CONV cows: first milking post-calving; FT and PT cows: first milking post 48 h bonding period). During this time, the following measurements were taken: udder clearance (distance between the ground and the medial suspensory ligament; cm), relative teat placement (front and rear; score and distance; cm), teat length (all teats; cm), and teat-end hyperkeratosis (score). Udder clearance (cm), relative teat placement (front and rear teats; score), and teat-end hyperkeratosis (score) were also assessed at weeks 4, 8, and 12 of the lactation.

Statistical analysis of data

All data were analysed using SAS (v9.4; SAS Institute). The procedures PROC UNIVARIATE and PROC MEANS were used to test normality against the residuals of all variables; where data sets were considered normal if $P > 0.01$ using the Shapiro-Wilk test. The shape of the histogram of the residuals was also examined. If a data set had $P > 0.01$, then the dataset was checked for outliers. Two variables had binomial distributions (udder firmness and milk leakage) and were analysed using PROC LOGISTIC. Cow was used as the subject in all mixed models. The Kenwood-Rogers method of determining denominator df was used for all ANOVAs. For all analyses with more than 2 weeks included, the covariance structure that gave the lowest Bayesian Information Criterion was used (compound symmetry, autoregressive lag 1, heterogeneous autoregressive lag 1, and unstructured were all tested; only compound symmetry and autoregressive lag 1 were used; see Supplementary Table S2 for variance components). The Tukey-Kramer test was used for all posthoc pairwise comparison tests between fixed effects. The threshold for significance was $P < 0.05$ and tendencies were $P < 0.10$. Descriptive statistics (mean and SD) were calculated in SAS for the health variables (total clinical health and total locomotion scores). Mean, variance, SEM, and coefficients of variation for all measured study variables are provided in Supplementary Table S3.

For the purpose of analysis, a three-tier parity structure was used: parity 1, n = 15; parity 2, n = 19; parity 3+, n = 16). Although the initial systems were blocked by parity, it was included in the models to help account for the difference in group-size. The FT cows that were removed from trial (due to calf health issues – see above for more details) were disproportionally of parity 3+ (one parity one cow, one parity 3, and two parity 4); when model fit was tested with and without parity, the Bayesian Information Criterion was lower with parity included as a fixed effect. However, we do not report it as we did not set out to estimate the effects of parity.

All variables (except udder firmness and milk leakage) were analysed using a linear mixed model (PROC MIXED). The model contained the fixed effects of system (CONV, FT, PT), parity (primiparous, second lactation, third lactation or higher), and cow breed (Holstein-Friesian, Holstein-Friesian × Jersey). Week was included as a fixed effect and a repeated measure where appropriate. Days in milk on 1 June 2021 was used as a covariate to account for the difference in calving date. For milk variable covariates, previous lactation cumulative or average values (for primiparous cows, their dam's first lactation data was used) that had been centred within parity (individual animal values were subtracted from the average value of each parity) were used as covariates: previous lactation cumulative MMY for MMY data, previous lactation average fat percentage for fat concentration data, and so on. Sub-indices of the Economic Breeding Index were used as covariates where appropriate (i.e. health sub-index for health-related variables, milk sub-index for milk-related variables, etc.; Kennedy et al., 2021; Murphy et al., 2023). The initial (week 1) BW or BCS was used as a covariate in those models to account for any initial differences.

For milk-associated measurements, only the first 35 weeks of lactation are used, as after that time point, some cows were dried off, depending on their subsequent spring calving date. Machine milk yield, MSY, SCS, and milk components (fat, protein, and lactose concentrations) were analysed as an average during three time periods: (i) weeks 1–8 of lactation (CCC period), (ii) weeks 9–35 of lactation (post-CCC period), and (iii) weeks 1–35 (full 35-week lactation). Cumulative lactation MMY and MSY (weeks 1–35) were also calculated and analysed. BW and BCS were analysed at the end of weeks 4, 8, 12, and 35 by taking the average weight or score from the last 2 weeks of the respective time period. In addition, for weeks 4, 8, and 12, the average change in BW (average daily change in BW over the 28 d period) and BCS (change in score from the previous period) within that period was analysed. The average change from weeks 1–12 was also calculated and analysed for BW and BCS.

Logistic regression (PROC LOGISTIC) was used to analyse udder firmness and milk leakage. The model included the fixed effects of system (CONV, FT, PT), week of lactation (1–12, udder scores), parity (primiparous, second lactation, third lactation or higher), and cow breed (Holstein-Friesian, Holstein-Friesian x Jersey). Covariates included days in milk and the appropriate sub-indices (health, management, or milk) of the Economic Breeding Index (centred within parity). The CONV cows, primiparous cows, Holstein-Friesian cows, and week 1 were designated as the reference categories (odds ratio (OR) = 1).

Results

Cow production

Machine milk yield and milk solids yield

An overview of MMY per system per week can be found in Fig. 3. During the CCC period (weeks 1–8), there were effects of system on daily MMY and MSY (Table 1). All systems differed, with the CONV cows having the highest MMY and MSY, followed by the FT, and then the PT cows. After the CCC period (weeks 9–35), the effect of system continued; CONV cows remained higher in MMY and MSY compared to the FT and PT cows. Across the entire lactation (weeks 1–35), average and cumulative MMY and MSY were affected by system. All systems differed, with the CONV cows yielding the most, followed by the FT, and then the PT cows (Table 1).

Milk composition

During the CCC period (weeks 1–8), there was an effect of system on milk fat concentration; the CONV cows produced milk with a higher fat concentration than the FT and PT cows (Table 1). There

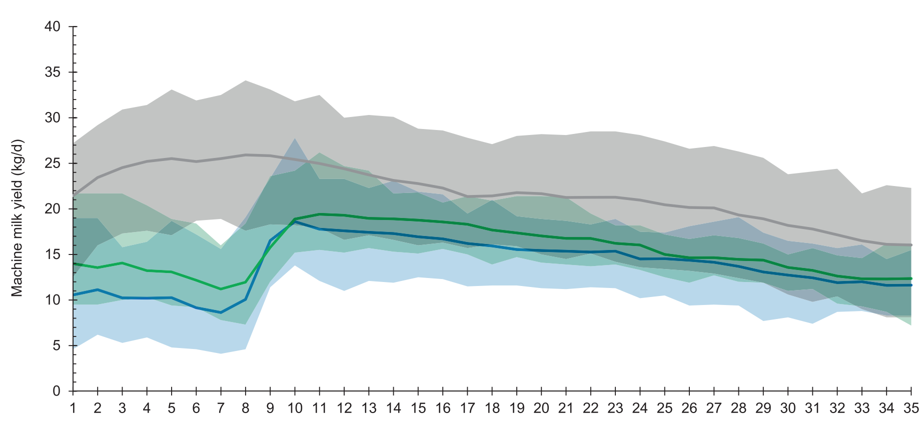

Fig. 3. Statistical means and range for average daily machine milk yield (kg/d) for dairy cows in three different cow-calf contact rearing systems (conventional (CONV; grey): no access to calf and milked twice-a-day; Full-time access (FT; green): full-time access to calf and milked twice-a-day; Part-time access (PT; blue): part-time access to calf and milked once-a-day) by week across the 35-week lactation. The shaded bars represent the range of machine milk yields observed in each system during each week of lactation.

Table 1
Effect of three different calf rearing systems (Conventional (CONV): cow and calf separated at birth and cow milked twice-a-day; Full-time access (FT): full-time access to calf and milked twice-a-day; Part-time access (PT): part-time access to calf and milked once-a-day) on average machine milk yield, milk solids yield, somatic cell score, and milk composition (fat, protein, and lactose concentration) during different periods across the first 35-weeks of lactation.

	Systems				
Variable	CONV	FT	PT	SEM	*P*-value
Machine milk yield (kg/d)					
Weeks 1–8	24.0[a]	13.6[b]	10.3[c]	0.50	<0.001
Weeks 9–35	20.2[a]	16.6[b]	15.7[b]	0.48	<0.001
Weeks 1–35	21.1[a]	16.0[b]	14.4[c]	0.42	<0.001
Cumulative weeks 1–35 (kg)	5 072[a]	3 872[b]	3 499[c]	97.0	<0.001
Milk solids yield, kg/d					
Weeks 1–8	2.14[a]	1.10[b]	0.82[c]	0.50	<0.001
Weeks 9–35	1.79[a]	1.45[b]	1.34[b]	0.48	<0.001
Weeks 1–35	1.87[a]	1.37[b]	1.22[c]	0.42	<0.001
Cumulative weeks 1–35 (kg)	450[a]	332[b]	294[c]	8.7	<0.001
Milk fat concentration (%)					
Weeks 1–8	5.36[a]	4.56[b]	4.70[b]	0.157	0.001
Weeks 9–35	5.04	5.05	4.88	0.117	0.527
Weeks 1–35	5.12	4.94	4.85	0.117	0.253
Milk protein concentration (%)					
Weeks 1–8	3.57	3.44	3.48	0.043	0.085
Weeks 9–35	3.86	3.68	3.70	0.054	0.034[1]
Weeks 1–35	3.79[a]	3.62[b]	3.65[ab]	0.049	0.036
Milk lactose concentration (%)					
Weeks 1–8	4.80[a]	4.74[ab]	4.67[b]	0.030	0.008
Weeks 9–35	4.72[b]	4.80[a]	4.76[ab]	0.021	0.050
Weeks 1–35	4.74	4.79	4.74	0.021	0.208
Somatic cell score					
Weeks 1–8	4.94[ab]	4.70[b]	5.15[a]	0.118	0.039
Weeks 9–35	4.98	4.85	5.12	0.133	0.388
Weeks 1–35	5.01	4.86	5.15	0.126	0.305

Values within a row with different superscripts differ significantly at $P < 0.05$.
[1] System means did not differ significantly at $P < 0.05$. Means were compared with Tukey's adjustment.

was no effect of system on milk fat concentration for the rest of the lactation (weeks 9–35) and overall (weeks 1–35). An overview of milk fat concentration per system per week can be found in Supplementary Fig. S1.

There was a tendency for an effect of system on milk protein concentration during the CCC period (Table 1). For the rest of the lactation (weeks 9–35), there was an effect of system, but the system means were inconclusive in the posthoc comparison test. When averaged across all weeks of lactation (weeks 1–35), there was an effect of system, with the CONV cows producing milk with a higher milk protein concentration than the FT cows, while the PT cows were inconclusive (Table 1). An overview of milk protein concentration per system per week can be found in Supplementary Fig. S2.

There was an effect of system on milk lactose concentration during the CCC period, with the CONV cows producing milk with a higher lactose concentration than the PT cows, while the FT cows were inconclusive (Table 1). For the rest of the lactation (weeks 9–35), there was a tendency for milk lactose concentration to differ (Table 1); however, there was no effect of system (Table 1) when milk lactose concentration was averaged across all 35 weeks. An overview of milk lactose concentration per system per week can be found in Supplementary Fig. S3.

Somatic cell score and mastitis incidence

There was an effect of system on SCS during the CCC period (Table 1); the PT cows had a higher SCS compared to the FT cows, while the CONV cows were inconclusive. An overview of milk lactose concentration per system per week can be found in Supplementary Fig. S4. Eleven incidences of clinical mastitis (three CONV cases, four FT cases, four PT cases) occurred in seven trial cows (two CONV cows; two FT cows; three PT cows) over the 35-week lactation. Four out of the 11 incidences occurred during the 1st 8 weeks of lactation (one CONV cow, one PT cow, and one FT cow with two occurrences in the same quarter).

Health

BW and body condition score

An overview of BW per system per week can be found in Supplementary Fig. S5. There was an effect of system on cow BW at the end of weeks 4 and 8 of lactation (Table 2), where the PT cows were heavier than the CONV and FT cows. However, there was no difference between the three systems at the end of week 12 of lactation. At the end of week 35 of lactation, there was an effect of system on BW, with the PT cows heavier than the FT cows, and the CONV cows were inconclusive (Table 2). There was an effect of system on average daily change in BW from weeks 1–4 and weeks 8–12. From weeks 1–4, the PT cows were gaining weight, while the CONV and FT cows were losing weight, and from weeks 8–12, the PT cows were losing weight while the CONV and FT cows were gaining weight (Table 2). There was no effect of system on daily change in BW for the other time periods.

An overview of body condition score per system per week can be found in Supplementary Fig. S6. There was an effect of system on BCS during weeks 4, 8, 12, and 35 of lactation (Table 2). The PT cows had a higher BCS score than the CONV cows at all observed time points. The FT cows were different to the PT cows at weeks 8 and 35, and all systems were inconclusive at weeks 4 and 12. There was an effect of system on average change in BCS from weeks 1–4 ($P = 0.024$; Table 2); the CONV lost condition and the PT cows maintained condition, while the FT cows were inconclusive. There

Table 2
Effect of cow-calf contact systems (Conventional (CONV): no access to calf and milked twice-a-day; Full-time access (FT): full-time access to calf and milked twice-a-day; Part-time access (PT): part-time access to calf and milked once-a-day) on BW, average daily change in BW, body condition score, and average change in body condition score. The values reported for week 1 BW and body condition score were included in the statistical analysis as covariates and thus were not analysed.

	Systems				
Variable	CONV	FT	PT	SEM	*P*-value
BW (kg)					
Week 1	522	509	515	58.8*	–
Week 4	474[b]	488[b]	523[a]	4.9	<0.001
Week 8	479[b]	487[b]	520[a]	6.8	<0.001
Week 12	490	489	504	7.2	0.242
Week 35	525[ab]	505[b]	535[a]	8.1	0.049
Average daily change in BW (kg/d)					
Week 1 to week 4	−1.50[b]	−1.01[b]	0.25[a]	0.175	<0.001
Week 4 to week 8	0.19	−0.02	−0.10	0.210	0.586
Week 8 to week 12	0.41[b]	0.05[b]	−0.56[a]	0.145	<0.001
Week 1 to week 12	−0.30	−0.32	−0.14	0.086	0.246
Body condition score					
Week 1	3.14	3.25	3.15	0.168*	–
Week 4	3.01[b]	3.07[ab]	3.14[a]	0.034	0.024
Week 8	2.94[b]	3.02[b]	3.16[a]	0.035	<0.001
Week 12	2.93[b]	3.07[ab]	3.22[a]	0.044	<0.001
Week 35	3.03[b]	3.01[b]	3.19[a]	0.043	0.009
Average change in body condition score					
Week 1 to week 4	−0.16[b]	−0.10[ab]	−0.03[a]	0.034	0.024
Week 4 to week 8	−0.07	−0.05	0.02	0.034	0.133
Week 1 to week 12	−0.01	0.04	0.06	0.035	0.354
Week 1 to week 12	−0.25[b]	−0.11[b]	0.04[a]	0.044	<0.001

Abbreviations: SEM = pooled SEM.
Values within a row with different superscripts differ significantly at $P < 0.05$.
* SD is reported rather than SEM.

Table 3
Basic descriptive statistics (mean and SD) for the total scores (sum of all component scores) for locomotion and clinical health in cows in three different cow-calf contact rearing systems (Conventional (CONV): no access to calf and milked twice-a-day; Full-time access (FT): full-time access to calf and milked twice-a-day; Part-time access (PT): part-time access to calf and milked once-a-day).

	Systems					
	CONV		FT		PT	
Variable	Mean	SD	Mean	SD	Mean	SD
Total locomotion score						
Week 1	8.8	1.88	8.7	1.33	8.1	1.17
Week 2	8.8	1.93	8.4	1.15	8.2	0.94
Week 3	8.4	1.50	8.4	1.08	8.6	1.33
Week 4	8.8	1.70	8.6	1.55	8.8	1.52
Week 5	8.8	1.62	8.2	1.37	8.8	1.48
Week 6	9.6	1.82	8.6	1.34	8.8	1.44
Week 7	9.3	1.53	8.7	1.64	8.8	1.55
Week 8	9.2	1.42	8.7	1.37	8.8	1.56
Week 9	9.2	1.69	8.9	1.14	8.8	1.52
Week 10	9.3	1.64	9.1	0.99	9.5	1.61
Week 11	9.4	1.85	9.3	1.35	8.9	1.24
Total clinical health score						
Week 1	0.6	0.65	0.7	0.66	0.5	0.61
Week 2	0.8	0.80	0.9	0.74	0.8	0.64
Week 3	1.1	0.93	0.8	0.89	0.7	0.77
Week 4	1.2	0.89	0.8	0.76	0.9	0.83
Week 5	1.3	0.79	1.1	1.03	0.9	0.84
Week 6	1.3	0.79	1.0	0.88	0.9	0.89
Week 7	1.5	0.85	1.1	0.94	0.9	0.75
Week 8	1.3	1.06	0.9	1.02	1.0	0.87
Week 9	1.8	0.92	0.8	0.65	0.9	0.69
Week 10	1.3	0.79	1.4	0.92	1.5	0.75
Week 11	1.7	0.78	1.3	0.87	1.3	0.96

Table 4
Udder composition measurements taken from the first parlour milking of cows in three different cow-calf contact systems (Conventional (CONV): no access to calf and milked twice-a-day; Full-time access (FT): full-time access to calf and milked twice-a-day; Part-time access (PT): part-time access to calf and milked once-a-day).

	Systems				
Variable	CONV	FT	PT	SEM	*P*-value
Teat length (cm)					
Front right	5.1	5.0	5.2	0.24	0.915
Front left	5.0	4.9	5.1	0.27	0.891
Rear left	4.4	4.9	4.3	0.22	0.168
Rear right	4.5	4.5	4.5	0.19	0.975
Front teat position (cm)	13.0	15.3	14.5	0.81	0.136
Rear teat position (cm)	6.8	7.9	7.0	0.83	0.602

Abbreviations: SEM = pooled SEM.

Table 5
Effect of cow-calf contact system (Conventional (CONV): no access to calf and milked twice-a-day; Full-time access (FT): full-time access to calf and milked twice-a-day; Part-time access (PT): part-time access to calf and milked once-a-day) and week (weeks 0, 4, 8, and 12 of lactation) on udder clearance (cm), front and rear teat placement (score), and teat-end hyperkeratosis (composite score of all four teats).

	Systems				
Variable	CONV	FT	PT	SEM	*P*-value
Udder clearance (cm)	57.7	56.9	58.5	1.00	0.544
Front teat position (score)	4.7	4.6	4.4	0.16	0.312
Rear teat position (score)	5.3	5.4	5.1	0.22	0.653
Teat-end hyperkeratosis (score)	1.4	1.3	1.4	0.08	0.772

Abbreviations: SEM = pooled SEM.

was also an effect of system on average change in BCS from weeks 1–12 (Table 2); the PT cows maintained their condition while the CONV and FT cows lost condition.

Health parameters

Basic descriptive statistics for total clinical health score (sum of all components: demeanour, ocular discharge, ear position, nasal discharge, cough, dehydration, mobility, interest in surroundings, and faecal hygiene) and total locomotion score (sum of all components: spine curvature, tracking, ab/adduction, speed, and head bob) can be found in Table 3. There were effects of system (P = 0.015) and week (P < 0.001) on total clinical health score. The CONV cows (mean ± SE; 1.3 ± 0.08) had higher total clinical health scores than the PT cows (0.9; P = 0.012), and tended (P = 0.057) to have higher total clinical health scores than the FT cows (1.0). Cows had the lowest total clinical health scores in week 1 (0.6 ± 0.09) and had increased in score by week 4 (0.9; P = 0.010). Cows in weeks 10 (1.4) and 11 (1.4) had the highest total clinical health scores and differed (P < 0.05) from weeks 1 through 4 (but not 5–9). There was no effect of system (P = 0.849) on the total locomotion score (sum of the five scored aspects of locomotion), but there was an effect of week (P < 0.001). Locomotion scores were lowest in weeks 2 (8.4 ± 0.23) and 3 (8.4) compared (P < 0.05) to the higher scores in weeks 10 (9.2) and 11 (9.1); all other weeks were inconclusive (P > 0.05) when compared to week 1. When the individual components of the locomotion score were analysed there were no significant effects of system.

Udder conformation and scoring

At the first milking postcalving, there was no effect of system (Table 4) on teat lengths and front and rear teat placements (distance in cm, not score). None of the monthly udder scores (udder clearance, front and rear teat placement score, and teat-end hyperkeratosis) were affected by system (Table 5). There were effects of system (P = 0.002) and week (P < 0.001) on udder firmness. The FT (OR = 0.399, CI = 0.224 – 0.711, P = 0.002) and PT (OR = 0.424, CI = 0.224 – 0.737, P = 0.002) cows were less likely to have a firm udder across the first 12 weeks of lactation compared to the CONV cows. All cows, regardless of system, were less likely to have a firm udder from week 5 (OR = 0.040, CI = 0.013 – 0.120, P < 0.001) onwards, compared to week 0. There were no effects of system (P = 0.405) or week (P = 0.090) on milk leakage.

Discussion

Implementing cow-calf contact in a seasonal calving, pasture-based dairy system

The first aim of this preliminary study was to investigate whether our two different CCC systems could feasibly be incorporated into the Irish spring-calving, pasture-based system. To do this, we compared three different calf–rearing systems within the context of the Irish spring-calving, pasture-based dairy system: CONV, where the cow had no access to her calf and was milked twice-a-day; FT, where the dam-calf pair had constant, unrestricted access to each other and the cow was milked twice-a-day; and PT, where the dam-calf pair had unrestricted access to each other by night and the cow was milked OAD in the morning. In this paper, we specifically report our results on the cows' production (MMY, MSY, milk composition, and SCS) and health (BW, BCS, clinical health, locomotion, and various aspects of udder health and conformation) within the three different systems. Calf-associated measurements, as well as information regarding the labour requirements of each system, can be found in Sinnott et al. (in press). Throughout this manuscript, we have tried to emphasise that we compared three different systems to investigate their potential viability, rather than experimental treatments;

therefore, variation from several different sources existed between the three different systems. As a result, we investigated not only the impact of novel exposure to CCC, but also the impact of milking frequency, housing, and diet.

We faced several practical implementation challenges over the course of this study, mainly centred on issues with calves, which led to a limitation of this study: group size. The PT pair removed due to calf illness occurred early enough in the calving season to be replaced. However, the three multiparous FT cows (3 + lactations) that were removed from the trial at the beginning of their lactation due to calf illness could not be replaced as no cows were available to replace them, leading to unequal group sizes and a reduction in statistical power. As this was a preliminary study, investigating first whether it was feasible to implement CCC on a seasonal calving, pasture-based system, it was not possible for us to run multiple replicates of the systems within the same year or across multiple years. However, our rolling intake of cows onto the experiment (as they calved) led to an 8-week enrolment window, causing cows to have slightly different experiences within the same system, increasing the independence and variation between individuals. The experimental farm that this research was performed on is also set up to be a model of a typical Irish dairy farm, with similar housing, managements, and calving rates; as such, we believe that our results are reasonably transferable to other dairy farms in Ireland. However, in the future, a multiple−year, multiple−farm trial of CCC will be needed to fully understand the feasibility and effects of CCC within seasonal calving, pasture-based systems.

In our PT system, the OAD milking did appear to have an effect on MMY, as well as BW and BCS, which has been typical of non-CCC cows milked OAD (Clark et al., 2006; Kennedy et al., 2021; Murphy et al., 2023). The PT cows also had a slightly different diet (*ad libitum* silage by night) and were housed indoor at night, which may have also contributed to the observed differences between the systems. We believe that the PT system was chosen for valid feasibility reasons (see Selection of management systems section in Materials and Methods); however, we acknowledge that in choosing this PT system, we made the comparison between the systems more difficult. In addition, slightly different management choices (i.e. PT access by day rather than night or milking the PT cows twice-a-day) may have significantly affected the results. Therefore, achieving successful CCC within a seasonal calving, pasture-based system likely will depend on finding the correct combination of factors (i.e. milking frequency, housing, timing of access, labour required, etc.) for each individual farm and farmer.

Cow-calf contact was a novel experience for both cows and humans involved in this study. The cows had never experienced CCC, which may have influenced their mothering ability and their response to weaning and separation. Although some personnel at the research farm (staff and researchers) had experience in keeping beef cows and calves together, all were new to keeping dairy cows and calves together. In addition, all facilities used on the farm were not specifically designed for CCC.

When implementing CCC systems, human health and safety should also be considered. Both of the CCC systems implemented here required the cow-calf pairs to be routinely separated once or twice a day, either for two 1-h periods during milking (FT system) or for several hours while the cows grazed (PT system). For the FT pairs, this separation occurred either at pasture (cows were removed from the field while the calves remained) or in a holding pen beside the parlour. For the PT cows, this temporary separation occurred in the cubicle shed. Although no incidences of cow aggression towards humans occurred during this trial, the human safety risks associated with the constant temporary separation of cow-calf pairs required for both systems to operate should be considered.

Effects of cow-calf contact on cow production within our systems

Reduced MMY during the CCC period was expected and observed from the FT and PT cows during the CCC period (weeks 1–8). Calves in this study had unrestricted access to their dam, as well as other cows within the same system, enabling the calves to nurse during allowed contact times, and thus decreasing the FT and PT cows' MMY. This result was comparable to other recent CCC studies (Barth, 2020; Wenker et al., 2022; Neave et al., 2024), which found a reduction in MMY when calves were able to nurse. Here, calf nursing was also confirmed by the udder firmness scores, which showed that the FT and PT cows had less firm udders than the CONV cows, likely due to calf nursing in between milking events. In addition to the decrease in MMY experienced by the FT and PT cows due to CCC, the PT cows also had a lower MMY than the FT cows during the CCC, yielding around 25% less milk in the parlour. This magnitude of decrease was typical of non-CCC cows experiencing OAD compared to twice-a-day milking frequency (Rémond et al., 2004; Murphy et al., 2023), especially during early lactation (Kennedy et al., 2021).

In addition to their milkings in the parlour, both FT and PT cows were being stimulated to produce milk by their calves multiple times a day. More frequent milking should increase milk synthesis, and thus total milk yield, by increasing the proliferation of mammary cells (Murney et al., 2015); therefore, we expected that although MMY might be decreased during the CCC period, it would only be reduced by the amount that the calves were consuming. Then, after weaning and separation, we expected that the FT and PT cows' MMY would increase to the level of the CONV cows. However, that is not what we observed in this study. Although the MMY of the FT and PT cows increased after weaning and separation, they never reached the level of the CONV cows. This effect persisted for the rest of the lactation and, in combination with the lower MMY produced during the CCC period, resulted in the FT and PT cows producing 24 and 31% lower cumulative MMY (weeks 1–35) than the CONV cows, who produced 5 072 kg (a typical cumulative yield for cows in Ireland milked twice-a-day, Kennedy et al., 2021).

The FT and PT cows' MMY may have not reached the level of the CONV cows after weaning and separation because they may have been producing less milk than the CONV cows during the CCC period. Here, the results for milk fat concentration, where the FT and PT cows had lower fat concentrations in the milk yielded at the parlour than the CONV cows during the CCC period, suggest that the FT and PT cows had impaired milk ejection in the parlour. Secretion of low levels of oxytocin can inhibit the milk ejection response in dairy cows, causing a larger amount of milk to be left in the udder post-milking (residual milk; Bruckmaier, 2005). Residual milk has the highest concentration of milk fat, compared to milk produced during the rest of the milking event (Ontsouka et al., 2003). Higher amounts of residual milk in the udder can decrease milk synthesis (Kuehnl et al., 2019) and lower MMY, especially in cows experiencing CCC (Metz, 1987; de Passillé et al., 2008). Kuehnl et al. (2019) found that the reduction in MMY due to incomplete milking persisted even with an increased milking frequency, which matches what we observed here; even though the FT and PT cows were stimulated more to produce milk via calf nursing, they were likely producing less total milk than the CONV cows.

Although calf intake was likely to have increased over the weeks until weaning and separation, it was unlikely that calf intake alone would account for the entire observed differences in MMY (i.e. during week 8, the FT and PT cows yielded −14.3 and −16.9 kg/d less, respectively, than the CONV cows (25.5 kg/d); raw statistical means; see Fig. 3). The FT and PT calves were of similar weight at 8 weeks old (82 kg), with average daily gains of 0.95 kg/d (averaged from weeks 5–8; Sinnott et al., in press). The required intake for an 80 kg large breed calf (i.e. Holstein-Friesian from North America) to gain 1.0 kg/d is 1.63 kg DM/d (NRC, 2021). If the estimated DM of whole milk is 12.5% (NRC, 2021), then the differences in MMY compared to the CONV of the FT and PT cows would yield 1.79 and 2.11 kg DM/d, respectively. If the reduction in MMY was due to calf intake alone, then we would have expected higher growth rates in the calves. Rather, we suggest that the FT and PT cows' milk synthesis had decreased during the CCC period and did not recover for the rest of the lactation.

Weaning and separation of a bonded cow-calf pair is an event known to cause distress in dairy cows and calves (Flower and Weary, 2003), and has previously been shown to temporarily reduce MMY (Everitt and Phillips, 1971; Walsh, 1974; Metz, 1987). Metz (1987) also showed that the change in environment (moving cows from one shed to another) temporarily decreased MMY in their cows, regardless of whether or not they had just been separated from their calf. In humans, psychological distress is hypothesised to impair oxytocin release (Nagel et al., 2022), thus reducing milk yield by impairing milk ejection, so it is possible that similar mechanisms were occurring in the FT and PT cows in this study. Although the decreases in MMY around weaning and separation found in previous studies were temporary, the timing of weaning and separation here may have further impacted the MMY of the FT and PT cows, causing the temporary decrease in MMY to become a long-term decrease. The CONV cows reached peak MMY around weeks 8–9 of lactation (Fig. 3), which coincided with the weaning and separation process for the FT and PT cows. Milk yield persistency has been shown to be negatively correlated with peak milk yield (Sorensen et al., 2008), so if the FT and PT cows' peak milk yield was reduced by various factors around weaning and separation, then this reduction may have persisted for the rest of the lactation.

Effect of cow-calf contact on cow health and udders within our systems

Previous CCC studies have shown that BW reduces temporarily after weaning and separation from the calf, for around 1–2 weeks (Everitt and Phillips, 1971, Metz, 1987, Bar-Peled et al., 1995). This has been attributed to a difference in feed intake during the distressful period (Metz, 1987). The data we presented in Table 2 show the average BW of cows in the different systems at week 12, 3–4 weeks after weaning and separation, so we are not able to determine if there was an immediate response in cow BW to weaning and separation. During week 8 of lactation, the PT cows were heavier than the similar CONV and FT cows, and during week 12, there was no difference in BW between the systems. Over the entire lactation, the PT cows remained in better condition and were numerically heavier than the CONV and FT cows. Although the differing diet of the PT cows may have also contributed to their increased BW, a similar carryover effect of BW and BCS was observed at the end of lactation in a comparison of pasture-based cows milked either OAD or twice-a-day in early lactation with identical diets (Kennedy et al., 2021; Murphy et al., 2023). Although cows in all systems lost BW during the first 12 weeks of lactation, they did so in a different pattern.

Suckling is thought to be beneficial in reducing the risk of mastitis and decreasing SCS (Johnsen et al., 2016; Beaver et al., 2019), despite it being a matter of concern for dairy farmers regarding the implementation of CCC systems (Neave et al., 2022). Here, the FT cows had lower SCS during the CCC period compared to the PT cows, while the CONV were similar to both. There appears to be some effect of suckling on SCS, and it is likely that the difference in SCS between the FT and PT cows was due to the combination of their differences in milking frequency and housing. Somatic cell score is known to be higher in cows milked OAD (Stelwagen et al., 2013, Kennedy et al., 2021, Murphy et al., 2023); however, this increase in SCS is not typically associated with a change in the risk of mastitis (Stelwagen et al., 2013). Cows housed indoors have more udder health problems (Goldberg et al., 1992), more incidences of mastitis (Washburn et al., 2002), and higher somatic cell counts (Kristensen et al., 2007) compared to cows kept at pasture. However, cows milked OAD and kept at pasture still were shown to have greater SCS during and at the end of the lactation compared to those milked twice-a-day (Murphy et al., 2023).

An increased risk of milk leakage has been a common explanation for why OAD cows often have increased SCS, as open teat sphincters can result in bacteria and other pathogens having easier access to the mammary gland (Gleeson et al., 2007). We did not observe any difference in milk leakage in the PT cows compared to the CONV and FT cows during the CCC period, but this was likely due to the fact that their calves were able to nurse from the PT cows until they went to the milking parlour in the morning. We noted that many calves would routinely nurse right before the cows would leave for the day (personal observation). We did not expect to find differences in udder characteristics and conformation between cows, and that is indeed what we found. This was especially important in this study, as the FT and PT calves were left to suckle naturally, and large pendulous udders have been correlated with slower suckling times postbirth (Edwards, 1982) and thus are thought to potentially lead to a reduction in calf immunity (as assessed by calf serum immunoglobulin G levels). We also did not observe any teat damage in the FT or PT cows. Teat damage has been observed previously in part-time CCC systems where the cow returns to the calf immediately after milking with an empty udder (Ospina-Rios et al., 2023); however, this was not an issue in this study, as the PT cows were not milked before they returned to their calves.

Future directions of cow-calf contact in Ireland

In this preliminary study, we compared three different dairy calf–rearing systems, which varied in the amount of CCC (with the dam) and milking frequency, within the context of the Irish spring-calving, pasture-based dairy system. We found that MMY was reduced in both of the CCC systems (FT and PT) during the CCC period, and although MMY did recover after weaning and separation, the MMY of the FT and PT cows never reached the level of the CONV cows, leading to a lower cumulative lactation MMY and MSY. The PT cows had a lower MMY during the CCC compared to the FT cows due to their OAD milking. Cow health and udders remained largely unaffected by CCC. Although we managed to incorporate CCC into the existing Irish spring-calving, pasture-based dairy system, our two CCC systems had a negative impact on MMY, which would be an implementation deterrent for the dairy farmer. In our opinion, a modified version of the PT system, where calves are kept indoors, the cow and calf have contact by night, and the cows graze during the day, but the cows are milked twice-a-day, might be the most successful within the current Irish dairy system. However, future work is needed to understand why MMY was so affected by CCC and to develop strategies to ameliorate this effect.

Supplementary material

Supplementary material to this article can be found online at https://doi.org/10.1016/j.animal.2024.101222.

Ethics approval

Ethical approval for this study was received from the Teagasc Animal Ethics Committee (TAEC2020-290), and procedure authorisation was granted by the Irish Health Products Regulatory Committee (AE19132/P124). Experiments were performed in accordance with European Union (Protection of Animals Used for Scientific Purpose) Regulations 2012 (S.I. No. 543 of 2012).

Data and model availability statement

None of the data nor the model were deposited into an official repository, but are available from the corresponding author upon reasonable request.

Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work the author(s) did not use any AI and AI-assisted technologies.

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Declaration of interest

None.

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