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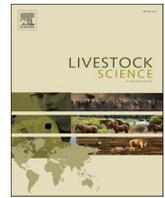
The effects of full-time, part-time and no cow-calf contact on calf health, behaviour, growth and labour in pasture-based dairy systems

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HIGHLIGHTS

- Cow-calf contact increased pre-weaning calf growth and reduced labour at calving.
- Full-time pasture-based cow-calf contact challenged calf health and daily labour.
- Part-time cow-calf contact affected calf behaviour and post-weaning growth negatively.

ARTICLE INFO

ABSTRACT

Preventing cow-calf contact in rearing systems has been scrutinised. This descriptive study investigated the effects of full-time contact outdoors on pasture (FT-O), part-time contact indoors (PT-I), or no contact indoors (NC-I) on calf health, behaviour, growth and labour in a pasture-based dairy system. Cows ($n = 55$) were balanced pre-calving on parity (16 primiparous and 39 multiparous), milk production (35 weeks) of previous lactation (4497 ± 193.8 kg), breed and predicted calving date. Contact pairs bonded for 48 h, whereas NC-I calves were separated from cows immediately, and remained in individual pens for three days before grouping. The FT-O pairs moved outdoors at 5 ± 3.3 days, only separated from cows for milking twice daily. Part-time cows were milked once-a-day (8:00) and grazed outdoors post-milking, returning indoors to calves from 15:00–8:00 the following morning. The NC-I calves were assigned to a feeding plan offering up to 9.5 L/day of milk replacer via automatic feeder. All calves had Ad libitum access to water, concentrates and forage. For NC-I calves, weaning started at 48 days, taking 12 days, for contact calves it started at 58 days, taking seven days. From birth to three weeks post-weaning, animal health and labour were evaluated twice-weekly, weight and linear body measurements were recorded weekly and behaviour was recorded weekly (daily during weaning). Following this, weighing was carried out fortnightly. Faecal related issues were seen most often in contact calves than NC-I calves. The PT-I calves also experienced eye issues more often than NC-I and FT-O calves. Illness resulted in 26 % of FT-O calves being removed from experiment (none removed from NC-I and PT-I). The PT-I calves expressed the most abnormal behaviours throughout weaning. Contact calves vocalised more at weaning than NC-I (7.8 % vs 1.5 % of time). The NC-I calves weighed less at 28 (49.0 vs 55.5 kg), 56 (69.0 vs 82.1 kg), 70 (79.0 vs 87.1 kg) and 77 (81.8 vs 90.8 kg) days than FT-O and PT-I calves. Labour associated with calving was greater for the NC-I system (00:15:56 ± 00:00:35) than contact systems (00:01:39 ± 00:00:35). Weekly labour was greater for the FT-O system (00:01:29 ± 00:00:05) than NC-I and PT-I systems (00:00:44 ± 00:00:05), which were similar. Weaning labour was negligible for NC-I calves (computerised feeder), but 00:02:08 ± 00:00:09 for contact systems, which were similar. To conclude, pre-weaning calf growth and reduced labour at calving as a result of cow-calf contact is challenged by calf health and human welfare (related to daily labour) in the FT-O system and by calf behaviour and stunted post-weaning growth in the PT-I system. Thus, cow-calf contact in pasture-based dairy systems require further research to safeguard calf and human welfare.

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1. Introduction

In seasonal calving systems of dairy production, where cows calve in a condensed period, the commencement of lactation and grass growth are synchronised (Dillon et al., 1995). Dairy cows and calves are typically separated shortly after birth for perceived biosecurity benefits and maximisation of saleable milk (Flower and Weary, 2003). Separating cow and calf immediately post-calving has come under scrutiny recently due to ethical implications and societal pressures favouring more natural husbandry systems. Natural systems provide opportunities for animals to roam and express natural behaviours such as socialisation and suckling in a natural state (Ventura et al., 2013; Hötzel et al., 2017; Placzek et al., 2021).

Cow-calf contact (CCC) systems allow calves to remain with their mother post-calving and are regarded as a more favoured management approach by society (USA and Canada; Sirovica et al., 2022). Previous CCC research has reported positive effects for cows and calves in terms of satisfaction of dam motivation to be with calves (Wenker et al., 2020), behaviour and response to stressors, as well as increased calf growth (Fröberg et al., 2011; Kisac et al., 2011). However, the effects of CCC on calf health remain inconclusive (Beaver et al., 2019). Integration of CCC systems into the prevailing management system is preferred due to incremental changes for on-farm implementation. For example, in Ireland cows graze pasture for, on average, 240 days per year (Crossley et al., 2021) and are turned out to pasture shortly after calving in spring (Kennedy et al., 2005). Recent CCC research has centred on indoor systems (Johnsen et al., 2021; Wenker et al., 2021), with few incorporating outdoor access (Barth, 2020; Nicolao et al., 2020; Mutua and Haskell, 2022). In the Irish pasture-based dairy system, full-time CCC would involve turning calves out to pasture at young ages in late winter/early spring (usually a period of variable and inclement weather). Although young calves can be reared successfully outdoors (Walshe et al., 1971; Ertugrul et al., 2000) it includes risks. For example, thermoneutral zones are influenced by weather; cold stress can cause energy diversion toward heat production (Roland et al., 2016). Although research indicates that elevated calf growth is expected in CCC systems (particularly with full-time access; Meagher et al., 2019), pasture-based CCC calves may experience reduced benefits associated with high milk consumption, due to greater levels of nutrition being directed towards maintenance. It is important to ensure that the implementation of CCC systems do not come at a cost to calf welfare. As such, a part-time contact system (Sirovnik et al., 2020) adapted to alleviate the risks associated with outdoor calf rearing, whereby calves remain indoors while the cow grazes by day, may be an alternative to a fully outdoor pasture-based contact system.

Achievement of One Welfare on-farm means it is important that both animal and human health and wellbeing are not being compromised (Colonius and Early, 2013). Spring is the most labour intensive period in a seasonal calving system, with calf care duties being particularly demanding (Deming et al., 2017). Artificial calf rearing requires individual management of each calf after birth (Gleeson et al., 2008) and labour input varies greatly depending on the feeding management and housing system in place (Sinnott et al., 2021; 2022). The labour implications of CCC systems for farmers has been largely unstudied to date. Knierim et al. (2020) postulated an assumed labour saving of approximately 10 h per dam-reared calf (for a 13-week suckling period; assumption based off research by Asheim et al. (2016)). While a number of tasks are common between artificial calf rearing and CCC systems (health inspections, cleaning and bedding pens) other tasks differ (such as feeding calves, cleaning feeding equipment in artificial rearing systems or separating cows and calves in CCC systems for milking) which may influence the associated time budget.

Studies examining CCC systems at pasture are limited, particularly those which evaluate the effect the system has on both the farmer and animal collectively. Although calves within a pasture-based system need to go to pasture at a few days of age to have continuous cow access, part-time contact systems may be equally, if not more viable, as a contact system operating within pasture-based boundaries. Therefore, the aim of this study was to track the effects of full-time and part-time CCC in a pasture-based system on calf health, behaviour, growth (weight and linear body measurements) and labour requirements, compared to calves with no cow-contact (separated immediately after birth).

2. Materials and methods

The study was carried out from 22 January to 23 September 2021 at Teagasc Moorepark Research Farm, County Cork, Ireland. The study population consisted of 55 cow-calf pairs with all cows rearing a single calf. Cows were balanced pre-calving for parity (16 primiparous and 39 multiparous; 20 second lactation, 6 third lactation, 10 fourth lactation, and 3 fifth lactation), milk production of previous lactation (4497 ± 193.8 kg; dams first lactation data was used for primiparous animals), breed (Holstein Friesian (HF) and HF x Jersey (JE)) and predicted calving date (16 February ± 15.2 days). Twenty-nine percent of cows enrolled on the study had previously been served with sexed semen to increase the likelihood of a heifer calf.

Ethical approval to undertake the study was granted by the Teagasc Animal Ethics Committee (TAEC2020-290); all procedures were authorized, licenced and carried out in accordance with the Health Products Regulatory Authority (HPRA) of Ireland (AE19132/P124). Experiments were undertaken in line with the European Union (Protection of Animals Used for Scientific Purposes) Regulations 2012 (S.I. No. 543 of 2012).

2.1. Experimental systems

A total of three balanced groups of cow-calf pairs were created and assigned to a randomised block design experiment (using Microsoft Excel file by individual independent of study). The systems were; i) full-time CCC, outdoors at pasture (FT-O), ii) part-time CCC, as calves were housed indoors (PT-I), and iii) no CCC with calves housed indoors (NC-I). The calf population was comprised of 39 females and 16 males (proportion of females due to sexed semen). Mean calf birth weight was 34.2 ± 5.75 kg and mean birth date was February 12 ± 16.6 days. Three calf breeds were enrolled and distributed evenly across the study: 27 HF, eight HF x JE, 20 HF x Aberdeen Angus (AA).

2.2. System comparison

It is important to highlight that this study acts as an observational systems comparison. This was done to reflect how this system may be integrated into existing commercial farm scenarios. The NC-I system reflects the conventional calf rearing system that is typically employed on-farm. As such, this system acts as a baseline for expected outcomes within this study when investigating both respective contact systems (PT-I and FT-O).

2.3. Calving and post-calving management

When a cow displayed imminent signs of calving, she was moved to an individual straw-bedded calving pen (20.3 m^2). All calving events were supervised and assistance provided as necessary. For cows with no calf-contact, following calving, the cow was restrained for milking/colostrum collection (via head-lock and calving gate; InterPuls, Wiltshire, United Kingdom). The udder and each teat surface was cleaned using methylated spirits, teat sealant was voided manually from each quarter. Following this, the cow was released and moved to an adjacent group pen, specifically used for freshly calved cows, (80.1 m^2) until the following scheduled herd milking time (either AM or PM). The calf was moved to an individual calf pen. For cows with calf contact, immediately after parturition the cow's udder and each teat surface was cleaned using methylated spirits as well as teat sealant voided manually.

Following this, the udder was washed thoroughly with warm water to remove any residues to prevent taste deterrent for suckling. All calves were weighed at birth (TruTest XR 3000, TruTest limited, Auckland, New Zealand).

Following calving, the FT-O and PT-I CCC pairs were moved to an individual bonding pen (16.7 m^2). Each contact pair remained here for a minimum of 48 h. Calf feeding behaviour and cows aggression were observed for. If no signs of colostrum consumption occurred within a six-hour period post-calving (i.e. hollowed hip area or no observed suckling), calves were manually fed colostrum collected, via a teat bottle (one instance), from a single cow not on the study (Barry et al., 2022); (≥22 % Brix (>50 g/L IgG), Brix refractometer; Milwaukee Instruments MA871 Digital Brix Refractometer). If calves avoided dam milk consumption for 24 h (one instance), or cows displayed continued aggression towards their calf (no instance), at any point during the study, they were excluded from the study. If the bonding process was successful (i.e. consistent suckling and no aggressive behaviours exchanged), the pair were then allocated to their respective group (2.4 ± 0.62 days).

2.4. Full-time cow-calf contact

Following bonding (two days), FT-O cow-calf pairs were moved into their experimental group indoors for approximately 3 ± 3.3 days (habituation to group setting and ensuring calf vigour before movement outdoors). Subsequently, pairs moved outdoors (5 ± 3.3 days old) to pasture until weaning. Cows and calves were only separated at milking (8:00 & 16:00). Calves either remained in the paddock until the cow returned post-milking, or accompanied the cow to the milking parlour (separated into pen adjacent to parlour until returning to the paddock with their dams following milking). Paddocks were rotationally grazed, with fresh pasture allocated daily, and up to 3 kg DM/day of concentrates, such that there were no restrictions on cow diet. Calves had ad libitum access to fresh milk (via suckling), water, grass and concentrates (straw and silage were offered as forage while indoors). Concentrate (18 % crude protein; ingredients: barley, soya bean hulls, rapeseed meal, maize gluten, maize, sugar cane, molasses, distillers dried grain, dehulled soya bean meal, whey permeate; Kaf Gro, Prime Elite, Dairygold, Cork, Ireland) was offered to calves at pasture in custom-built bird-proof feeders in a separately fenced creep area, accessible only by calves.

In periods of extreme weather (i.e., excessive wind and rain), cow-calf pairs were housed indoors by night until conditions improved (five occasions of on-off grazing occurred throughout study i.e., outdoor grazing by day and housed indoors by night (Kennedy et al., 2009, 2011); no occasion where pairs were housed fully indoors day and night). While housed indoors, cows were offered silage ad libitum.

2.5. Part-time cow-calf contact

Following bonding (3 ± 0.65 days), PT-I cow-calf pairs joined their experimental group indoors. Calves remained indoors at all times until weaning. Cows and calves were separated in the morning for milking (approx. 08:00), with calves enclosed in a designated creep area. Cows were only milked once per day. Following milking, cows grazed outdoors (without their calf and followed similar grazing management rules to the FT-O) until the evening (approx. 15:00), when they returned indoors and were housed for the night. Calves had unrestricted access to their dams in this period. Similar to FT-O, paddocks were rotationally grazed with no restriction on cow diet. *Ad libitum* silage was offered to animals by night. Calves had ad libitum access to fresh water, forage (straw and silage) and concentrates (as above) throughout the day and night. Access to fresh milk (via suckling cow) was possible from approximately 15:30 until 08:00 the following morning, daily. When it was not possible for PT-I cows to graze outdoors during the day (e.g., inclement weather; five occasions throughout study), they remained indoors but calf access was still prevented by day (i.e. no physical contact between the cows and calves until the designated time).

2.6. No cow-calf contact

Following birth, calves were removed from the cow immediately and placed in an individual pen for approximately three days, with no further dam contact. A herd containing cows with no CCC was created, and as cows calved, they joined this herd. These cows were milked and managed according to general herd management practices (i.e., rotational grazing outdoors and twice-a-day milking). Calves were fed 8.5 % of birth body weight (BW) of colostrum from their own dam via a teat bottle (quality determined and recorded using a Brix refractometer; Milwaukee Instruments MA871 Digital Brix Refractometer). If calves refused colostrum consumption via the bottle and teat, the calf was fed via a stomach tube (three occasions). Following colostrum feeding, calves were offered five feeds of transition milk from their own dam twice per day (10 % of birth BW) using an individual teat bucket. At three days old calves were moved to a group pen (18 calves) and were provided with milk replacer (Volac Heiferlac Instant, Volac, Hertfordshire, United Kingdom; 26 % crude protein, 19.7 ME MJ/kg DM). Milk replacer was reconstituted at a rate of 150 g/L and distributed using an automatic milk feeder (Volac Förster Technik Vario, Germany). Calves received 6–9 L/day (depending on age i.e. milk increasing gradually from 6 to 9 L/day will all calves provided the opportunity to consume 9 L/day consecutively before weaning) with a total milk powder allocation of 65.7 kg. Concentrates (as described above), water and forage were offered ad libitum from three days old.

2.7. Housing

Indoor PT-I cow accommodation was comprised of two areas (total area for both = 166 m^2); a feeding area (incl. feed barrier; 50 m^2) and layback cubicle area (116 m^2). Twenty-three cubicles (2.90 m^2) and were elevated 25 cm above ground level. Cubicles were disinfected daily in the morning using ground lime. The floor was solid concrete, with a slatted underfloor tank located at the exit of the pen. Two automatic scrapers were present: one in the feeding area and one in the cubicle area, which collected and transported excrement to the slatted tank. Calf housing for the PT-I systems consisted of separate large straw-bedded creep pens (67 m^2; 3.7 m^2 per calf). All bedding was removed, the pen cleaned, disinfected and re-bedded with fresh straw weekly, to a depth of 15 cm. Straw bedding was topped up twice weekly. The cow and calf areas were connected by a creep gate and walk-way (4.2 × 3.1 m), which offered calf-only access to the straw bedded area. Auditory and olfactory cues could be exchanged between cow and calf at all times when cows were housed, with visual stimulation of the calves possible for the cows from the feeding area of the cow accommodation. For periods where the FT-O system required indoor housing, housing conditions were the same as PT-I cows and calves.

Following a period of individual housing (3 days), NC-I calves moved to a group pen (48 m^2 for 18 calves; 2.7 m^2 /calf) which contained a concrete feed area (16 m^2) and a lay back area with straw bedding (32 m^2). The feed area of each pen was cleaned in the morning (9:30–10:00) and evening (16:30–17:00) using water and disinfectant. All bedding was removed from the lay back area weekly, it was cleaned, disinfected and re-bedded with fresh straw weekly, to a depth of 15 cm. Straw bedding was topped up twice weekly.

2.8. Weaning

2.8.1. Contact systems

Calves were weaned based on age at 58 ± 3.9 days. For the CCC systems, the cow and calf were removed from the herd in either the paddock (FT-O) or the shed (PT-I) in batches of two or more pairs and moved indoors to be weaned. Cows of the same system were grouped together, and similarly, calves of the same system were grouped together (e.g., FT-O cows were grouped together and FT-O calves were grouped together in an adjacent pen; same for PT-I cows and calves). Cows were

kept separated from their calves but visual, auditory, olfactory and tactile stimulation were possible at all times (with the exception of milking times, twice-a-day for all systems) through the separation gate. Calves were provided with ad libitum water, forage (straw and silage), and concentrates at this time, with no additional milk substitution provided. The weaning process lasted seven days for contact calves (weaning from both milk and the dam) and was broken into three stages. Stage one (weaning day (WD) one to three); calves were allowed to have one hour where separation gates were opened to allow full contact and suckling of the cow after the morning milking (at approximately 10:30). Stage two (WD four and five), no contact was provided with stimulation only possible through the separation gate. Stage three (WD six and seven), the cow was removed from the weaning shed (WD six), having completed the weaning process and re-joined the outdoor grazing herd (separate herd to the animals remaining on the FT-O system). The calf remained in the pen until day eight, when it was moved as the weaning process was complete. Following weaning, regardless of system, calves were grouped together in an indoor pen (40 m^2; average space allowance of 2 m^2 per calf) bedded with straw for 8 ± 1.7 days before being moved outdoors to a paddock at 71 ± 4.5 days old.

2.8.2. No-contact calves

Upon entry into the group pen at approx. three days old, NC-I calves were assigned an individual feeding plan using the automatic feeder (Volac Förster Technik Vario, Germany). As part of the feeding plan, weaning commenced at 48 days of age and lasted 12 days, gradually reducing the volume of milk offered to calves. Once a calf was fully weaned off milk for two days (i.e., 0 L consumed for 48 h), it was moved from the system pen to the larger weaned pen (with calves from all systems).

2.8.3. Additional comment

Despite obvious system differences related to weaning. Care has been taken to ensure the overall basic process of eliminating milk from the diet is comparable among systems. i.e. upon complete cessation of milk for calves, all calves are within a similar age (i.e. 60 ± 3.9 days).

2.9. Measurements

2.9.1. Health scoring

Animal health scores were assigned to calves on an individual basis twice-weekly (non-consecutively) from birth until three weeks post-weaning (no association to labour related health inspections). Health factors assessed were those used by Sinnott et al. (2021) and included the following: overall demeanour, nasal discharge, ocular discharge, ear position, attitude, coughing, faecal hygiene, dehydration, mobility and hind quarter cleanliness of faecal matter. A four-point scale was used, whereby zero represented no health complications and three represented the most severely affected. Health scoring was carried out by two observers, with inter-observer reliability performed (89 % agreement first time and 97 % agreement second time following discussion and clarification).

2.9.2. Morbidity and removal from system

Any incidences of morbidity (any calf requiring antibiotic treatment for illness from 0 to 11 weeks) and mortality were recorded throughout the study. Permanent removal from system (due to illness related complications) was also noted throughout the study period.

2.9.3. Behaviour

Weekly behavioural observations were carried out on the same day every week from birth until three weeks post-weaning by a team of two observers (measuring different systems simultaneously; inter-observer reliability performed - 85 % agreement first scan and 98 % agreement second scan following discussion and clarification). Observations were carried out by a single observer using the scan sampling method:

scanning at one minute intervals, for a period of 15 min, three times per day (07:00, 11:30 and 16:30). To ensure calves were familiar with the observer's presence, an adjustment period of five minutes was allowed before the first observation was made. Behaviours related to the ethogram are defined in Table 1. In short, the list of required observed behaviours included: lying, standing, walking, pacing, drinking water and milk, eating grass, eating concentrates, eating forage or eating silage, rumination, scratching, rubbing and stretching, self-grooming, play, vocalisation, socialisation, defecation and urination, tongue rolling, oral manipulation of pen or prepuce of another calf and cross sucking.

Behaviour observations around weaning were carried out daily for a period of seven days during the weaning process (weaning from cow and milk for contact systems; weaning from milk only for NC-I system).

Table 1
Ethogram adapted from Barry et al. (2019b) which categorises and defines various behaviours used for behavioural observations.

Category	Behaviour	Description
Standing	Standing	In a static upright standing position with weight placed on all four legs
Lying	Lying	Resting either sternally or laterally with either four legs hunched close to body or stretched and awake or asleep.
Movement	Walking	Actively moving from one point in the pen to another
	Pacing	Repeated actively walking up and back the same area successively
Consume liquids	Drinking water	Drinking water from trough
	Drinking milk	Consumption of milk from either an automatic milk feeder or cow udder
Consume solids	Eating grass	Grass consumption via grazing
	Eating concentrate	Concentrate intake from trough feeder
	Eating forage	Forage intake from either manger (hay), bedding (straw) or feed barrier (silage)
Rumination	Rumination	Chewing movements of the mouth whilst not actively consuming feed source either standing or lying
Comfort	Scratching	Scratches itself with one of their legs (generally hind legs)
	Rubbing	Rubs/presses any body part on pen structure in an up, down or sideways motion
	Stretch	Stretches (includes leg extensions and or arched back) generally followed by period of lying.
	Grooming	Uses tongue to repeatedly lick own back, side, leg, tail areas
Abnormal	Tongue Rolling	Repeated rolling movements with its tongue inside or outside its mouth
	Urine drinking / oral manipulate prepuce or naval	Drinking the urine of another calf / attempts to suck the naval or prepuce area of another animal
	Cross sucking	Attempts to suck any body part of another animal except prepuce or naval area.
	Oral manipulation of pen structure	Licks, nibbles, sucks, or bites at the pen structure (barriers, walls, buckets, troughs etc.)
Play	Playful behaviour/ Mounting / Head butting	Runs, jumps, changes direction suddenly, bucks, kicks hind legs, twists or rotates body / animal mounts, or attempts to mount, a pen mate / animal is engaged in head to head pushing with another animal.
	Play with object	Head-butting any inanimate object within a pen
Vocalisation	Vocalisation	Any sound emitted from the mouth of a calf
Socialise	Social interaction	Calf licks another calf multiple times or nudges another calf with its nose.
Defecate/ Urinate	Defecation/Urination	Defecates or urinates

Observations were completed in a similar way to weekly measurements (scan sampling at one minute intervals for 15 min; three daily time points – 07:00, 11:30 and 16:30). For CCC pairs, behavioural observations around weaning began when pairs entered the weaning pen and ended when the calf was fully weaned and removed from the weaning pen. For NC-I calves, observations began five days prior to cessation of milk replacer feeding and ended two full days after milk was completely withdrawn from the diet. Measurements over the seven day period ensures that behaviour is recorded before, during and after the cessation of milk for all systems.

2.9.4. Body weight

The BW of calves was measured at birth, weekly until three weeks post-weaning and fortnightly thereafter (scales described above) until six-months of age.

2.9.5. Linear body measurements

Linear body measurements (body length (BL): top of the withers to the ischium; withers height (WH): vertical distance from ground to top of withers; and heart girth (HG): circumference of body directly behind front legs; Costigan et al., 2021) were taken weekly from birth until weaning, and monthly for two months post-weaning to identify if differences between systems in terms of frame growth could be identified. The BL and HG were measured using a soft measuring tape (Tape Measure 150 cm/60 inch, Korbond Industries Ltd. Grantham, UK). The soft measuring tape length was verified weekly against a known length to ensure consistency among measurements. The WH was taken using a measuring stick and crossbar (Nasco, Fort Atkinson, Wisconsin, USA). Measurements were taken by a single trained person throughout the study period for consistency, and data were recorded in centimetres.

2.9.6. Concentrate intake

Calf concentrate intake was measured on a group basis for seven weeks pre-weaning and for each weaning group. A known quantity of concentrate was placed in the feeder of each system and particulars recorded. Once empty, the date was recorded and concentrate replenished, repeating the process. For contact weaning, refusals were recorded following each weaning period. This was subtracted from the total concentrate provided to the calf group. It was not possible to distinguish pre-weaning and weaning intakes among NC-I calves due to pre-weaning and weaning animals being located in the same pen.

2.9.7. Labour

Three periods of labour evaluations were carried out during this study; i) immediately post-calving, ii) routine daily tasks and iii) weaning.

Tasks specifically related to NC-I for the aforementioned periods include: i) colostrum collection and feeding, ii) feed preparation, feed inspection (ensuring milk allocation consumption), daily cleaning of feeding equipment, daily cleaning of pen feeding area. Tasks related to weaning NC-I calves were negligible (explained in discussion). Tasks specifically related to contact systems (i.e., FT-O and PT-I) for the aforementioned periods include: ii) movement of cow calf pairs to and from the milking parlour and the separation and reuniting of cow calf pairs after milking, and iii) cow movement to and from the parlour, and the reuniting and separation of cow calf pairs in weaning pens. Common tasks among all three systems relative to periods include: i) udder cleaning, movement of calf to allocated pen, calf tagging and navel spraying, and ii) health checks.

With the exception of immediately post-calving, evaluations were carried out during two non-consecutive days per week until all calves were fully weaned. Measurements were repeated morning and evening and timed using a stopwatch (SW; time is expressed as hh:mm:ss). The start/stop cues for the SW for each labour related task are defined in Supplementary File 1. The sum (total hh:mm:ss) of each task was quantified on a daily basis and divided by either the number of cow calf

pairs, or the system related calf numbers in the pen on that day.

2.9.8. Temperature and relative humidity

TinyTag data loggers were used to record temperature and relative humidity every 10 min throughout the study period (Tinytag TGP 4017 Temperature Data Logger; Gemini Data Loggers, West Sussex, United Kingdom). Data loggers were positioned out of cow and calf reach inside the bonding pens, the indoor calf creep area (contact calves), the indoor cow cubicle area (contact calves) and the calf only group pen (no cow contact). External weather conditions were recorded by a weather station located < 1 km from the experimental site (Met Eireann, Fermoy, Cork, Ireland).

2.10. Data processing

Health and growth data were divided into four periods with each period marking an important transition for calves. The early and late pre-weaning periods (3 to 28 days and 29 to 56 days, respectively) divided the pre-weaning period into two equal halves. The early post weaning period (57 to 70 days) accounted for weaning and the week indoors habituating post-weaning. The late post-weaning period (and 71 to 77 days) marked movement outdoors for all calves. A fifth period, the carry-over period, was added for growth data only, accounting for calf growth after the late post-weaning period. To account for differences in weekly behaviour, data was divided into five periods: early and late pre-weaning (same intervals outlined above), weaning was 57 to 64 days, early and late post-weaning were 65 to 70 and 71 to 77 days, respectively. Data specifically related to weaning behaviour were divided into stages to account for changes during the weaning process: weaning day (WD1-3 (day 1-3), WD4-5 (day 4 and 5) and WD6-7 (day 6 and 7).

Health scores were consolidated from four scores (0, 1, 2, 3) for each health factor to two categories, creating binary data for analysis. Category one were calves scoring 0 or 1 (none to mild health issue) and category two were calves scoring 2 or 3 (moderate to severe health issue). This created a division between health scores: scores that may not impact calves in a severe way, verses scores that may. Related to calf morbidity, calves requiring medical treatment were scored as one, whereas those who did not were scored as zero. Similarly, any calf that did not necessitate removal from system were scored as zero, with the alternative scored as one.

Average concentrate intake per calf/day was calculated by dividing the weight of concentrate consumed, by the number of calves and number of days over which the concentrates were consumed. Due to limited observation numbers this is reported on a raw average basis.

Behaviour data was categorised as binomial, calves were observed 8 times (every minute with one minute intervals for 15 min) where they could complete the same or a different behaviour (e.g., a calf's lying behaviour was observed on three occasions during the observation period; this was coded as 3/8 times). Resulting analysis expresses behaviour as a percentage of total observations. To account for variance in behaviour relative to age, week-of-treatment was included in the dataset, tracking a calf weekly from birth until completion of the study.

Data related to daily labour was collected on a group level, as such it was not possible to track weekly labour requirements relative to calf age. As calves were weighed on a fixed day every week, BW and linear body measurement data were corrected for calf age to allow accurate age comparisons among calves. This involved the alignment of a calf's closest age (and associated weight) to seven day increments from birth (changed to 14 day increments during carry-over). Average daily gain (ADG) for each period was calculated based on the difference between weighing dates and weight values.

Daily TinyTag temperature and humidity data (between 00:00 and 23:50 daily) were averaged to attain a single daily figure for each parameter. For analysis (health and behaviour), temperature and humidity were consolidated into two categories; 1) temperatures below calf thermo-neutral zone (TNZ) based on age (i.e., lower critical

temperature (LCT); ≤10 °C; Davis and Drackley, 1998) and 2) temperatures within calf TNZ based on age (≥ 11 °C to 24 °C). Temperature never rose above TNZ during the study. The number of days a calf was within their TNZ was calculated for each individual based on the days they were on treatment.

2.11. Statistical analysis

Due to pseudo-replication, all analysis carried out will be reported in a descriptive capacity only, with no significant inference made. Sample size was calculated based on calf weaning weight using existing results from previous bodies of work (Sinnott et al., 2021, 2022) with 95 % confidence interval (CI) and 80 % power. This sample size would allow for detection of a 3.2 kg difference in weaning weight. Analyses were conducted using SAS (Version 9.4, SAS Institute Inc, 2002). The frequency procedure (PROC FREQ) was used to describe the non-normal distribution of categorical variables related to health scoring. The logistic regression procedure (PROC LOGISTIC) was used to examine associations between the independent variables; system, location, period of life and temperature, on faecal, eye and nose related health scores (binary data).

Kaplan–Meier survival estimates (PROC LIFETEST) were used to determine differences between interest variables and the time from birth to illness (morbidity) and successful weaning among systems. In this analysis, calves either experience the event of interest (i.e., illness or completion of weaning) or were 'censored', meaning calves did not experience the event of interest (illness), or were removed from the study before the event of interest (weaning). The STRATA statement was used to account for calves within each system. To evaluate differences at the beginning of the survival curve, Peto and Wilcoxon tests were used, whereas the log-rank test was used to evaluate differences at the end of the curves. The PROC PHREG procedure (Cox proportional hazard models) was used to examine effects of calf breed and sex on morbidity and mortality.

A multivariable mixed logistic regression model (PROC GLIMMIX) with repeated measures was used to evaluate the differences in weekly and weaning calf behaviour relative to contact systems. Calf was included as a random effect, while date was included as a repeated effect. Data followed a binomial distribution pattern and included a logit link function. Similarly, least square means and interactions examined between variables in each model. Categorical variables in the behaviour model included; sex, breed, system and period and their interactions. Sex and breed did not influence any behavioural outcomes, these variables remained in the model, however no further comments have been made in the results section. As grazing behaviour was incomparable between periods for each rearing system, analysis could not be undertaken using PROC GLIMMIX, instead frequency distribution was used to compare grazing frequency for each system in each period for each rearing system.

Linear mixed models (PROC MIXED) were used to evaluate the effect of system on calf growth (BW and ADG), linear body measurements and daily labour input. A normal distribution pattern was followed by dependent variables. Birth BW was centred within breed and subsequently included in the models as a covariate. Calf was included in the model as a repeated effect. Categorical variables in the BW and linear body measurements models include; system, age, sex, breed, period and health status. Additionally four time points of BW (coinciding with the end of periods) were analysed individually (without repeated measures) to show calf weight without the influence of other time points. For linear body measurement analysis, the Economic Breeding Index (EBI; Berry et al., 2005) sub-index for beef carcass (relevant for dairy and beef animals), accounting for genetic variation in body size, was included in the model as a covariate. Regressions of BW on HG, WH, BL and their combinations were tested (PROC REG). Least square means were assessed in each model.

Linear mixed models (PROC MIXED) were also used to evaluate the effect of system on the daily labour input. Categorical variables in the labour model were system, level of CCC and week-of-experiment. To account for variance in labour over time, week-of-experiment was included in the data set. This tracked the progress of the study from beginning (entry of first calf from each system into group pen following bonding/individual housing) to end (beginning of weaning process for last calf of each system) over time (in weeks).

Due to illness associated complications (outlined in results), 25 % of the FT-O group were removed from treatment (i.e. four cow-calf pairs out of 18 removed). For clarification in relation to animal numbers when analysing data, all cow calf pairs (18 in each system) were included in health and growth measurements (accounting for differing numbers within each system). For all other measurement analysis, these animals removed from system were not included in the analysis.

3. Results

3.1. Health

Calves received a score of one most frequently for each health score, regardless of system, meaning calves were either healthy or displayed mild ill-health symptoms (Table 2). Issues related to faecal hygiene, eyes and nose were observed most often amongst calves.

Throughout the study, PT-I and FT-O groups saw elevated scores related to faecal cleanliness (i.e. dirty hindquarters) compared to NC-I calves. Distribution frequencies of health scores shows the incidence of faecal score ≥2 was greatest in the early pre-weaning period among all systems. In this period, PT-I calves had elevated faecal scores ≥2 compared to NC-I and FT-O calves (+12.9 % and +9.0 %, respectively). Early post-weaning, FT-O calves experienced elevated faecal scores compared to NC-I and PT-I calves (+12.1 % and +7.0 %, respectively).

Calves in the PT-I group had more issues related to eyes compared to NC-I and FT-O calves, particularly in the late post-weaning period (+11.5 % and +8.8 %, respectively). In the same period, NC-I and PT-I calves had slightly increased frequency of health scores ≥2 for nasal discharge (+8.1 % and +6.1 %, respectively).

3.2. Morbidity and removal from treatment

Of the total number of calves in this study, 21.8 % experienced one or more episodes of illness requiring antibiotic treatment in the pre-weaning period. Calves in the FT-O system (37 %) received more antibiotic treatments than the other two systems (17 % of PT-I and 6 % of NC-I calves). Illness associated complications meant 25 % of calves in the FT-O system were removed from the experiment (no calves from the other systems were removed).

3.3. Weekly behaviour

Results related to weekly behaviour can be found in Table 3. The time spent lying decreased over time (Table 3), decreasing from early to late pre-weaning and early to late post-weaning. Standing time increased over time for PT-I calves, and although a similar trend was seen among NC-I and FT-O calves, it intermittently decreased during weaning (NC-I) and early post-weaning (FT-O). Calves lay more in LCT (55.5 % of time, compared to 49.1 % of their time when temperatures were within TNZ; Supplementary File 2). The NC-I calves moved less than both contact systems throughout the study (0.5 % vs 1.4 %, respectively).

Rumination trends fluctuated for each system. However, contact calf rumination increased consistently until late post-weaning. Rumination for NC-I calves decreased following weaning. The FT-O calves gradually increased grazing from 1.2 % (16/1312; n/N) early pre-weaning, to 6.8 % (93/1368) late pre-weaning. Late post-weaning, FT-O calves spent 37.2 % (140/376) of time grazing, followed by PT-I (26.8 % (167/624)) and NC-I calves (20.0 %; 91/456). Time consuming solids peaked with

Table 2
Distribution (%) of health scores carried out twice weekly over an 11 week period (where ≤1 indicates none or mild health issues and ≥2 indicates moderate to severe health issues) for no (NC-I; 18 calves), full-time (FT-O; 14 calves), and part-time (PT-I; 18 calves) contact systems in the early and late pre- and post-weaning periods. Percentages express the frequency of health scores for each category (either ≤1 or ≥2) relative to the total number of health scores recorded for a health factor.

| | | Health score per feeding system (%) | | | | | | | |
| | | Early pre-wean | | Late pre-wean | | Early post-wean | | Late post-wean | |
		≤1	≥2	≤1	≥2	≤1	≥2	≤1	≥2
	NC-I	83.6	16.4	97.5	2.5	95.8	4.2	98.7	1.3
Faecal	FT-O	79.7	20.3	92.3	7.7	83.7	16.3	97.3	2.7
	PT-I	70.7	29.3	93.2	6.8	90.7	9.3	93.8	6.2
	NC-I	100	0	100	0	100	0	100	0
Demeanour	FT-O	97.5	2.5	100	0	100	0	100	0
	PT-I	99.2	0.8	100	0	100	0	100	0
	NC-I	100	0	100	0	100	0	100	0
Ears	FT-O	97.5	2.5	98.5	1.5	100	0	100	0
	PT-I	99.2	0.8	100	0	100	0	100	0
	NC-I	100	0	99.4	0.7	100	0	94.6	5.4
Eyes	FT-O	96.6	3.4	100	0	97.7	2.3	91.9	8.1
	PT-I	94.8	5.2	98.3	1.7	97.7	2.3	83.1	16.9
	NC-I	95.4	4.6	99.4	0.6	97.9	2.1	91.9	8.1
Nose	FT-O	100	0	98.5	1.5	97.7	2.3	100	0
	PT-I	100	0	98.9	1.1	95.3	4.7	93.9	6.1
	NC-I	100	0	100	0	100	0	100	0
Cough	FT-O	100	0	100	0	100	0	100	0
	PT-I	100	0	100	0	100	0	100	0
	NC-I	100	0	100	0	100	0	100	0
Dehydration	FT-O	98.3	1.7	100	0	100	0	100	0
	PT-I	100	0	100	0	100	0	100	0
	NC-I	100	0	100	0	100	0	100	0
Mobility	FT-O	98.3	1.7	100	0	100	0	100	0
	PT-I	97	3	100	0	100	0	100	0
	NC-I	100	0	100	0	100	0	100	0
Interest	FT-O	99.1	0.9	100	0	100	0	100	0
	PT-I	99.3	0.7	100	0	100	0	100	0

Table 3
Weekly behavioural observations (% of total scans) and SEM related to period of life (i.e. early pre-weaning, late pre-weaning, weaning, early post-weaning and late post-weaning) for calves in no (NC-I), full-time (FT-O) and part-time (PT-I) contact systems.

| | Early Pre-wean | | | Late Pre-wean | | | Weaning | | | Early Post-wean | | | Late Post-wean | | | |
	NC-I	FT-O	PT-I	NC-I	FT-O	PT-I	NC-I	FT-O	PT-I	NC-I	FT-O	PT-I	NC-I	FT-O	PT-I	SEM
Lying	63.7	68.8	69.8	61.8	63.2	54.3	67.5	48.5	53.8	56.3	53.8	40.6	27.1	30.8	26.4	5.18
Standing	35.1	24.8	27.5	36.2	33.7	41.5	31.9	49.7	45.5	41.9	45.8	58.9	68.8	65.9	69.2	5.02
Rumination	5.2	5.9	6.2	21.7	25.0	10.0	35.5	27.4	16.2	25.7	30.1	33.4	7.9	22.6	13.3	4.09
Defecate/ Urinate	0.2	0.1	0.1	0.5	0.6	0.6	0.6	0.2	0.3	0.8	0.1	0.5	0.5	0.6	0.5	0.02
Eat Solids	3.5	1.1	2.8	3.7	1.2	2.1	8.6	9.8	12.1	9.8	16.8	34.8	13.5	7.2	5.6	2.12
Comfort	1.6	1.3	3.1	2.8	4.4	7.5	1.8	1.7	3.6	2.6	3.9	3.6	4.9	2.7	4.7	1.05
Abnormal	1.0	1.0	3.2	3.1	3.1	7.5	1.7	2.1	6.2	2.5	4.3	2.9	3.4	3.0	2.4	1.09

Table 4
Weaning behavioural observations (% of total scans) and SEM related to stage of weaning (i.e. stage 1 where pairs had one hour of unrestricted contact per day, stage 2 where pairs had restricted contact through gapped gate and stage 3 where the cow was removed from the weaning pens) for calves in no (NC-I), full-time (FT-O) and part-time (PT-I) contact systems.

| | Stage 1 | | | Stage 2 | | | Stage 3 | | | |
	NC-I	FT-O	PT-I	NC-I	FT-O	PT-I	NC-I	FT-O	PT-I	SE
Lying	69.4	50.8	64.0	69.9	45.7	46.4	66.1	46.9	54.3	4.44
Standing	11.1	20.5	14.6	13.2	23.4	26.2	5.7	15.8	11.7	2.45
Rumination	43.8	24.6	21.1	29.8	28.2	27.4	33.6	30.1	24.8	4.10
Movement	0.2	1.2	1.0	0.1	0.5	0.3	0.3	0.2	0.1	0.24
Vocalisation	2.2	7.4	5.5	1.9	8.6	12.4	0.4	7.8	5.0	1.65
Defecate/Urinate	0.3	0.2	0.5	0.8	0.6	0.2	1.2	1.1	0.3	0.27
Consume Liquids	2.3	1.2	0.7	2.3	0.8	1.6	1.9	1.1	1.5	0.56
Consume Solids	10.6	9.5	5.8	8.8	15.8	12.5	14.1	18.0	18.9	2.21
Comfort	1.8	5.8	4.2	2.5	5.3	2.3	4.6	5.6	2.6	0.90
Abnormal	1.5	4.5	5.4	2.3	3.4	5.3	3.1	3.3	4.2	0.98
Social	0.7	2.4	2.4	1.8	2.1	1.8	1.1	2.1	3.5	0.65

the PT-I calves early post-weaning. While NC-I calves spent less time consuming solids than contact calves, this increased consistently through pre and post-weaning periods. As temperature entered a calf's TNZ, time consuming solids increased (7.7 % vs 4.7 % during LCT).

The PT-I system expressed the most abnormal behaviours late pre-weaning and comfort behaviours throughout the pre-weaning periods. In general, comfort behaviours decreased at weaning, but recovered post-weaning. Playing time appeared to be similar among systems, however social interaction with others was less for NC-I calves (0.09 %) than their contact counterparts, which were similar (0.30 %).

3.4. Weaning behaviour

Results pertaining to weaning behaviour are outlined in Table 4. The NC-I calves spent more time lying and less time standing throughout weaning. Standing time peaked for all calves WD 4–5, then decreased below initial WD 1–3 levels, during WD 6–7. Movement for all calves was greater in WD 1–3 than all other stages.

Calves in the NC-I system ruminated more than contact calves during WD 1–3. The PT-I calves had the lowest rumination at all points of weaning. Although solid consumption duration appeared similar among systems, the PT-I system had the lowest instance in early weaning (WD 1–3).

The PT-I calves expressed the most abnormal behaviours throughout weaning. Weaning vocalisations and socialisation were greatest for contact calves. The FT-O calves carried out comforting behaviours most throughout weaning.

3.5. Growth and linear body measurements

Calves in the NC-I system weighed less at the end of each period than FT-O and PT-I calves, which appeared similar (Table 5). Calves in the FT-O system weighed more in the carry-over period on day 134 (124.1 ± 2.57 kg) and 189 (174.3 ± 2.57 kg), than both the NC-I and PT-I calves (113.7 ± 2.57 kg and 161.3 ± 2.57 kg, respectively).

Both FT-O and PT-I calves had similar ADG in the early and late pre-weaning periods and were higher on both occasions than NC-I. In the early post-weaning period, NC-I calves had a greater ADG than both contact systems. In the late post-weaning period, the ADG of FT-O calves was higher than both the NC-I and PT-I calves. No differences were found between systems in the carry-over period.

Calf girth in the NC-I system was lower than the FT-O from 35 to 84 d (Fig. 1) and PT-I systems from 42 to 84 d, FT-O and PT-I were always similar. There were no apparent differences in girth circumference among systems at the end of the carry-over period (112 d). There were no notable differences between system and calf length or height throughout.

Table 5
Calf weight (kg ± SEM) for age (days) and Average Daily Gain (ADG) (kg/day ± SEM) related to period of life (i.e., early pre-weaning (0–28 days), late pre-weaning (29–56 days), early post-weaning (57–70) and late post-weaning (71–77 days)) for calves with no contact indoors (NC-I), full-time contact outdoors (FT-O) and part-time contact indoors (PT-I).

		NC-I	FT-O	PT-I	SEM
Age	Weight (kg)				
28		49.0	54.7	56.2	1.56
56		69.0	82.1	82.1	2.35
70		79.0	87.4	86.8	2.45
77		81.8	92.2	89.3	2.59
	ADG (kg/day)				
0–28		0.53	0.73	0.79	0.053
29–56		0.69	0.97	0.93	0.066
57–70		0.68	0.32	0.32	0.09
71–77		0.41	0.89	0.46	0.15

3.6. Concentrate intake

Raw averages indicate that pre-weaning concentrate intakes were similar among the FT-O (0.13 ± 0.11 kg per calf/day) and PT-I (0.17 ± 0.11 kg per calf/day) systems. During weaning, FT-O calves consumed 0.65 ± 0.23 kg per calf/day, and PT-I calves consumed 0.44 ± 0.05 kg per calf/day. The NC-I calves consumed 1.05 ± 0.60 kg per calf/day during the pre-weaning and weaning periods.

3.7. Labour

The NC-I system required the most labour at calving (00:15:56 ± 00:00:35) and contact systems (FT-O and PT-I) required the least (which were similar; 00:01:39 ± 00:00:35). This difference is mostly attributable to the collection (00:09:07 ± 00:00:32) and feeding of colostrum (00:05:02 ± 00:00:27) for NC-I calves. Although it took longer to clean the udder of contact cows (00:00:47 ± 00:00:04) compared to non-contact cows (and 00:00:24 ± 00:00:04), there were no differences between systems for the labour required to spray the navel and tag the calf (00:00:47 ± 00:00:05).

The total weekly labour for the FT-O system appeared greater than both the NC-I and PT-I systems (Table 6). The time to move and reunite cow-calf pairs and inspecting calf health was greatest for the FT-O system. The total time required to milk cows differed between each system. This was determined by the length of time cups were on the cows teats; AM and PM for NC-I and FT-O (milking twice-per-day) and AM only for PT-I (milking once-per-day). Milking time per day was greatest for NC-I cows (00:12:06 ± 00:00:23), followed by FT-O (00:10:08 ± 00:00:25) and PT-I (00:07:13 ± 00:00:23).

Weaning labour appeared similar between contact systems; time required to move cows was 00:01:39 ± 00:00:07 per cow/day and to move calves was 00:00:35 ± 00:00:03 per calf/day, respectively.

4. Discussion

It is important to reiterate that this study acts as a systems comparison, which was done to reflect how this system may be integrated into existing commercial farm scenarios. The NC-I system reflects the conventional calf rearing system that is typically employed on-farm. As such, this system acts as a baseline for expected outcomes within this study when investigating both respective contact systems (PT-I and FT-O).

4.1. Calf health

Cow-contact may influence calf health, as suggested by hindquarter faecal matter build-up for contact calves, compared to NC-I calves. High volumes of milk consumption is common among CCC systems (Johnsen et al., 2016), which could have resulted in softer faeces. Faecal consistency is an indicator of dry-matter (Renaud et al., 2020), which would suggest a low dry-matter diet pre-weaning for contact calves. A heavy reliance on milk pre-weaning may result in diet transition difficulties moving into the post-weaning period as dependency shifts to solid feed (Meagher et al., 2019) and grazed-grass intake. It is possible that the diet transition presents itself as a change in faecal consistency. Although, it may be argued that weaning of calves in this incidence was early, research into artificial calf rearing indicates weaning calves by eight weeks old did not affect calves negatively when compared to weaning at 12 weeks of age (in relation to growth and fertility indicators; Costigan et al., 2022). That said, high dietary dependency on milk may mean more time is needed for these animals to become fully functioning ruminants. Environmental exposure to changeable weather for FT-O calves appears to have challenged calf health, a concern echoed by seasonal pasture-based CCC farmers (Neave et al., 2022), seeing more calves requiring removal from treatment due to illness. Aside from the dietary aspect of CCC, cows often act as vectors for infections in young stock (e.
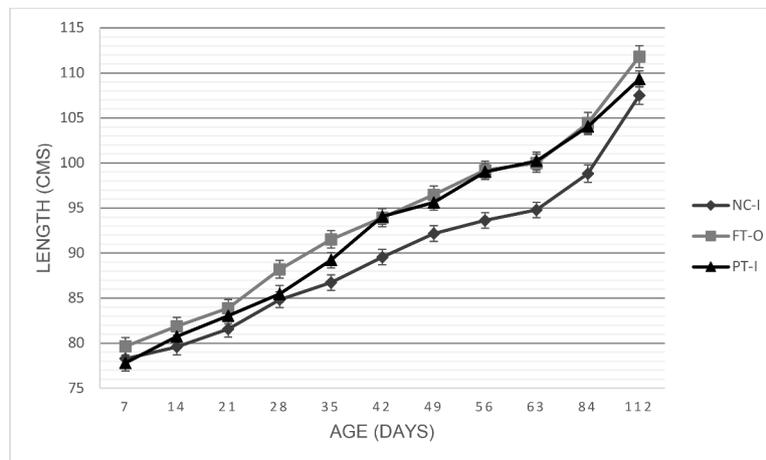
Fig. 1. Calf girth (cm ± SEM; represented in the error bars) relative to age (days) for calves with no contact (NC-I), full-time contact (FT-O) and part-time contact (PT-I) with weaning commencing at 58 days for contact calves and 44 days for NC-I calves.

Table 6
Mean labour input per calf per day (± SEM; hh:mm:ss) related to daily tasks associated with rearing calves in no (NC-I), full-time (FT-O) and part-time contact systems (PT-I).

(hh:mm:ss)	NC-I	FT-O	PT-I	SEM
per calf/day				
Total Labour	00:00:38	00:01:29	00:00:49	00:00:05
Fill Hopper	00:00:06	NA	NA	00:00:01
Feed Inspection	00:00:04	NA	NA	00:00:01
Cleaning pen/equipment	00:00:22	NA	NA	00:00:02
Separation	NA	00:00:11	00:00:09	00:00:02
Movement	NA	00:00:52	00:00:31	00:00:04
(calf and or cow)				
Reunite	NA	00:00:15	00:00:02	00:00:02
Health Inspection	00:00:06	00:00:11	00:00:07	00:00:01

g., Bovine Viral Diarrhoea (Veterinary Ireland Journal, 2019), Johne's Disease (AHI, 2021) and Cryptosporidium (AHDB, 2022)), particularly when exposed to cow faecal matter (Pelan-Mattocks et al., 2000). Although literature in support of this is conflicting (Beaver et al., 2019), elevated morbidity statistics for the contact systems (compared to non-contact), in the present study suggests that calf health is challenged by either CCC itself, or the type of CCC systems implemented in this study.

4.2. Weekly and weaning behaviour

In this study, behavioural observations have captured daily snapshots. While this does not track all calf behaviours during the study, it is hoped this will inform other studies related to future areas of interest for CCC behaviour.

Elevated standing for contact systems during weaning may indicate stress during the weaning process. This is echoed by observations following abrupt weaning of free-suckling contact calves (Fröberg et al., 2011), but challenges results found for fence-line dam contact post-weaning in beef animals (however, calves were typically weaned at over six months old; Price et al., 2003). Furthermore, weaning response was highlighted by elevated vocalisations in contact calves (Newberry and Swanson, 2008).

The NC-I calves ruminated the most during early weaning, with Fröberg et al. (2011) finding the same to be true (comparing free-suckling contact calves to milk restricted calves with automatic feeders). Contact calves may not have been accustomed to consuming large quantities of solid feed (reliance on milk pre-weaning), thus the reduction in rumination. Fröberg et al. (2008) found less solid feed consumption and rumination in restricted suckling system (one hour suckling/day) versus artificial rearing (access one hour/day; volume from 3 L - 7 L). Regulation of solid consumption thereafter may indicate accustomisation as weaning progressed. Rumination was less for NC-I late post-weaning, this would coincide with movement outdoors and reflect a lower intake of grass (Swanson and Harris. (1958) show positive correlation between intake and rumination duration). The FT-O calves grazed most post-weaning, suggesting social learning and imitation from the dam (Fukasawa et al., 1999; Costa et al., 2014; Nicolao et al., 2020). Additionally, this could be due to pre-weaning exposure and familiarity with grass, also found in a study by Phillips (2004). During weaning, solid feed consumption was similar among calves, however PT-I calves consumed the least during early weaning. This may be due to anticipation of reuniting with dams following restriction (as would be expected with their daily routine).

Calves in all three performed abnormal behaviours (predominately oral manipulation), however PT-I calves expressed more during late pre-weaning and weaning. As abnormal behaviours can be considered a stress response, partial contact (repeated separation and reuniting) may have been more stress inducing than complete contact or none at all. Reductions in abnormal behaviours for FT-O calves suggest unrestricted contact and suckling reduces these behaviours (Veissier et al., 2013 and Fröberg et al., 2011). Social interaction was greatest in contact systems throughout, which is likely due to dam social learning. Studies show calf socialisation is comparable to dam socialisation for development (Krohn et al., 1999; Duve et al., 2012). This study suggests CCC is more effective (perhaps due to both cow and calf exposure). That said, contact groups had twice the number of animals for interaction (i.e. cows; compared to NC-I calves).

4.3. Calf growth and body measurements

Pre-weaning growth was elevated for contact calves, which was expected on account of high milk consumption within such systems (Fröberg et al., 2011; Kisac et al., 2011). Dietary advantage appears to be related primarily to weight gain, than bone growth and development (length and height) in calves. Although PT-I calves had restricted access to cows, rebound suckling may have occurred through the night, resulting in similar pre-weaning growth rates to FT-O calves. Additionally, cows were milked only once-per-day which may have resulted in more milk availability, compared to FT-O calves. Contact ADG declined considerably during weaning, likely attributable to dietary, social and environmental changes inducing stress. Average concentrate intakes indicate that ad libitum milk satiety may have left contact calves unmotivated to consume concentrates (Margerison et al., 2002; Fröberg

et al., 2011). Time spent grazing pre-weaning increased for FT-O calves over time. Grazed grass is of high nutritional value in spring, (Kennedy et al., 2005) which potentially could have been a small contributing factor to higher pre-weaning growth for FT-O calves. Although weaning took place indoors, an initial effort was made to maintain a constant environment for outdoor weaning of FT-O calves (calf at pasture with the group with cows removed; industry recommendation for suckler beef systems (Teagasc, 2014)). However, due to calf distress and paddock absconding in search of their dam (similar to Wagner et al., 2013), an indoor alternative was implemented, resulting in dietary and environmental changes. Post-weaning, PT-I ADG remained low, suggesting that weaning stressors were not offset by time. Similarly, the transition from indoor to outdoor environments also appears to have challenged NC-I calves ADG (Lorenz et al., 2011). Interestingly, FT-O ADG was higher than both PT-I and NC-I calves during late post-weaning, with higher levels of grazing behaviour highlighting the advantages associated with pre-weaning exposure to grass (Phillips, 2004).

4.4. Labour

While discussion speculating the labour implications of CCC systems is active (Ventura et al., 2013; Asheim et al., 2016; Meagher et al., 2019; Neave et al., 2022), this is the first to quantify differences in three CCC systems. Differences between systems immediately post-calving are substantial with NC-I calves requiring considerable assistance following birth (Gleeson et al., 2008). Much was attributable to dam colostrum collection for NC-I calves (to provide feeding consistency among systems). Barry et al. (2022) indicated, high quality colostrum from a single other dam is sufficient for calves. As such, post-calving labour may be mitigated slightly by collecting and storing a reserve of high-quality colostrum. The daily labour of the FT-O system was greatest, attributable to time required to move and separate cow-calf pairs, validating farmer concerns regarding animal handling challenges in these systems (Neave et al., 2022). Furthermore, safety risks associated with performance of protective behaviours by the dam, in relation to the calf, must be considered. Personal observation found that dams turning suddenly to have their calf in-sight can be a threat to the handler. Contact system variation was expected due to once-a-day milking of the PT-I system (Bewsell et al., 2008). Labour estimations are low for the NC-I and PT-I systems because cow movement around the grazing platform is not accounted for. This is farm dependent as cows are often long distances from the parlour, dependant on herd and farm size. Labour for FT-O movement around the grazing platform was recorded as an estimation for outdoor CCC systems. Their grazing block was closest to the parlour, so comparison against the other systems would be biased. Similarly, forage and concentrate provision labour is not included as it would also depend on resource location relative to the system pen/paddock. A considerable demand of the FT-O system was time spent inspecting calf health. This system occupied a larger space, taking longer to move inspect each calf. It may also be related to calf avoidance behaviours due to lack of human interactions. Additionally, it could be due to the morbidity statistics reported herein, where the FT-O system required the greatest illness intervention. Health complications would lend itself to inspecting the health of calves to ensure successful corrective action. During weaning, contact system labour was similar, as expected due to identical weaning strategies. Weaning labour associated with the NC-I system was negligible, due to the pre-programmed automatic feeder managing all weaning plans without human intervention (Käck and Ziemerink, 2010).

4.5. System opportunities and challenges

When evaluating CCC systems, it is important to be mindful of the cow, calf and people implementing these practices on-farm. The daily labour involved with calf care increased with the full-time CCC in this study would challenge farmers, during a labour intensive time when calving seasonally (Deming et al., 2018). Investment in additional housing (adaption of cubicle housing) and general infrastructure (i.e., fencing) may be needed to cater for these systems in a pasture-based seasonal calving capacity (Neave et al., 2022). That said, automatic milk feeder cost and associated milk replacer was eliminated with this system.

Calf growth is an undeniable benefit of CCC. That said, PT-I calves faced challenges during weaning and thereafter. These calves experienced three primary stressors; environmental (indoor to outdoor), social (de-bonding) and diet (milk and concentrate to grass-based and concentrate). Weaning challenges had long-lasting effects, emphasised by stunted calf weight-gain post-weaning. Although FT-O calves experienced similar stressors, environmental changes were short-term (indoor for weaning), growth rates indicate that pre-weaning grass exposure potentially mitigated weaning stressors.

Health difficulties faced by FT-O calves raises welfare concerns. Our data suggests one quarter of calves in this type of system could succumb to life-threatening health complications. A hybrid model between this and the PT-I system may be better for the calf. This could see calves remain indoors for longer until a better ability to cope in outdoor spring environments.

There are undoubtedly benefits and opportunities for future improvements. For example, provided calves consume sufficient high quality colostrum, labour savings immediately post-calving would be an attractive feature of the system for farmers. Additionally, exposure to grass (grazed or cut indoors) on post-weaning growth, where calves move on to a predominantly grass-based diet, should be examined further.

5. Conclusion

To conclude, CCC pre-weaning enables exceptional calf growth rates and reduces labour demands around calving. Although pre-weaning cow contact and grass exposure was beneficial for FT-O calves, the current system appears to challenge calf health and human labour. Similarly, PT-I calf behaviour patterns, such as abnormal behaviour expression, and stunted growth post-weaning suggests challenges faced before, during and after weaning. Thus, CCC in pasture-based dairy systems requires further research to ensure the safeguarding of calf and human welfare.

CRediT authorship contribution statement

Alison M. Sinnott: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Writing – original draft. **Eddie A.M. Bokkers:** Conceptualization, Methodology, Supervision, Writing – review & editing. **John Paul Murphy:** Investigation, Methodology, Writing – review & editing. **Sarah McPherson:** Conceptualization, Investigation, Methodology, Writing – review & editing. **Katie Sugrue:** Investigation, Methodology, Writing – review & editing. **Emer Kennedy:** Conceptualization, Funding acquisition, Investigation, Methodology, Supervision, Writing – review & editing.

Declaration of competing interest

None.

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