Finding the Balance

Improving labour efficiency and animal welfare in calf rearing

Alison Maime Sinnott

Propositions

1. Moving towards a natural image of calf rearing leaves the needs of calves behind. (this thesis)

2. The development of successful novel calf rearing systems require considering the collective welfare of both farmer and animal.
(this thesis)

3. To succeed, the dissemination of scientific knowledge needs to account for the reduction in attention span of the public.

4. Awareness of somnology data from fitness trackers influences personal sleep perception too much.

5. Perfectionism is not striving to be the best at something, it is rather the fear of an alternative.

6. The anticipation of having tomorrow off work is a better feeling than experiencing the day off.

Propositions belonging to the thesis, entitled

Finding the balance: improving labour efficiency and animal welfare in calf rearing

Alison Maime Sinnott
Wageningen, 18 January 2022

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Thesis committee

Promotor

Dr E.A.M. Bokkers

Associate Professor, Animal Production Systems Group

Wageningen University and Research

Co-promotor

Dr E. Kennedy

Senior Research Officer, Grassland Science Department Teagasc, Moorepark, Ireland.

Other members

Prof. Dr T.B. Rodenburg, Wageningen University & Research

Prof. Y. Le Cozler, L’institut Agro Rennes-Angers, France

Dr A.T.M. van Knegsel, Wageningen University & Research

Dr R. Meagher, Dalhousie University, Canada

This research was conducted under the auspices of the Graduate School of Wageningen Institute of Animal Sciences (WIAS)

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Alison Maime Sinnott

Thesis

submitted in fulfilment of the requirements for the degree of doctor

at Wageningen University & Research

by the authority of the Rector Magnificus,

Prof. Dr A.P.J. Mol,

in the presence of the

Thesis Committee appointed by the Academic Board

to be defended in public

on Wednesday 18 January 2023

at 1:30 p.m. in the Omnia Auditorium.

Alison Maime Sinnott

Finding the Balance: Improving labour efficiency and animal welfare in calf rearing

234 pages.

PhD thesis, Wageningen University, Wageningen, the Netherlands (2023)

With references, with summary in English

ISBN: 978-94-6447-505-0

DOI: 10.18174/581834

ABSTRACT

Decisions made on-farm surrounding calf rearing practices impact calf and farmer welfare. Therefore, this thesis aimed to evaluate labour inputs required for various calf management strategies and housing systems and examine how these also affect calf health, growth, behaviour and overall welfare. Calf-housing facilities and management practices on Irish farms were reviewed. Farmers demonstrated sufficient planning for calves and lacked concern about upcoming spring workloads. Surplus sheds are commonly converted for calf housing, so appropriate modifications are required to safeguard animal and farmer welfare (e.g., drainage, slopes and facilitation of efficient cleaning). Management appears in-line with current recommendations (e.g., discourage feeding waste-milk), however areas require further attention (e.g., increasing colostrum testing and reducing hours of work). In an experimental study comparing automatic and manual feeding systems, calves assigned to both feeding systems exhibited good health, normal behavioural patterns and similar growth, but the automatic system was consistently more labour efficient. The health, behaviour, growth and associated labour of calves housed in groups indoors with automatic or manual feeding systems compared to calves manually fed in individual or group hutches outdoors was examined in another experiment. Health and growth patterns among all calves showed positive calf development, however behavioural patterns in outdoor individual hutches may indicate compromised wellbeing. Although outdoor group hutches do not negatively impact the calf, indoor housing provides improved labour efficiency. Finally, the impact of full-time cow contact outdoors on pasture, part-time contact housed indoors, or no cow contact housed indoors on calf health, behaviour, growth and labour in a pasture-based systems were studied. Results show pre-weaning cow contact and grass exposure was beneficial for full-time calves, but this system currently compromises calf health and increases farm labour. Calf behaviour and growth were compromised in the part-time system, highlight challenges that need to be addressed. In conclusion, although farms are wide-ranging in relation to calf housing and management practices employed, this thesis describes how it is possible to improve labour efficiency and promote animal welfare collectively when developing calf rearing strategies on-farm.

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Chapter 1

General Introduction

Human, animal and social welfare have all previously been viewed as independent entities. First introduced in 2013, the concept of One Welfare highlighted the interdependence of the aforementioned, particularly in the context of agricultural research (Colonius and Early, 2013). In this circumstance, human welfare refers to factors influencing mental health and well-being, animal welfare looks at the well-being of the animal managed within the agricultural system and social welfare explores societal and generational welfare and acceptance (Colonius and Early, 2013). Evidently, the dairy sector has a definite interrelationship between human, animal and society. Dairy cow and calf welfare has previously received attention through the lens of research, particularly management practices promoting animal welfare on-farm, and identifying ways in which practices can be improved (e.g., risk factors associated with lameness in dairy cows (Browne et al., 2022) and methods of disbudding in calves (Ede et al., 2020)). Oftentimes, farmer welfare in relation to adapting and adopting these welfare promoting practices, is something that is acknowledged in-text, but over-looked in relation to the logistics of what is involved and how these changes can be implemented. As the dairy sector evolves, increasing emphasis is being placed on farming sustainably, referred to as resting upon three pillars of social, environmental and economic factors (Purvis et al., 2019), and therefore it is necessary to weight animal, human and social welfare, alongside environmental impact with analogous importance moving forward.

The European dairy sector has experienced considerable reform since milk quota abolition occurred in 2015. While previously restricted by the quantity of milk which could be produced, farmers across Europe have been relatively unbounded by this constraint for a number of years now. In this time, the response across Europe has been varied. Although for some countries, production was restricted once again (France) or declined (Greece), many other countries increased herd sizes and production (Germany and Ireland; Brodam, 2021). In Ireland, domestic production of milk increased by over 41% (from 2015 to 2019; Shalloo et al., 2020) and the sector continues to see many new entrants into dairy farming (Forde, 2021). With the sector undergoing considerable changes, particularly in Ireland, it is imperative to implement the One Welfare ethos of educating and promoting improved working efficiency for those working with animals (at farm level in this instance), while facilitating the implementation of sustainable development goals (One Welfare, 2022).

Agricultural systems are heavily influenced by the social and political environments they are situated and operate within (Archer et al., 2008). In recent years, society has become increasingly interested in animal welfare, showing heightened preference for agricultural products derived from more natural husbandry systems (Risius and Hamm, 2017). One such example being a low acceptance found among society and consumers for management practices failing to provide prolonged cow calf contact (CCC; Cardoso et al., 2017), because on most dairy farms the cow and calf are separated immediately after birth, resulting in farmers adopting the role of the mother. Following separation, calves are typically housed individually (Teagasc 2017), provided colostrum, and then move into group housing (Marcé et al., 2010) with conspecifics within a week of being born (Teagasc 2017). As a result, considerable attention should be given to calf management practices when adopting the One Welfare approach. In order to improve sustainability for calf and carer as well as the efficiency of the overall system, it is important to first understand the logistics of the Irish dairy sector and establish factors contributing to labour and welfare concerns related to calf rearing.

Irish dairy systems

To successfully produce milk every year, a cow must give birth to a calf annually. The Irish system, alongside the dairy system in New Zealand, capitalise on low costs of production aided by the utilisation of grass as a low-cost primary feed resource (Doyle et al., 2022). To exploit grazed-grass in the diet and where seasonal calving systems are employed, the commencement of lactation must synchronise with grass growth (Dillon et al., 1995). Seasonal calving systems see cows calve in a condensed time period. As such, calf care and management of labour peaks for a 12-week period in spring (Gleeson et al., 2008). However, a target has been placed to calve the majority of cows within a six week period (90% of cows) to maximise the potential for milk production and farm profit (Teagasc, 2016). Of calves born on-farm, a percentage of heifers are commonly kept and reared as replacement animals, with remaining surplus calves (either bulls or heifers) moved off-farm. When the replacement animals have given birth to their first calf, they enter the herd in place of cows which have been removed (Teagasc, 2014b). Removal from the herd is undertaken for many reasons, including age, loss of production, prolonged or persistent health issues, fertility or milk quality related issues (Teagasc, 2020).

Labour on Irish dairy farms

As the scale of dairy production increases, the labour input associated with the farming system follows a similar trend (O'Donovan et al., 2008). The total labour demand for farmers is heavily influenced by season, the most intensive being spring, on Irish dairy farms (Deming et al., 2017). Dairy related labour timelines reflect this and as a result, approximately 1,777 total farm hours worked are completed in spring (February, March and April), compared to 1,663 in summer (May, June and July), 1,412 in autumn (August, September and October), and 885 in winter (November, December, January; Deming et al., 2017).

Irish dairy farms have typically operated on a family-owned basis, procuring labour via family members (O'Donnell et al., 2008, Chen and Holden, 2017). However, as post-quota intensification occurs, it appears as though the requirement for hired labour, aside from family labour has increased (Hogan et al., 2022a). This places additional strain on the farmer due to the associated costs of qualified hired labour, as well as the notable difficultly in sourcing said labour in recent years (Eastwood et al., 2018; Kelly et al., 2017). For these reasons, the streamlining of work processes through the evaluation of labour inputs, particularly in relation to calf rearing, is the first focal point of this thesis.

Calf care is highlighted as one of the most labour intensive processes on-farm (O'Donovan et al., 2008), second only to milking (Hogan et al., 2022a). Labour intensive tasks associated with calf care include individual care after separation from the cow, feeding and hygiene practices (Gleeson et al, 2008). While emphasis on improving the six-week target calving rates remain in effect (increased by 9% from 2016 to 2021; ICBF 2021), calving will likely become even more compact in future. This compaction of calving, alongside increased herd sizes, will mean more calves being born and require a high level of care within a short time-frame in spring. Consequently, avenues for reducing workload must be explored, but more specifically for calf rearing, such as the use of technology (e.g., automatic milk feeders) or alternative management strategies (e.g., alternative housing or feeding systems). Although research in recent years has identified general problem areas associated with labour in spring (O'Donovan et al., 2008; Deming et al., 2018; Hogan et al., 2022a), few have identified specific areas where calf rearing labour can be improved. For research in this area, many relied on farmer recordings (Deming et al, 2018), information recall (O'Donovan et al., 2008; Cummins et al, 2016), estimates (Bostad et al, 2010) or snapshot data collection (Gleeson et al, 2008), but none have taken direct measurements consistently throughout the rearing process, when farmers are conducting their calf care tasks. Thus, highlighting the need for controlled studies, which continuously examine the effect these technologies and management strategies have on calf rearing labour.

Calf welfare

The term welfare has a multitude of different meanings to many people. Historically, animal welfare in a dairy context, considered mainly the physical wellbeing of the animal in the view of the producer (i.e., health, growth, productivity and physical environment (von Keyserlingk et al., 2009). While these are undoubtedly important components, animal welfare has since evolved alongside these physical attributes to also consider if the animals can behave naturally in their environment as well as affective states (Fraser, 2008; Mellor and Beausoleil, 2015). In addition, welfare is described as dynamic rather than static (Curtis, 1987), indicating welfare status is ever-changing and invites regular reassessment.

Allowing calves to express behaviours and patterns of behaviour that are natural to the animal and their functioning is crucial in the development of welfare-friendly management practices (von Keyserlingk et al., 2009). Cow-calf pairs are particularly motivated to perform allogrooming and suckling behaviours daily (da Costa et al., 2006; Johnsen et al., 2021a). Evidently, the separation of cows and calves shortly after birth ceases the natural occurrence of these processes. Moreover, individual calf housing (lack of social contact) and manual feeding systems (commonly fed only twice per day) restrict a calf's ability to perform these behaviours to a level required to meet their needs. Provided appropriate bonding has occurred between the cow and calf, the cow also provides round-the-clock care to the calf (nutrition, comfort, warmth) and is a source of social learning (Costa et al., 2014; Nicolao et al., 2020). However, when separation occurs, the farmer assumes the role of the dam in the rearing process. Although farmers can provide appropriate nutrition, housing (related to comfort) and treatment for illness, they cannot cater for calf needs the same way a cow can, particularly during spring-time when facing considerable workloads. That said, the separation of calves from their dam could induce a pessimistic response bias, suggesting low moods (Daros et al., 2014). While positive affective states can be achieved through CCC systems, de-bonding of the cow and calf following contact can also have a negative influence. De-bonding is the process of breaking social ties between calf and dam during the weaning process (Wenker et al., 2022). This is generally carried out using either anti-suckling devices (e.g., nose flaps; Loberg et al., 2007) or fence-line separation (i.e., gradual separation of pairs before complete separation; Johnsen et al., 2015). Minimising the stress associated with this social change is of utmost importance in reducing the associated negative effects on affective states.

Affective states in animals range from positive to negative; positive being pleasure and happiness, and negative being pain and fear (Boissy et al., 2007; Webb et al., 2019). The study of affective states is difficult due to its association with emotions, leading it to be subjective in nature (Chalmers, 1995). As such, recent referral to affective states in terms of valence (whether experience is positive or negative) and arousal (the intensity of the affective state experienced) is used (Ede et al., 2019). Research has highlighted the influence of pessimism and fearfulness in a calf's selectiveness when establishing relationships (Lecorps et al., 2019). Furthermore, management practices employed on farm have an influence on calf affective states and their over-arching welfare (Ede et al., 2019). It is evident that calves favour full social contact among other calves, with research indicating a greater motivation to work for this, than just partial contact (head only) with conspecifics (Holm et al., 2002). It has been demonstrated that such socialisation influences learning and diet selection for young ruminants (Nolte et al., 1990; Provenza et al., 2003), whereby animals learn to recognise suitable diets and habitats to reside in (Key and MacIver, 1980; Mirza and Provenza, 1992; Costa et al., 2016; Mahendran et al., 2021). The expression of abnormal behaviours is linked to negative experiences and environments (e.g., decreased rearing and sniffing in rats housed in metabolic cages; Whittaker et al., 2016). Such behaviours are often exhibited in calves as oral behaviours, such as tongue rolling and oral manipulation of the environment (Wiepkema et al., 1987; Kooijman et al., 1991; Veissier et al., 1998;

Mattiello et al., 2002). Research has highlighted the benefits of social housing in reducing abnormal behaviours (Chua et al., 2002; Tapki, 2006). Although social housing can increase the incidence of cross-sucking (Jensen, 2003), compared to individual housing, appropriate nutritional provisions (such as sufficient milk allowances and teat availability to suckle) and stimulation can aid in the alleviation of these issues (Jung and Lidfors, 2001; Jensen, 2003).

Calves are vulnerable from birth as a result of being born without protective immunoglobulins, requiring ingestion of colostrum from their mother or another dam for passive transfer of maternal immunoglobulins (Ig) (Lorenz et al., 2011a). With the provision of high quality colostrum immediately after birth (high quality means >50 g/L IgG; Schneider and Wehrend, 2019), calves are equipped with the basic tools for defence against illness (Yang et al., 2015). Following this, management decisions made on farm heavily influence a calf's welfare status. Such examples, many of which will be discussed further herein, include decisions around; separation, housing environments, hygiene practices employed, health treatment plans, feeding, weaning and transport. Thus, the second focal point of this thesis is to evaluate how various management strategies and housing systems employed on-farm affects calf welfare, to ensure that those decisions made promote the wellbeing of the animal.

Calf feeding and technology utilisation

Technology has been utilised in agriculture to minimise the labour associated with the job and increase productivity of the farmer (Hogan et al., 2022b). Such technology includes robotic milking machines, automatic cluster removers, automatic backing and drafting gates, among many other advancements (Hogan et al., 2022b). Traditionally in Ireland, calves are fed post-colostrum via a multi-teat feeder (in a group housing environment (Barry et al., 2019a), often following an individual housing period of approximately 7 days (Teagasc, 2017)). Although producers noted manual feeding as useful, with regards to identifying and monitoring calf health (Medrano-Galarza et al., 2017a), it is largely understood that technology in general has the ability to increase feed efficiency and in turn, productivity through nutrition on dairy farms (Akbar et al., 2020). Automatic milk feeders are a technology commonly associated with calf rearing (Medrano-Galarza et al., 2017a). These feeders are computer-operated systems utilising RFID technology in a calf's ear tag, to control calf milk consumption (Hnatiuc and Caracostea, 2017). This technology grants the ability to control individual calf feeding plans while animals are housed in group settings (Jensen and Weary, 2013). This provides ease of specific milk allowance adjustment on an individual basis, rather than having to group feed calves an average volume of milk (as one would with manual feeding in a group setting). Additionally, automatic milk feeders provide an opportunity to feed calves multiple meals per day, while manual feeding generally restricts feedings to twice per day.

Automatic feeders are valuable tools to detect deviations in feeding patterns that may indicate illness (Johnston et al, 2016), track growth performance (in the presence of a scale instalment; Moran, 2012) and provide calves with an opportunity to mimic natural suckling and feeding behaviour most closely (Medrano-Galarza et al, 2017a). Calf health when using these feeders is often scrutinised due to group housing, whereby calves are often maintained in larger group sizes than optimal, potentially leading to infection spreading quickly among calves (Moran, 2012). Similarly, sick calves within the pen can easily contaminate teat surfaces, spreading illness within the group (Moran, 2012). Research suggests however, this is a reflection of management practices implemented on-farm, rather than the feeder itself (e.g., group-size (Maatje, 1993; Svensson et al, 2003; Svensson and Liberg, 2006) and introduction age to feeder (Jensen, 2007)). Automatic feeders may also have the potential to increase efficiency related to calf growth rates, with frequent milk consumption stimulating abomasal emptying (Mylrea,

1966) potentially encouraging calves to consume more milk, more often. That said, a number of other barriers exist to installing automatic feeders on-farm. Although costs are believed to be mitigated by labour advantages (Kung et al., 1997; Käck and Ziemerink, 2010), these systems carry considerable financial burden with additional costs such as servicing and electrical demand. Farms with smaller herd sizes (< 80 milking cows) used this technology less often than larger ones (Medrano-Galarza et al, 2017b). It is possible that farms with smaller herd sizes may find it difficult to justify the expense associated with automatic feeders (a concept also suggested by Hogan et al. (2022b)). In an Irish context, automated milk feeders would be used for up to six months of the year, lying idle for the other part of the year. Additionally, farmers that were potentially more resistant to change (indicated by use of tie-stalls) and greater than 55 years old, were also less likely to use the feeders (Medrano-Galarza et al, 2017b). That said, it must be noted that regardless of milk feeding system (manual or automatic), milk is rarely fed on an *ad libitum* basis. This is a very obvious deviation from a natural calf rearing system, where an unlimited supply of whole milk would be supplied to the calf via the dam.

Few studies to date have examined the labour implications of using an automatic calf feeder on-farm. While Medrano-Galarza et al. (2018b) researched the effect of age of introduction to these feeders on labour, labour measurements ceased once calf familiarity with the feeder was achieved. Gleeson et al. (2008) indicates that automatic feeders were least efficient when compared to manually feeding once or twice per day (with and without use of teat feeders). Snapshot data collection points within this study make it difficult to identify whether labour peaks and troughs related to manual and automated systems may have been missed throughout the pre-weaning period. In addition, more recently labour efficiency within these systems has been remarked as the main driver for their implementation on German farms (Käck and Ziemerink, 2010). It is also possible that technology within automatic feeding systems has advanced and improved since this study was carried out. Thus, detailed evaluations need to be carried out to determine the labour implications of using automatic calf feeding systems consistently across the duration of the pre-weaning period.

Calf housing systems

Calves are most commonly reared indoors in Ireland, typically grouped together in pens (Marcé et al., 2010), following seven days in an individual pen (Teagasc, 2017). It is difficult to say definitively whether group housing has a positive or negative impact on calf welfare, in relation to health, due to conflicting reports (Wells et al., 1996; Svensson et al., 2003; Nikkhah and Alimirzaei, 2022). That said, much research comparing paired to individual housing has demonstrated the benefits of grouping calves together (e.g., increased starter intake and decreased fearfulness of novel foods; Whalin et al., 2018). In addition, at the root of behavioural needs, cattle are social animals with separation often leading to the on-set of stress (Daros et al., 2014). In light of this, much like automatic calf feeders, it appears as though calf health and over-arching welfare is determined by the management decisions made, rather than the housing structure itself. For example, calves kept in smaller group sizes (< 10 calves) had lower issues related to the respiratory system, than in groups of 12-18 calves (Svensson and Liberg, 2006). Provision of airspace of at least 7 m^3 per calf and prevention of shared airspace with older stock can aid in the inhibition of respiratory infections (AHI, 2021c). Additionally, greater floor space allowance provides calves increased opportunity for active behaviours (such as standing and walking), likely satisfying their need to perform a normal range of these behaviours (Sutherland et al., 2014).

In light of the increased number of calves being born on farms across Ireland, it is imperative to ensure that the housing provisions made are sufficiently protecting their welfare. Little research has tracked the expansion of calf housing facilities since 2015, however one survey of Irish farms recently found that approximately 82% of calves born could be housed on-farm currently (no further information on the other 18% of calves, which presumably had to be sold, or how long they could house all calves for; Osawe et al., 2021). Furthermore, 60% of farms believe they either had sufficient facilities (house 100 % of calves) or had invested in calf housing (Osawe et al., 2021). It must be recognised that this study did not validate farmer answers with on-farm measurement of housing facilities. This is an important step to minimise potential social desirability bias, whereby participants adjust their answers to reflect what they perceive researchers would find acceptable (Medrano-Galarza et al., 2017a). As such there is an evident need for comprehensive research into current calf housing facilities in Ireland, to identify whether these structures are fit-for-purpose and if sufficient extensions were made to existing calf housing to account for herd expansion on-farm.

Compact calving can increase demand for calf accommodation even more, particularly at peak calving (when the number of cows calving per day is at its highest), potentially resulting in a farm's inability to provide sufficient accommodation. With the nature of calving patterns in Ireland, where permanent purpose-built calf housing would not be in use year-round, it is often difficult to justify the expense of building such a facility. In this case, fit-for-purpose alternatives must be sourced so that calf welfare is not compromised in any way, relative to the housing system they experience. For example, the use of calf hutches may offer potential alternative to permanent facilities, as demonstrated by their use in countries such as the United States (Kung et al., 1997).

Rearing calves in outdoor structures is largely inconclusive, with some research suggesting it is beneficial to calf health, weight gain and solid feed intake (Lorenz et al., 2011c; Wójcik et al., 2013), and more detecting no difference in pre-weaning growth (Jorgenson et al.,1970; Kung et al., 1997). Although improved calf health is linked to individual housing, the benefits of group housing for behavioural expression (i.e., social development), encourage this type of management for calves (Vieira et al., 2012). The labour implications of indoor and outdoor individual pens indicated that indoor pens were the most labour intensive (Jorgenson et al., 1970). In addition, when using hutches indoors, grouping calves was more efficient than individual housing calves (Kung et al., 1997). However, it must be recognised that research surrounding calf hutches is quite dated. As a result, there is an obvious need for research comparing outdoor hutch accommodation (both individual and group) to indoor housing systems, in terms of the labour implications and the resulting effects on calf welfare.

Cow-calf contact at pasture

As research into animal-friendly welfare practices continues to grow, it brings into question if the current level of human intervention is required and if this is truly for the benefit of calf and farmer. Cow-calf contact systems reflect a more natural approach to calf rearing, whereby calves have contact (to varying degrees) with the cows following birth (Wenker et al., 2022), often including the consumption of colostrum (Quigley et al., 1995) and subsequent feeds from the dam or an alternative foster cow (Kent, 2020). Much consideration has been given to CCC operating in indoor dairy systems, which has led to developments in knowledge surrounding behaviour and animal motivations (Wenker et al., 2020), welfare (Johnsen et al., 2021a; Wenker et al., 2021), calf growth and productivity (Barth, 2020). For example, a distinct advantage of CCC systems is the exceptional calf growth experienced in the pre-weaning period, because of high milk consumption (Roth et al., 2009; Fröberg et al., 2011). That said, few studies have focused on incorporating outdoor access (Barth, 2020; Mutua and Haskell, 2021), and the impact these systems would have on farms operating pasture-based production systems, as well as seasonal compact calving with CCC. In the Irish pasture-based dairy system, full-time CCC would involve turning calves out to pasture at young ages in the spring, to coincide with the commencement of lactation and outdoor grazing for the cow. Farmer concerns related to making these provisions in seasonal pasture-based production systems with compact calving include; poor animal welfare (i.e., mastitis, inadequate colostrum intake and early movement outdoors), increased labour and staff stress, and the system level changes that would be required (i.e., infrastructure and herd management; Neave et al., 2022). In addition to these concerns, the labour implications of any CCC systems (indoor or outdoor) has also been largely unstudied to date, with research acting on assumptions made (Asheim et al., 2016; Knierim et al., 2020). For this reason, it is important to research potential avenues for CCC in farms operating within seasonal pasture-based boundaries, to ensure that animal and human needs, as well as societal expectations, are considered.

Knowledge gaps within research

To summarise the above in relation to gaps within existing knowledge; animal, human and social welfare must be weighted with equal importance to encompass the One Welfare concept, thus creating and promoting sustainable farm management practices. This is topical currently, as the dairy sector within Ireland has, and continues to, change considerably in response to milk quota abolition.

To improve working and labour efficiency for animal carers (at farm level in this instance) and implement sustainable development goals, streamlining work processes through the evaluation of labour inputs, particularly calf rearing, is necessary. While research has identified calf rearing as a labour intensive component of the dairy enterprise, particularly in spring, few studies have identified and evaluated specific areas of interest related to labour intensity. For those that have, namely related to feeding practices and automatic milk feeders, research is potentially somewhat dated and lacks controlled examination of the effects these technologies and management strategies have on calf rearing labour. Similarly, management strategies and housing systems must be evaluated based on their effects on calf welfare, to ensure future systems promote the wellbeing of the animal. There is a lack of clarity on how calf housing has expanded and progressed in light of sectoral expansion following quota abolition. As such, research must evaluate current calf housing facilities in Ireland, establish whether these structures are fit-for-purpose and if they contain sufficient area to provide adequate space allowance. Similarly, in the event of insufficient housing being available, research into alternative housing options that promote calf welfare and labour efficiency is required.

Society and consumer concerns continue to change within the dairy sector, particularly prolonged CCC. While a plethora of research has focused on this topic in recent years, much of this has been centred on confinement/indoor dairy systems. As such, it is important to establish if a CCC system is viable in a seasonal calving pasture-based context. Moreover, evaluation related to the implications of this system on calf welfare and labour efficiency require investigation.

General aim and thesis outline

The general aim of this thesis was to 1) evaluate labour inputs required for various calf management systems and housing strategies and 2) examine how these systems and strategies employed on-farm affect calf health, growth and over-arching welfare.

In Chapter 2, a survey of calf housing facilitates, pre-weaning management practices and farmer perceptions of calf welfare on Irish dairy farms is examined. In Chapter 3, manual and automated milk feeding methods are compared in relation to their effects on group-housed calf health, behaviour, growth and labour. Chapter 4 evaluated indoor and outdoor calf housing systems using automated and manual feeding methods and their effect on calf health, behaviour, growth, and labour. Chapter 5 examines the effects of full-time, part-time and no CCC on calf health, behaviour, growth and labour in pasture-based dairy systems. In the final chapter, the inter-relationships of the previous four chapters are discussed, and the implication their results have on the agricultural and greater scientific communities (Chapter 6).


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Chapter 2

A survey of calf housing facilities, pre-weaning management practices and farmer perceptions of calf welfare on Irish dairy farms

Alison M. Sinnott[ab], Eddie A.M. Bokkers[b], Emer Kennedy[a]

[a] Teagasc, Animal and Grassland Research and Innovation Centre, Moorepark, Fermoy, Co. Cork, Ireland

[b] Animal Production Systems group, Wageningen University & Research, P.O. Box 338, 6700 AH Wageningen, the Netherlands

ABSTRACT

It is unknown whether calf-rearing facilities in the Republic of Ireland are fit for purpose, or if facilities sufficiently consider calf and farmer welfare. The aim of this study was to review current calf-housing facilities and management practices on Irish farms to determine if calves are reared in structurally appropriate facilities with management decisions that safeguard calf and farmer welfare. Fifty-one farms were visited twice; 1) Pre-calving (Dec-Jan) and 2) Peak-calving (Jan-Mar). During visit one herd owners completed a questionnaire regarding calf housing and management practices on-farm and each facility used to rear calves was measured (measurement of cubic air capacity, ventilation, pen area, drainage etc.; without calves present). Visit two consisted of a short interview with the principal calf manager to validate previously asked questions and environmental based measurements from each calf house were recorded, with any deviation from the first visit noted (measurements of temperature, wind speed, light intensity, facility provisions in-house and in-pen; calves present). Average herd size was 254, operating a spring calving system with a median calving season length of 11.6 weeks. While most farms expanded (88 %; N = 51), this did not appear to have negatively affected calf space allowances (9.9 % houses overcrowded at a space allowance of 1.5 m^2/calf; N = 121). Calves were most commonly housed in group sizes of < 12 calves (71.6 % of all groupings; N = 394), with farmers moving away from individual housing for a period post-birth, grouping immediately instead (58.8 %; N = 51). The number of farmers testing colostrum was 31.4 % (N = 51). Although calving season was compact, most farmers were unconcerned about upcoming spring workload (58.8 %; N = 51). Farms appeared sufficiently prepared for spring, with most using the same number or less sheds during visit two than declared in visit one (76.5 %; N = 51). To conclude, farmers made sufficient provision for calf housing and space allowances for calves that facilitated group housing post-birth. While structural and management components of rearing systems appear in-line with sectoral recommendations, certain areas require attention on many farms (e.g., colostrum testing), to safeguard calf welfare and reduce the workload associated with calf rearing for farmers.

INTRODUCTION

Post-quota expansion has changed the dynamic of the Irish dairy sector in recent years, whereby herd size (Kelly et al., 2017) and the number of new entrants into dairy farming (Forde, 2021) have increased, leading to a greater volume of milk production (increased by 41% from 2015 to 2019; Shalloo et al., 2020). Increases in herd size understandably result in more calves being born on-farm annually. However, any increases in herd size should not compromise calf and human welfare, by leading to unsustainable workloads, created by sub-standard facilities, poor calf welfare and sub-optimal management practices.

In Ireland, calf housing standards are regulated under the council of the European Union (2008/119/EC), which details the minimum specifications required (e.g., space requirement of 1.5 m^2 for calves <150 kg/ <19 weeks, smooth solid floors with a non-slip finish and permanent open ventilation; EU, 2008). However, in this generalised framework, considerably varied housing systems can be implemented while still complying with outlined regulations (Marce et al., 2010). Although Barry et al. (2020) identified Irish farms as providing sufficient space allowance, but other facility factors are unknown. Similarly, while Brown et al. (2021) examined calf housing design on commercial farms in Northern Ireland, calving patterns and subsequent housing requirements vary greatly to the south of Ireland (year-round calving vs. compact seasonal spring calving). Thus, it is largely unknown if current calf rearing facilities in the Republic of Ireland are fit for purpose and whether facilities have grown in-line with herd expansion and are of sufficient quality.

Structural components of indoor housing can have negative implications on calf welfare. For example, inappropriate drainage can cause excrement build-up followed by increased bacterial growth, eventually leading to health complications in calves (Nordlund and Halbach, 2019). This might happen when pre-existing sheds are converted for the purpose of calf rearing. Such structures are often only suited for temporary use and eventually require a purpose-built facility (AHI, 2021b). Previous research has echoed this, showing that calves are at a higher risk of severe respiratory disease in such facilities (comparison of mono-pitch, patterson, kennel, climatic, converted and mechanically ventilated housing; Kelly et al., 1984). Although structural elements of calf housing influence welfare, the management decisions and practices employed on-farm also play an integral role. For example, calves kept in smaller group sizes (<10 calves) had lower respiratory issues than groups of 12-18 calves (Svensson and Liberg, 2006). Appropriate airspace (at least 7 m^3/calf) and preventing shared airspace with older stock helps prevent respiratory infections (AHI, 2021c). Additionally, greater floor space increases the opportunity for active behaviours (i.e., social interactions, playing and walking), likely satisfying needs to perform a normal range of these behaviours (Sutherland et al., 2014). In addition to ensuring appropriate environments promote calf welfare, it is important to also consider the needs of the calf carer. Good housing systems should facilitate the efficient completion of routine tasks associated with calf care (Teagasc, 2017). Such provisions include accessible pens for inspection and care of sick calves (Teagasc, 2017) as well as tractor access to allow the cleaning out of rearing pens (Gleeson et al., 2008). To ensure calf-rearing progresses in a viable and sustainable way, the needs of both calf and carer should be considered collectively to encompass a One Welfare approach, to further develop farm management practices (Pinillos, 2018).

Therefore, the aim of this study was to review current calf-housing facilities and management practices on Irish farms to determine if calves are reared in structurally appropriate facilities, with management decisions that safeguard calf welfare. Additionally, this research aimed to evaluate if appropriate measures are in place to promote labour efficient practices for calf carers.

MATERIAL AND METHODS

This study was carried out between December 9, 2019 and March 13, 2020. Ethical approval for the study was received from the Teagasc animal ethics committee (TAEC241-2019).

Herd selection

This study focused solely on herds where the predominant enterprise was dairy. Suitable herds were located within approximately 80 km of Teagasc Moorepark to facilitate data collection and minimise associated travel. This area represents the region most densely populated with dairy herds in Ireland (ICBF, 2019). To reflect current dairy systems in Ireland, herds that adopted a predominately spring calving system (Feb – Apr; calving >90% of the herd in this timeframe) were sought. A minimum herd size threshold of 75 cows was imposed. In addition, herds had to be subscribed to HerdPlus (data management and reporting system operated by the Irish Cattle Breeding Federation; ICBF, Bandon, Co. Cork, Ireland) while also actively participating in a Teagasc discussion group. Herds were selected by contacting discussion group facilitators, with facilitators inviting each group member (herd owner) to participate. Potential participants were informed of study objectives, measurements to be undertaken, information they were required to supply and feedback they would receive after study completion. Expressions of interest for inclusion were collected by the facilitator and a list of willing participants and associated contact details was compiled. Fifty-two herd owners agreed to part-take (74.3% response rate), with herd sizes ranging from 87 to 550 cows; herd-owners were contacted by telephone for specific farm location and a suitable visit time and date.

Survey composition

Each farm was visited twice; the first was conducted pre-calving between December 9, 2019 and January 17, 2020. During this visit, herd owners completed a comprehensive face-to-face questionnaire regarding calf housing and management practices on-farm (survey available upon request). It contained 81 questions (2 open-ended questions; 79 closed questions) categorised into eight sections. Section one focused on general information of the farm enterprise such as number of cows expected to calve, date calving expected to commence, expected date of peak calving. Section two sought farmer opinions, asking questions on a range of topics; calf welfare on their farm, calf husbandry skills, concerns and how prepared they are for the upcoming calving season (rank from

1-10). Section three focused on housing facilities for calves on the farm, providing information on where calves were reared (indoor, outdoor or both), how many houses are used to rear calves, whether they are purpose built, when they were last updated and the farmers plans to invest in calf rearing facilities in future. Section four asked questions regarding calving and first feeding (i.e., number of labour units on-farm, number of people involved in calf rearing and colostrum feeding and management). Section five gathered information on post-colostrum feeding practices. Section six related to animal health and antibiotic usage. Section seven asked about calf rearing hygiene practices. Finally, section eight focused on weaning and the sale of calves. Physical measurements pertaining to calf housing facilities were also gathered by the research team.

The second visit (January 23 to March 13, 2020) aimed to coincide with peak calving (based on information farmers supplied during the first visit). Visit two consisted of a short interview with the principal calf manager to validate questions asked during visit one. There were seven questions regarding the number of cows to calve, the date calving started, how many cows had calved up to the point of visit, plans for the sale of calves and calf health. Environmental based measurements of calf housing were also gathered by the research team. One herd owner declined a second visit.

Full consent was given by participants, through signing a GDPR data release form, to allow collection of data and analyses of their data on a group basis. For each farm visit, two people were present: an individual experienced in animal handling and conducting housing and environmental measurements and an individual who had received basic training in the aforementioned.

On-farm measurements

Facility measurements

During the first farm visit, each facility used to rear calves was measured (reducing time required on-farm during visit two). No calves were present at the time of facility measurements. To determine cubic air capacity of the building the length, width, height at ridge and height at eaves were taken using a laser distance meter (Spectra Precision QM95 Laser Distance meter - range 0-200m; Trimble Navigation LTD. Ohio USA).

Within each calf house, facility measurements were taken of all group and individual pens using the laser distance meter. The total area of each pen was calculated to determine the number of calves each pen could accommodate (based on a minimum space requirement of 1.5 m^2; EU, 2008). Drainage conditions were considered by measuring the slope of the floor and noting the type of drainage present (i.e., channel or free-flow). Slope was measured by placing a spirit-level in the middle of the unobstructed floor surface. Using a clinometer application (Plain Code Clinometer; validated by manual measurement of slope) on a Samsung Galaxy S7 mobile phone, the phone was placed on the spirit level and the slope figure was presented digitally. If more than one slope was present in the surrounding area, all slopes were recorded. A trundle wheel (DuraWheel DW-PRO Distance Measuring Wheel 12.5" Diameter; DuraWheel, USA) was used to measure the distance of the calving pen to the calf house.

Environmental measurements

During the second visit, environmental based measurements were taken in each calf house, as well as area measurements taken during the first visit checked. If the calf housing plan deviated from the first visit, it was noted. If any additional houses were in-use for calves, both facility and environmental measurements were taken.

Measurements of wind-speed, temperature, relative humidity and light intensity was recorded from both the internal and external environments. To measure wind-speed, an anemometer (Kestrel 1000 Wind Meter; Kestrel Meters, PA, USA) was used in three different positions at chest height; i) vertically parallel with measurer, ii) vertically perpendicular to the measurer and iii) horizontal to the measurer. The same three measurements were taken externally, outside of the house, in an area free from obstructions. Internal house measurements were taken at the mid-point of each house (regardless of whether it was in a pen or alleyway). The anemometer was held in each position to give a more accurate representation of average wind-speed from all directions. The average and maximum figure was recorded for each position.

Temperature and relative humidity were measured using a data logger (Tinytag TGP 4017 Temperature Data Logger; Tinytag, United Kingdom). This recorded measurements constantly at one-minute intervals. One data logger was placed outside the house and one was placed inside, in areas free from obstructions for the duration of data collection. A time-stamp was recorded for each device upon entry and exit of the house, so data was comparable (minimum measurement duration was five minutes).

Light intensity (LUX) was measured using the Doggo Apps Lux Light Meter application (Nugroho et al., 2018; Thongjan and Sirisathitkul., 2020) on a Samsung Galaxy S7 mobile phone. The phone was held horizontally to the sun (externally), and horizontally to the roof of the house (internally), without any obstruction of light. One measurement was taken in each area (internally and externally), 50 cm (approximate calf height) from ground level. The maximum figure for natural lux from each individual measurement was recorded.

A map was made of the house including each pen and the number of calves housed within. This map provided a reference for each house, whereby actual space allowance per calf could be calculated using previous measurements of pens. In addition, environmental based measurements were recorded using five pens in each building (based on a sample size calculation). Pens were selected at random upon entering the house. The presence of water, concentrates, and availability and type of forage was noted. Two measurements of wind-speed were taken in each selected pen at calf height (50cm from bedding level).

Data editing

To facilitate comparisons among farms, continuous data related to herd size and percentage rate of expansion (relative to pre-quota abolition cow numbers) were also converted to categorical data. For herd size; 1 = <150 cows, 2 = 151-200 cows, 3 = 201-300 cows and 4 = >300 cows. For percentage rate of expansion;

1 = <10%, 2= 11-20%, 3 = 21-35% and 4 = >35%. For a number of questions asked, farmers could select multiple responses. As such, for responses where this occurred, total population numbers exceed N = 51 (total number of farmers surveyed). Farmer opinion related questions were scored from 1 to 10, however this was collapsed into a six-point scale; 1 = 1, 2 = 2 and 3, 3 = 4 and 5, 4 = 6 and 7, 5 = 8 and 9 and 6 = 10. Responses for 1 and 10 were allocated their own point as these were the two extremes of responses (i.e., no possibility outcome could be better or worse, whereas if 2 or 9 were included outcome could improve or deteriorate further). Additionally for ease of interpretation and to facilitate word association, each point was assigned a description ranging from one extreme to the other (e.g., extremely unconcerned, very unconcerned, somewhat unconcerned, somewhat concerned, very concerned, and extremely concerned). While we acknowledge pitfalls in collapsing after data collection, in this instance it facilitates data interpretation (Colvin and Gorgun (2020) highlight that values are largely unaffected by collapsing following data collection).

Space allowance provided was calculated for individual houses by summing the total area available to calves, divided by the number of calves present in the house during evaluation. This figure was compared independently to the following space allowances: 1.5 m^2 (minimum space allowance requirement; DAFM 2016), 1.7 m^2 (lower space allowance recommendation; Teagasc 2017) and 2.0 m^2 (upper space allowance recommendation; AHI 2021c). Cubic air capacity (length x width x height of house) was calculated by dividing the total cubic volume of a house by 7 m^3. This provided a figure for the total number of calves a house can hold, which was compared to the number of calves actually in the house during evaluation. If a house did not provide sufficient space allowance or cubic air capacity for the calves housed within, it was recorded as overcrowded.

Statistical analysis

Statistical analyses were conducted using SAS (Version 9.4, SAS Institute Inc., 2002). Descriptive statistics (PROC FREQ) were calculated for each variable to identify frequency distributions. For categorical variables, the percentage response was presented including the number of observations. Additionally, the relationships between categorical variables of interest were studied. For continuous variables, the mean, minimum and maximum values were reported. The associations between farmer responses as well as observed values were tested for normality and examined using Pearson's chi-squared tests. From here, logistic regression (PROC LOGISTIC) was used to investigate associations between non-normally distributed variables with binary outcomes and categorical variables that had been identified as significant ($P<0.05$).

RESULTS

General herd information

Of 51 farms surveyed, 88.2 % operated a dairy-only enterprise and 11.8 % operated a dairy-mixed enterprise; four dairy-beef, one dairy-beef-tillage, one dairy-poultry. Spring calving was the predominant system employed (96.1 % of farms) with only 3.9 % adopting spring-autumn calving systems. On average, 254 cows were expected to calve on-farm in spring 2020 (range: 87 to 550 cows) and nine in autumn (range: 8 to 10 cows). The expected calving season length ranged from 8 to 14.5 weeks (median: 11.6 weeks). Farmers expected to rear approximately: 68 replacement heifers (range: 0 to 250), seven bulls (range: zero to 62) and 13 additional heifers (range: zero to 120) past the point of weaning.

Farm facilities: space allowance and cubic air capacity

During visit 2 which coincided with peak calving, 41.2 % of all farms surveyed (N = 51) had deviated from the calf housing plan outlined ahead of calving commencement. Of farms who deviated from the housing plan (visit one), 17.7% used more houses and 23.5 used less. When asked if at least one house was overcrowded on-farm out of all houses they declared, 54.9 % said yes and 45.1% said no. However, when houses were examined for space allowances of 1.5 m^2, 1.7 m^2 and 2.0 m^2 per calf; at least one house was overcrowded on 20 %, 33 % and 49 % of farms, respectively.

Based on the total number of houses declared by farmers (N = 137), 32.9 % of these were thought to be overcrowded by farmers. Examination of occupied calf houses (N = 121) for space allowances of 1.5 m^2, 1.7 m^2 and 2.0 m^2 per calf showed that 9.9 %, 18.2 % and 27.3 % of all occupied houses were overcrowded, respectively.

Group sizes of ≤12 were found in 71.6 % of all calf groupings (N = 394) across farms. A cubic air capacity of at least 7 m^3 per calf was provided in 95.9 % of all calf houses evaluated (N = 121). In 33.1 % of all calf houses examined (N = 121) airspace was shared with older animals. Farmers whose houses had sufficient space for calves (space allowance and cubic air capacity; OR = 0.243; CI = 0.08 to 0.77) or had larger herds (OR = 0.497; CI = 0.296 to 0.837) were less likely to have issues related to diarrhoea (based on farmer perception of diarrhoea issues: responses were yes, no, not particularly).

Farm facilities: house structures and facilities

Individual pens for new-born calves were 0.8 m wide by 1.25 m long (minimum) in 85 % of houses using such pens (N = 35). Out of the houses whose individual pens did not provide this area to calves (N = 5), pen length was shorter in 20.0 % of cases, and width in 80 %. Front only perforations were provided in 48.5 % individual pens, and 24.2 % provided side only perforations (27.3 % had both). A group pen floor slope of a 1:20 (2.86 °) fall was not found in 86.3 % of calf group pens evaluated (N = 394). The median slope in all calf pens was 1.6 ° (range: 0 to 8.16 °). Partitions between pens were at least 1.2 m high across 67.4 % of pens where divisions were applicable (N = 193) (excl., solid wall divisions from floor to roof). A cold water supply (i.e., tap or water faucet) to facilitate the provision of water for calf and human (to facilitate labour efficiency during water provision) was not provided in 31.6 % of sheds surveyed. Wind speeds greater than 0.5m/s at calf level were present on 3.3 % (4/121) of calf sheds surveyed. Relating to light intensity, a minimum level of 50-LUX was provided in 70.3 % of all houses evaluated (N = 121). Average house temperature (indoor) was 10.6 °C (range: 5.7-17.2 °C), with average external temperatures of 11.1 °C (range:

3.4-20.9 °C). Average relative humidity in-house was 73.0 % (range: 47.5-100 %) and the average outdoor humidity was 73.0 % (range: 31.6-100 %).

Farmer opinions

The majority of farmers rate welfare on their farm as very good (72.6 %), they also rated their calf husbandry skills (82.4 %) or the main rearers husbandry skills (70.8 %) as very good (Table 1). The majority of farmers (58.8 %) said they were unconcerned about the upcoming spring work load. While farmers with the largest herd sizes had a range of concerns from being somewhat to very concerned about the workload (62.5 %). Retaining non-replacement calves for >10 days (current regulation; DAFM 2007) in spring was not a concern for the majority of farmers (64.7 %), with 45.1 % reporting to be extremely or very prepared if this happened. Farms with large herd sizes were also very unconcerned about keeping non-replacement calves (37.5 %) and were very prepared if this was required (62.5 %). Farms with the smallest herd size were not concerned about keeping non-replacement calves longer than 10 days (40 %; 4/10), but these farms were somewhat to very unprepared if this happened to occur (60 %; 6/10).

Calf housing and grouping

Calving and calf rearing pens were in different houses on 88.2 % of all farms (N = 51). For these, the mean distance between calving and calf rearing pens was 59.1 m (range: three to 500 m; any additional calf house that required transit by car was not included in this metric due to distance inaccuracies compared to the trundle wheel). Multiple houses were used to rear calves on 84.3 % of all farms (N = 51; range: one to seven; Supplementary File 1). The basis for allocating calves to different houses varied, but calf sex was the most common separation criteria (42 % of farms; N = 51), according to farmers. Provided information also indicated that grouping of calves directly post-birth, rather than using individual pens, was common-practice among farms (58.8 %; N = 51). Additionally, the majority of farms kept heifer and bull calves in different pens (76.9 %; N = 51).

Table 1. Farmer opinions (N=51) on calf related topics

Variable	Response	Percentage
Rate calf welfare on-farm	Extremely poor	0
	Very poor	0
	Somewhat poor	0
	Somewhat good	17.7
	Very good	72.6
	Extremely good	9.8
Rate your calf husbandry skills on-farm	Extremely poor	0
	Very poor	0
	Somewhat poor	2.0
	Somewhat good	13.7
	Very good	82.4
	Extremely good	2.0
Rate calf husbandry skills of main rearer on-farm	Extremely poor	0
	Very poor	0
	Somewhat poor	0
	Somewhat good	29.2
	Very good	70.8
	Extremely good	0
Concerned about associated workload with upcoming calving	Extremely unconcerned	7.8
	Very unconcerned	29.4
	Somewhat unconcerned	21.6
	Somewhat concerned	29.4
	Very concerned	7.8
	Extremely concerned	3.9
Concerned about keeping non-replacement calves for >10 days in spring	Extremely unconcerned	9.8
	Very unconcerned	25.5
	Somewhat unconcerned	29.4
	Somewhat concerned	15.7
	Very concerned	13.7
	Extremely concerned	5.9
If had to keep non-replacement calves for >10 days how prepared are you	Extremely prepared	5.9
	Very prepared	39.2
	Somewhat prepared	21.6
	Somewhat unprepared	21.6
	Very unprepared	11.8
	Extremely unprepared	0

Age was the most common basis for separation of calves between pens (37 %; Table 2). Heifer calves were more likely to be in fixed pens for the duration of the rearing period while bull calves were more likely to be in dynamic groups, according to farmers. Bull calves were mainly grouped in groups of 15 or less (66.0 % of farms; N = 51) while the majority of heifers were penned in groups of 16 or more (56.9 % of farms; Table 2). Most farms rear calves in both indoor and outdoor environments (62.8 %; N = 51), with movement outdoors common before weaning (76.5 %). Farms who did not separate bull and heifer calves (12/51; n/N) were more likely to move calves outdoors before weaning (OR = 40.54; CI = 2.69 to 610.22). Outdoor exposure typically commenced after a calf was three weeks old (82.4 %; N = 34).

House structures, modifications and investments

Since 2016 cow numbers increased on 88.2 % of farms surveyed (N = 51), with the median level of expansion being 22.2 % (range: 0 to 57.5 %), relative to pre-expansion herd size. Of respondents who expanded (N = 44), 75 % stated calf housing increased to account for expansion. The average age of calf housing was 29.5 years (range: one to 100 years), however according to farmers surveyed (N = 51), 51 % built a calf house in the past 10 years. If no new calf house was built in the past 10 years (25/51), farms were less likely to have a purpose built house (OR = 0.10; CI = 0.01 to 0.79). According to farmers, the number of calves a house was designed to hold ranged from 8 to 200 calves. Out of houses declared (N = 137), 36.5% were purpose built for rearing calves, however 78.4 % of farms (N = 51) had at least one calf house which was purpose built for calf rearing. Of the houses not specifically built for calf rearing, they were most commonly used for cow and cattle housing, followed by straw storage, among others (Table 3). Modifications to improve suitability for rearing calves were made to at least one house on 76.5 % of farms, 83.7 % of which were made in the past 10 years. Half of the modifications were to reduce labour, followed by improving calf health (41.9 %) and safety (8.1 %; animal handling provisions). There were plans to invest in calf rearing facilities on 51 % of farms, the majority of which would be made within the year (57.7 %; N = 26). Sources for information regarding investments vary among farms. Alternative housing, such as calf hutches and igloos, are not used on 92.2 % of farms (N = 51), however 41.3 % of farmers would consider using them in the future.

Table 2. Calf pre-weaning rearing location and grouping information (N=51 unless otherwise stated).

Variable	Response	Percentage
Use individual pens	No	58.8
	Yes	41.2
Time in individual pens post-calving (Bull N=20; Heifer N=21)	**Bulls**	
	1-2 days	45.0
	≥2-5 days	55.0
	Heifers	
	1-2 days	42.9
	2-5 days	57.1
Most common separation criteria for calves between pens (N=92)	Age	37.0
	Breed	2.2
	Drinking ability	12.0
	Sex	28.3
	Size	20.5
More than one selection criteria for separating calves between pens	Yes	70.6
	No	29.4
Bulls and heifers grouped in separate pens	Yes	76.9
	No	23.1
Formation of calf groups	**Bull**	
	All-in all-out	25.5
	Subject to change	74.5
	Heifers	
	All-in all-out	54.9
	Subject to change	45.1
Calf group size	**Bulls**	
	1 to 10	46.0
	11 to 15	20.0
	16 to 20	16.0
	21 to 25	4.0
	>25	14.0
	Heifers	
	1 to 10	25.5
	11 to 15	15.7
	16 to 20	11.8
	21 to 25	9.8
	>25	35.3
	Unsure	2.0
Calves rearing location pre-weaning	Indoor	37.3
	Indoor & outdoor	62.7

Table 2 continued. Calf pre-weaning rearing location and grouping information (N=51 unless otherwise stated).

Variable	Response	Percentage
Age calves begin moving outdoors (N=32)	0-3 weeks	17.7
	4-8 weeks	58.8
	≥ 8 weeks	23.5
Type of outdoor facility (N=32)	House with field access	60.6
	Field with shelter	30.3
	Both	9.1
Time calf remained indoors post-wean	Outdoors before wean	58.8
	<2 days	11.8
	3-5 days	7.8
	6-10 days	9.8
	>10 days	9.8
	Unsure	2.0

Table 3. Summary of house structures, modifications and investments of surveyed farms

Variable	Response	Percentage
Previous use of houses not purpose built for calf rearing (N=137)	Calving	10.3
	Cow/Cattle housing	32.2
	Feed	4.6
	House	1.2
	Machinery	4.6
	Parlour	6.9
	Pigs/Sheep	4.6
	Potato	1.2
	Straw	28.7
	General/Other/Unsure	5.8
Plan to invest in calf rearing facilities (N=51)	Yes	51.0
	No	47.1
	Unsure	1.9
When will investments be made (N=26)	<1 year	57.7
	2-5 years	38.5
	6-10 years	3.8
What investment will be made (N=26)	Converting old shed	3.1
	Extension onto house	12.5
	New house	40.6
	Roof	3.1
	Feeding equipment	18.8
	Pen structures	21.9
Source likely to seek advice from related to investment (N=26)	Advisor	19.4
	Builder	5.6
	Company	5.6
	Discussion	11.1
	Self	50.0
	Specialist	8.3
Plan to consult other party (except self) for investment advice (N=26)	Yes	46.2
	No	53.9

Calf rearing labour units

Additional labour units were hired on 84.3 % of farms (N = 51), with the majority hiring one person (51.2 %; Table 4). Additional labour units were hired specifically for the calving season on 54.9 % of farms, with most hiring one other person (96.4 % vs 3.6 % hiring two). Common methods for sourcing additional labour units were students (25.8 %), word of mouth (25.8 %) and farm relief services (13.6 %), among others. Over 72 % of farms have two to three people involved with calf rearing. The average number of calves per labour unit was 98, (range: 36 to 250). Larger herd sizes (201 to >300 cows) typically had 51 to 150 calves per labour unit (86.2 % of large farms; 25/29), whereas smaller herd sizes had 36 to 100 calves per labour unit (86.4 % of small farms; 19/22). When more than one person is involved, overlapping in the handover of duties occurs on 87.8 % of farms (N = 51), according to farmer interviews. Additionally, a calf rearing guide is available to all people involved on 73 % of farms (proof of document not requested during survey). All primary calf rearers are present on the farm more than 5 days per week (100 %) and commonly have >20 years of experience with calf husbandry (64.7 %).

Table 4. Labour unit related information for 51 surveyed farms (N=51 unless otherwise stated)

Variable	Response	Percentage
Number of labour units hired on-farm (N=43)	1	51.2
	2	30.2
	3	18.6
Method of sourcing additional labour units (N=66)	Employees	1.5
	Farm relief services	13.6
	Family	9.1
	Internet	4.6
	Word of mouth	24.2
	Neighbour	12.1
	Students	25.8
	Newspaper	9.1
Number of people involved with calf rearing on-farm	1	5.9
	2	39.2
	3	33.3
	4	15.7
	5	3.9
	6	2.0
Calf husbandry experience of main rearer (years)	1-5	11.8
	>5-10	7.8
	>10-15	7.8
	>15-20	7.8
	>20	64.7

Calf feeding

In general, frequency distributions varied relating to colostrum, transition milk and daily feeding of bull and heifer calves (Table 5). Regardless of sex, most farms (N = 51) stated they fed calves within two hours of birth (80.4 %) using a bottle and teat, or stomach tube if not drinking (40.0 %). Calves were typically fed two to three litres of their own dam's first milk as their first feed. According to farmers, colostrum was stored on 72.6 % of farms, with the main storage location being the fridge (43.5 %). Quality was tested on 31.4 % of farms, with 75 % (12/16) testing all colostrum samples. Refractometers were the most commonly used implement (93.7 %; 15/16) to test quality (6.3 % used colostrometers). All calves were fed six or more feeds of transition milk most often. Following this, bulls were mainly offered whole milk (50 %), while heifers were predominantly offered milk replacer (69.5 %); however bull calves were more likely to be fed waste milk (high somatic cell count/antibiotic) than heifers. Post-colostrum milk was typically fed using multi-teat feeders (non-compartmentalised). Of farms that switch from twice-a-day to once-a-day feeding (41.2 %), 42.9 % of these farmers did so before a calf was three weeks old.

According to farmers, calves were weaned gradually on 91.7 % of farms (N = 48; any unsure or withheld number of days for weaning were omitted from dataset; three farmers). However, determined by the number of weaning days (<4 days being abrupt), 81.3 % of farms weaned calves gradually. Farmers generally used a combination of methods (54.9 %; N = 51) to assess if calves were ready to be weaned, the most common method was visual assessment of readiness (66.7 %; 34/51), followed by age (37.3 %; 19/51), weight (35.3 %; 18/51) and concentrates (23.5 %; 12/51).

Table 5. Colostrum, transition and general feeding practices for 51 surveyed farms (N=51 unless otherwise stated)

Variable	Response	Percentage Bull*	Percentage Heifer*
Latency from birth to first feed (hours)	≤ 2	80.4	
	≤ 2 if possible	11.8	
	≤ 6	7.8	
Milk provided for first feed	Own dam's first milk	29.4	37.3
	Another cows first milk	25.5	23.5
	Pooled first milk	27.5	21.6
	Own dam or another cows first milk	9.8	9.8
	Own dam or pooled first milk	3.9	3.9
	Another cow or pooled first milk	3.9	3.9
Volume of milk given as colostrum	<2 litres	0	0
	2-3 litres	58.0	56.0
	>3-4 litres	40.0	42.0
	>4 litres	2.0	2.0
Method used to feed colostrum	Bottle and teat	9.8	
	Stomach tube only	27.5	
	Bottle and teat or stomach tube if wont drink	49.0	
	Left with cow	5.9	
	Left with cow or bottle and teat	2.0	
	Bucket and teat	5.9	
Location of choice for colostrum storage (N=69)	Freezer	31.9	
	Fridge	43.5	
	Room temperature	24.6	
Number of transition milk feeds given	0	0.0	2.0
	1-2	9.8	9.8
	>2-3	17.7	15.7
	>3-4	11.8	13.7
	>4-5	21.6	25.5
	≥6	39.2	33.3
Method used to feed transition milk	Buckets (no teats)	1.7	
	Compartmentalised multi-teat feeders	16.7	
	Individual buckets and teats	16.7	
	Multi-teat feeders (non-compartmentalised)	65.0	
Type of milk fed following transition milk	Milk replacer	15.5	69.5
	Waste-milk antibiotic	12.1	1.7
	Waste-milk high SCC	5.2	1.7
	Waste-milk both	17.2	3.4
	Whole milk	50.0	23.7

*data merged and centred if frequency distributions were identical between bulls and heifers for a variable

Table 5 continued. Colostrum, transition and general feeding practices for 51 surveyed farms (N=51 unless otherwise stated)

Variable	Response	Percentage Bull*	Percentage Heifer*
Type of milk fed following transition milk	Milk replacer	15.5	69.5
	Waste-milk antibiotic	12.1	1.7
	Waste-milk high SCC	5.2	1.7
	Waste-milk both	17.2	3.4
	Whole milk	50.0	23.7
Method used to feed milk following transition feeding	Compartmentalised multi-teat feeders	14.3	9.7
	Automatic feeders	5.4	12.9
	Individual buckets and teats	1.8	0
	Mobile multi-teat feeders	8.9	21.0
	Multi-teat feeders (non-compartmentalised)	69.7	56.5
Volume of milk fed per day (litres)	4	11.8	9.8
	>4-5	19.6	15.7
	>5-6	54.9	60.8
	>6-7	5.9	0
	>7-8	5.9	3.9
	>8-10	0	7.8
	Adlib	2.0	2.0
Manual feeding: feeders shared between pens	Yes	90.2	
	No	9.8	
Manual feeding: feeders washed before sharing (N=47)	Yes	10.6	
	No	89.4	
Frequency of milk feeds per day	Twice	52.9	
	Twice then once-a-day	41.2	
	Many (automatic feeder)	5.9	
Calves fed at same time every day	Yes	100	
	No	0	
Commencement of once-a-day feeding (weeks; N=21)	<2.5	4.8	
	<=3	38.1	
	>3-4	33.3	
	>4-5	9.5	
	>5-6	9.5	
	>6	4.8	
Calf milk temperature	Warm only	80.4	
	Cold only	9.8	
	Warm or cold	9.8	

*data merged and centred if frequency distributions were identical between bulls and heifers for a variable

Hygiene and cleaning

Feeding equipment was washed daily on 84.3 % of farms (N = 51), according to farmer responses, with a cleaning agent used at least weekly on 56.9 % of farms (at least monthly on 64.7 % of farms). A hose was used on 94.1 % of farms to clean feeding equipment and facilities, with 47.9 % of these farms reporting hose water pressure as high (39.6 % medium; 12.5 % low). Pens were cleaned out fortnightly, at least, on 54.9 % of farms, however regardless of frequency, 76.5 % of farms used a disinfection agent when cleaning out occurred. Calves moved outside the pen when cleaning took place on 41.2 % of farms. Of houses declared, farmers believe 32.1 % could have a better layout to facilitate cleaning.

Calf health

According to farmers, diarrhoea was the most prevalent calf related health issue, followed by pneumonia and navel infections (Table 6). The average calf morbidity on farms in spring 2019, as reported by farmers, was 7.5 % with a range of 0.9 to 28.8 %. Veterinary assistance was not required for calves on 21.6 % of farms in spring 2019 (N = 51), with 49 % of farms requiring assistance one to two times (including issues related to births). According to farmers, health issues arose on-farm as a result of overcrowding on 21.6 % of farms, where diarrhoea was the main illness indicator for these farmers (50 %). Forty four percent of farmers reported diarrhoea related problems on-farm with *Cryptosporidium* and Rotavirus the most frequent causative agents (58.6 %). Pneumonia was cited as an issue on 15.7 % of farms, particularly when a calf was two to three weeks old (44.4 % of farms). Average calf morbidity up to the point of visiting in 2020 (calf requiring antibiotic treatment; expressed as percentage of total cows calved at point of visit) was 4.2 % (range: 0 to 80 %). The average calf mortality up to the point of visiting in 2020 (expressed as percentage of total cows calved at point of visit) was 3.6 % (range: 0 to 9 %).

Table 6. Summary of farm calf health data (N=51 unless otherwise stated)

Variable	**Response**	**Percentage**
Main health issues encountered on-farm by calves (N=78)	Colic	1.3
	Genetic issues	2.6
	Navel infections	14.1
	Pneumonia	28.2
	Diarrhoea	53.9
Number of calves treated with antibiotics (Spring 2019)	≤10	51.0
	>10-20	23.5
	>20-30	11.8
	>30-40	5.9
	>40-50	3.9
	>81	3.9
Number of veterinary visits to calves (Spring 2019)	0	21.6
	1	13.7
	2	35.3
	3	9.8
	4	13.7
	5+	5.9
Overcrowding impact on calf health (N=10)	Diarrhoea	50.0
	Pneumonia	30.0
	Both	20.0
Calf diarrhoea issue on-farm	Yes	44.0
	No	42.0
	Not really	14.0
Age diarrhoea becomes issue on-farm (weeks; N=29)	≤1	17.2
	>1-2	24.1
	>2-3	27.6
	>3-4	20.7
	Mid-spring	6.9
	Out to grass	3.5
Most common calf related diarrhoea encountered on-farm (N=41)	Coccidiosis	7.3
	Corona	2.4
	Cryptosporidium	34.2
	E.coli	2.4
	Nutritional	14.6
	Rota	24.4
	Unsure	14.6
Calf pneumonia issue on-farm	Yes	15.7
	No	66.7
	Not really	17.7

Table 6 continued. Summary of farm calf health data (N=51 unless otherwise stated)

Variable	Response	Percentage
Age pneumonia becomes issue on-farm (weeks; N=18)	<=1	5.6
	>1-2	22.2
	>2-3	44.4
	>3-4	11.1
	>5-6	5.6
	>7-8	5.6
	March-born calves	5.6
Location of sick calves (N=61)	Individual pen	26.2
	Isolation house	6.6
	Isolation pen	44.3
	Remain in group	23.0
Recovered calves go back to original group or enter a new one (N=45)	Original	71.1
	New	24.4
	Situation dependent	4.4

Destination of surplus calves

When managing surplus calves the previous year (2019), 80.4 % of farmers used multiple avenues when moving these animals off-farm. Calves were most often sold to a buyer (47.9 %), followed by the mart/auction (32.3 %) and export (19.8 %). In 2020, of the farmers who had moved surplus calves off-farm (90 %), sourcing a buyer was most common (49.6 %), followed by mart (31.8 %) and export (18.0 %).

DISCUSSION

Facilities

The majority of farms surveyed maintained their original calf housing plan during peak-calving in spring (i.e., same number of houses used in spring as specified pre-calving). This indicates farmers had good foresight and planned effectively for spring expectations. Additionally, some farmers used less houses than expected, further suggesting heightened readiness for various outcomes in spring. Over half of farmers said at least one calf house was overcrowded, however when space allowance was evaluated on-farm, most houses were not.

This is evident at the 1.5 m ^{2}/calf space allowance cut-off, a legal requirement for all calves in Ireland. This indicates farmers were self-critical in relation to overcrowding on-farm and may overestimate overcrowding issues, which may be beneficial for calves in terms of their welfare. Current space recommendations of 1.5 m^2/calf reflect a live weight of less than 150 kg (EU regulations: Council Directive 2008/119/EC), increasing thereafter. However, this study indicates most calves move outdoors pre-weaning, meaning calves would not remain indoors to achieve such weights. Therefore, movement of calves below 150 kg outdoors at an early stage may facilitate space allowances that move toward the lower end of the regulatory scale, in these situations. That said, space allowance is one of many management decisions made at farm level which influences calf welfare, such as group sizes (Svensson and Liberg, 2006) and sharing airspace (McGuirk, 2003), among others (Stull and Reynolds, 2008). While most farmers said group sizes were often > 12 calves/pen, spring examination indicated groupings were most often < 12 calves/pen. This is positive, as smaller calf groupings (ideally < 10 calves) is linked to reduced respiratory related issues (Svensson and Liberg, 2006) and improved welfare (expression of play behaviour; Barry et al., 2020). Larger groupings likely coincide with automatic milk feeder usage, (Moran, 2012). Sufficient air volume was commonly provided to calves on-farm which is positive for calf health. The promotion of air changes within a house regulates temperature and humidity while minimising stagnation of airborne microorganisms (Roe, 1982). Similar to previous studies (Muktar et al., 2015), an association was found in this study whereby diarrhoea was less likely to be an issue on-farm if sufficient air and floor space allowances were provided to calves. Airspace is not often shared with older livestock and calving pens are most frequently in a different house to the calf-rearing house. Older livestock tend to carry and transfer pathogens to young stock which can threaten calf health, particularly in relation to respiratory infections (Pardon et al., 2020).

Sheds utilising individual pens generally meet the legal minimum specifications (0.8 m width by 1.25 m length; DFAM 2016), however most do not provide both front and side contact with adjacent calves. Given time spent in these pens does not generally exceed five days (grouping occurs thereafter), social isolation may not be a considerable issue during this short time-frame (in natural setting calves commence group socialisation and increase distance from dam in second week of life; Vitale et al., 1986). That said, most farms group calves immediately post-birth, meaning this is not an issue. Grouping post-birth can save labour as personnel can care for calves collectively rather than individually. It can also lessen equipment requirements (i.e., group feeders rather than both individual and group feeders). Most group pens did not have a sufficient 1:20 slope, likely lending to drainage issues (Robertson, 2020). This causes excrement accumulation within pen, saturating bedding and thus increasing risks of calf illness (Nordlund and Halbach, 2019). The majority of houses did not have any draughts (defined as a wind speed greater than 0.5 m/s at calf level; Lundborg et al., 2005) however, for those that did, most were not at calf level. As five to six air changes are expected within a house every hour (Teagasc, 2017), this overhead air movement may promote these changes. Airflow is cited as a way to safeguard calf health in terms of regulating temperature, humidity, gases (e.g., ammonia) and stagnant microorganisms, which is beneficial to overall welfare (Roe, 1982).

Calf grouping and movement outdoors

Two calf houses were commonly seen across farms, which was somewhat likely due to the main separation criteria for different houses being sex. This may be a biosecurity precaution to minimise calf exposure to buyers purchasing calves on-farm, who may introduce foreign pathogens to a house which was a concern brought forward by farmers from a study by Wilson et al. (2020). Additionally, more than one house would allow for biocontainment of disease outbreaks among all calves (Maunsell and Donovan, 2008), by limiting issues to one house. If houses were not separated by sex, most farmers kept bulls and heifers in separate pens. This is favourable because it would mean calf groupings would be more static than dynamic (i.e., heifers not continually disturbed due to sale of bull calves). Dynamic groups are groups where new calves are continuously introduced and removed, and can have negative implications on calf health, growth and overall welfare (Pedersen et al., 2009; social stress exhibited in five month old dairy heifers (Nogues et al., 2020)). Heifer calves were often maintained in fixed pens with calves of similar ages, meaning once a group pen became full, no calves were moved in or out of the group. This grouping minimises pathogen exposure as well as facilitation of disinfection between group pens.

A fusion of indoor and outdoor calf rearing is popular among farmers. For the calf, outdoor exposure pre-weaning allows for the introduction of grass as a feed source, thus potentially improving foraging skills. Research indicates that sheep forage more efficiently when they experience plants previously (Arnold and Maller, 1977), which may be the case for calves also. Additionally, as the season progresses, calf houses with organic material offer the perfect environment for pathogen proliferation (warm, damp and humid conditions) and infections can spread exponentially among confined calves (McGuirk, 2003). Movement outdoors may alleviate space allowance and stocking pressures within the shed, reducing the associated risks. This would directly impact calf rearing labour, as tending to sick calves is likely a very laborious process (similar to time consuming process of providing individual health care to poultry; Vermeulen et al., 2002). Calves typically moved outdoors after three weeks old; this delay can be positive because calves become more robust with age, i.e., improved thermoregulation (older calves have a better ability to thermoregulate; Borderas et al., 2009b) and digestive development (movement towards functioning ruminant; rumen fermentation may aid with heat production; Collier et al., 1982). Additionally, shelter is always provided to calves, facilitating micro-climate creation, warmth via body heat and protection from interchangeable spring weather patterns (Macaulay et al., 1995; Roland et al., 2016).

Structure modifications and investment

In general, farmers said housing had increased in response to on-farm expansion. When examined, sufficient space allowances among calves indicate these sentiments to be true. This is positive because, it is evident facilities have grown to consider cow needs, but it was unclear if this also occurred for calves. Furthermore, this echoes findings from a previous study in Ireland (Barry et al., 2020), where farms also had sufficient calf space allowances. While calf house age varies, half of farms built a purpose-built calf house in last 10 years. In contrast, farms were less likely to have purpose built facilities if a house was not built in the last 10 years, which suggests conversions of existing sheds occurred. However, while conversions are often necessary, it is important to ensure these spaces are appropriate for both calf and carer needs (AHI 2021b). For example, when considering water provisions, facilities that promote efficiency (i.e., water source within the house) should be considered. Measures such as this have taken priority for surveyed farmers, as most made modifications to at least one house in the past 10 years for labour gains and calf health. This indicates that farmers heeded advice regarding increasing labour productivity to facilitate herd expansion post-quota abolition (O’ Donnell et al., 2008). Investment in rearing facilities within the year is a priority for half of farmers. Most plan to seek advice from multiple outlets (e.g., advisor, builder etc.), however out of the 50% of farmers who will draw on their own knowledge, over half will not consult another party before investing. While farmer knowledge is extremely valuable for on-farm investment decisions, the search for up to date and relevant research and information from others should also be encouraged. A recent study has shown the value of farm visits, walks and group meetings as a less intimidating space to share knowledge selectively and give contextualisation for farmers about aspects of other farms (Thomas et al., 2020). Effective use of discussion groups in this manner could be beneficial encouraging collaboration during farm building investment. For example, most farms surveyed did not use alternative housing options such as calf hutches but, over one third of farms would consider them in the future. This highlights a potential avenue for future research detailing how alternative housing systems might be integrated into an Irish system and whether it might be an alternative investment to permanent housing.

Labour at calving

Additional labour is typically hired on-farm, suggesting a slight redirection from what has been typically seen on European farms, whereby half of working labour is accounted for by family (Eurostat, 2018b). The average number of calves per rearer was 98, similar to what is recommended for cow to labour unit ratio (100:1; Teagasc, 2022). While there is no specific ratio for this relative to calves, it is likely farmers have adopted a similar approach to cow recommendations. The hiring of additional labour units for calving is an expected response to what is highlighted as an extremely labour intensive period (Deming et al., 2017). However, due to seasonality of much farm work, it is often unattractive for employees (Schell, 2021). In response to this challenge, farms appear to frequently utilise students, who offer short-term solutions, to bridge this labour gap. Most farms have a calf rearing team of many people, however in this case careful and clear communication is required to ensure rearing runs smoothly. This echoes a farmer sentiment in a recent study (Russell et al., 2022) which noted the difficulty in identifying inconsistencies in calf care when too many people are involved in the process. Most farms demonstrate good communication, whereby time is taken to hand over daily tasks from one rearer to another. Additionally, calf rearing guides detailing standard operating procedures are available on most farms aiding with role transition and task completion. These are a tool, which has been cited as valuable in the calf rearing process on-farm (Russell et al., 2022). All primary calf rearers are on-farm at least five days per week. While this provides consistency within the rearing process, burnout is a risk when a person operates in stressful conditions for long periods of time (Schaufeli et al., 1996). Studies indicate people are less productive and more inclined to make work related mistakes if over-worked (Da, 2015).

Feeding, hygiene and cleaning

According to farmer responses, colostrum feeding practices on-farm are in-line with recommended advice, whereby colostrum is fed to calves within two hours of birth (Teagasc, 2017). On-farm improvement can be made in relation to colostrum volume fed to calves: currently typically 2-3 L, whereas the aim is for calves to consume at least 3 L (Teagasc, 2017). Additionally, while colostrum testing appears to have increased on-farm since a survey carried out on Irish farms in 2017 (Barry et al., 2019a), improvements could still be made. Considering colostrum is a calf's first line of defence against infection, it is extremely important to ensure that colostrum provided is of high quality (high quality means >50 g/L IgG; Schneider and Wehrend, 2019) to facilitate appropriate passive transfer (Yang et al., 2015). Calves are typically offered upwards of five feeds of transition milk following colostrum, a finding similar to previous research conducted on Irish dairy farms (Barry et al., 2020). While according to farmers surveyed, waste milk is offered more frequently to bulls than heifers, lower numbers of farmers were engaging in this practice compared to a previous Irish study (Barry et al., 2020). This is a positive indicator that information campaigns (AHI) related to this area are proving successful, as it is strongly advised not to feed waste milk to calves on-farm, as this is linked to antimicrobial resistance on-farm (Aust et al., 2013). Whole milk is most commonly fed to bulls, possibly for economic reasons relative to the cost of milk replacer, while milk replacer is most commonly fed to heifers, potentially for biosecurity and disease transfer reasons or to offset reductions in cash flow due to a reduced volume of milk sales (Asheim et al., (2016), compares the reduction in saleable milk with cow-contact systems). Milk is mostly fed manually via non-compartmentalised teat feeders, thus there is no control over the quantity calf milk ingested in a group setting. This is concerning, particularly in a restricted feeding capacity, because drinking speeds vary considerably among calves (with sorting by drinking speed common in the veal sector; Damiaans et al., 2019). Without sorting due to drinking speed, calves with fast drinking speeds would consume significantly more milk than calves which drink more slowly. Although automatic feeders have been noted as useful technology in relation to calf rearing (Medrano-Galarza et al., 2017a), a relatively low uptake of this equipment was found on-farm. Manual feeding systems were also more popular than automated systems in a Canadian study, whereby farmers found costs a barrier to investment in automatic feeders, and instead liked the level of disease detection and ease of calf handling associated with manual systems (Medrano-Galarza et al., 2017a). While not surveyed directly on reasoning, it is possible this may also be the case for the farmers in this survey. Another point of concern related to feeding practices is the age once-a-day feeding commences. Almost half (42.9%) of farms implement once-a-day feeding before three weeks old, which is a welfare concern. Once-a-day feeding should only commence once a calf reaches 28 days old as their digestive systems are unable to manage infrequent high volumes of feed before this point (Teagasc, 2017), however, this is still quite young. Furthermore, this infringes on a calf's ability to perform natural suckling behaviours, in a way that would mimic a natural scenario with the cow (a highlighted benefit of automatic milk feeders by Medrano-Galarza et al, 2017a).

The majority of farms wash feeding equipment daily with over half using cleaning agents at least weekly (some more frequent). Inadequate and infrequent cleaning is a huge issue in calf rearing; hygiene management (as well as biosecurity measures) can minimise infectious agent transmission among calves (de Graaf et al., 1999; Maunsell and Donovan, 2008; Barry et al., 2019a). Half of farms surveyed clean out pens fortnightly, with the majority also using disinfection agents. Appropriate hygiene and environmental disinfection are an effective way to control the spread of disease agents (Barrington et al., 2002; Villarroel et al., 2007). Farmers have highlighted almost one third of sheds declared as needing modifications for labour efficiencies around cleaning out. This demonstrates the ability to look at the farm critically and identify areas requiring improvement. Critical thinking is an important skill to attain in the work place as it demonstrates communication, decision-making, analytical and problem solving skill development (Lau, 2011), all which likely lends itself to the development of viable farm practices.

Health and calf movement

The most common calf health issues, as experienced by the farmers in this survey, were diarrhoea and pneumonia. This finding is in line with literature which states these areas as problematic for calf health (Lorenz et al., 2011b; 2011c). In relation to diarrhoea, *Cryptosporidium* and Rotavirus were mentioned as the two main causative agents, among others. This is in accordance with much other calf research (e.g., Gulliksen et al.,2009; Silverlås et al., 2010). According to farmer opinion, health issues related to overcrowding were not experienced on most farms. However, for farmers that believed this was an issue on their farm, health complications due to overcrowding generally presented as calf diarrhoea (an eventuality previously outlined by Bazeley, (2003)). Mortality statistics reported by farmers for 2019 were quite similar to a previous study conducted on Irish farms in 2017 (Barry et al., 2020), however it must be remembered that in this instance, mortality statistics were recounted by farmers (recounted in December 2019 for calves born in 2019).

Farmers utilise multiple means to move surplus calves' off-farm, however in 2019 and 2020, sourcing a buyer was the most popular method. Compared to export, a buyer minimises the degree of transport these calves are subjected to and ensures calves move regularly off-farm creating more space for those remaining. Transport is stressful for calves and distance travelled has been linked to calf morbidity (Knowles, 1995) and mortality during or shortly after transportation has occurred (Cave et al., 2005). Additionally, when calves are sold at marts (auctions) co-mingling with calves of other dairy herds occurs (Marquou et al., 2019), which can increase the risk of pathogen exposure.

Farmer opinions

Most farmers surveyed rated their calf welfare and calf husbandry skills as 'very good'. This result is positive, as most farmers acknowledge that improvements can be made to their skills and it perhaps demonstrates an openness to upskilling in farm related practices (due to the top rating not being selected frequently). A similar willingness of farmers to engage in various levels of upskilling was found in New Zealand (Fleming, 2021), however this article highlights the need to provide appropriate supports to the farmer to do this. Animal welfare has been acknowledged as dynamic and changing constantly (Curtis, 1987), as a result continued professional development and upskilling is important to ensure practices and knowledge are in-line with welfare concepts (e.g., One Welfare; Pinillos, 2018). Conversely, farmers rating themselves as 'very good' in terms of their calf welfare and husbandry may also suggest they over-rate their qualities in these areas. While many may have knowledge related to a number of welfare issues, the may be blind to issues related to their own farm.

Study limitations

It is important to recognise limitations that exist within this study in relation to herd selection and farmer response bias. The farmers surveyed in this current study may not be typical of all dairy producers in Ireland for a number of reasons including; larger average herd size, interaction and participation in discussion groups as well as a high level of data recording carried out on-farm compared to the national average. That said, due to the geographical location of farms surveyed (the region in Ireland most densely populated with dairy cows) as well as the larger nature of herd sizes, it could be argued that these farmers are also those who may be most likely to remain in dairying and represent the future of the Irish dairy herd/producer.

A potential social desirability bias may also have existed, whereby survey participants adjust their answers to reflect what they perceive researchers would find acceptable (as mentioned by Medrano-Galarza et al., 2017a), particularly related to the face-to-face nature of data collection. However, care was taken to communicate that survey responses were in line with GDPR guidelines, meaning all information collected was anonymous and confidential, with no identifiable farm or farmer characteristics report thereafter.

CONCLUSION

To conclude, farmers demonstrated sufficient planning for spring, providing appropriate housing and space allowances for calves that facilitated group housing post-birth, influencing calf welfare positively. Planning was also apparent by the lack of concern among farmers regarding upcoming spring workload. Large proportions of sheds are converted for calf housing, so emphasis must be placed on modifying sheds appropriately so provisions are made to safeguard animal and farmer welfare (e.g., drainage and slopes and facilitate cleaning out). Management components of rearing systems appear in-line with current sectoral recommendations (e.g., advice against feeding waste-milk), and improvements have been made, however areas require further attention on many farms (e.g., colostrum testing and extended working hours), to safeguard calf welfare and reduce associated workloads. Thus, calf housing provisions seem to be sufficient for calf numbers born on-farm in Ireland, however structural components and management decisions should be continually reviewed to ensure that calf and human welfare is considered.

ACKNOWLEDGEMENTS

The authors wish to thank all those who participated in the study. The authors also wish to acknowledge the funding supplied from the Walsh Fellowship funding scheme.

SUPPLEMENTARY FILES

Supplementary File 1. Summary of calf housing information

Variable	Response	Percentage
Number of houses used to rearing calves (N=51)	1	15.7
	2	41.2
	3	15.7
	4	19.6
	≥5	7.8
Most common selection criteria for separation between houses (N=69)	Age	39.1
	Breed	5.8
	Drinking ability	1.5
	Sex	42.0
	Size	11.6
More than one selection criteria for separating calves between houses (N=44)	Yes	52.3
	No	47.7


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Chapter 3

The effects of manual and automated milk feeding methods on group-housed calf health, behaviour, growth and labour

Alison M. Sinnott[a], Emer Kennedy[a], and Eddie A.M. Bokkers[b]

[a] *Teagasc, Animal and Grassland Research and Innovation Centre, Moorepark, Fermoy, Co. Cork, Ireland*

[b] *Animal Production Systems group, Wageningen University & Research, P.O. Box 338, 6700 AH Wageningen, the Netherlands*

Livestock Science, 244: 104343.

ABSTRACT

It has been suggested that the integration of automatic feeding systems into calf rearing programmes has the potential to improve calf welfare and the associated labour. Thus, the objective of this study was to compare the effects of automatic and manual feeding systems on calf health, behaviour, growth and labour. A population of 60 dairy heifer calves was used: 44 Holstein-Friesian (HF) and 16 HF x Jersey (JE), balanced for birth weight (33 ± 4.1 kg), birth date (26 January ± 3.2 days) and breed. The experiment was a randomised block design including two treatments; i) automated calf feeding system (AFS) and ii) manual calf feeding system (MFS). Each treatment was replicated once, so a total of four balanced groups of 15 heifer calves were created. Milk replacer was offered at a rate of 6 L per calf/day (reconstitution rate 15%), with fresh water, *ad libitum* concentrates and hay offered from three days old. Calves were weaned based on weight (90 kg for HF and 85 kg for HF x JE). Total labour input/day was consistently less for AFS compared to MFS (-00:01:06 per calf/day). Automatic feeding systems had a higher labour requirement for health inspections and training to the system (+00:00:15 per calf/day and +00:02:06 per calf/day, respectively), on a per calf basis, compared to MFS. The MFS-calves had an increased likelihood of experiencing faecal scores > 0 (Odds Ratio (OR) = 2.009; Confidence Interval (CI) = 1.463 – 2.759). The MFS-calves were also more likely to defecate and urinate (OR= 1.450; CI = 1.080-1.945), eat (OR= 1.281; CI = 1.140 – 1.439) and socially interact (OR= 1.300; CI = 1.111 – 1.521), compared to standing. There was no difference in number of days from birth to weaning (80.8 days) and weight at weaning (92.9 kg); average daily gain in both the pre (81 days) and post weaning (79 days) periods was similar between the two treatments (0.74 and 0.70 kg/day, respectively). Patterns for behaviours such as lying and playing were similar and low levels of abnormal behaviours were found in both treatments. Calves in both treatments exhibited good health and normal behavioural patterns as well as similar growth rates. Thus, when managed appropriately, the saving of labour and facilitation of nature-like feeding behaviours are distinct advantages automated feeding systems have over their manual counterparts when rearing group-housed calves.

INTRODUCTION

In response to global demand, milk production quotas were abolished across Europe in April 2015, this resulted in a sharp increase in expansion of dairy herds throughout many EU countries. In Ireland alone, dairy cow numbers have increased by almost 20% since 2015 (ICBF, 2019). However, post-quota expansion is threatening the social sustainability of dairy farming in Ireland, due to the growing labour demand associated with a large increases in herd size. Adapting farming practices to facilitate social sustainability is an important step in ensuring that farming is seen as an attractive career, in terms of work life balance (Kelly et al, 2017).

Calf rearing is labour intensive, particularly on seasonal calving dairy farms (Gleeson et al, 2008), such as those that predominate in Ireland and New Zealand. Within these systems, the majority of cows calve within a 12-week period, which in conjunction with increasing herd sizes, places amplified pressure on an already labour intensive period (Deming et al, 2018). A recent study on 38 labour efficient Irish dairy farms, pre-determined by previous interaction with the farmers, has shown that labour inputs for calf rearing can vary greatly among farms (from 0.48 h/cow/yr to 2.85 h/cow/yr; average 1.4 h/cow/yr; Deming et al., 2018). In addition, sourcing labour has been identified as one of the most limiting factors affecting expansion of the Irish dairy sector (Kelly et al, 2017). Consequently, alternatives such as automation of various tasks e.g., calf feeding, need to be considered, as their increased use is perceived as an efficiency investment for farmers (Medrano-Galarza et al, 2017a). Traditionally, Irish dairy farms manually feed group-housed calves through multi-teat feeders (Barry et al, 2019a). However, as the dynamic of the Irish dairy sector changes, it is possible that the introduction of automatic calf feeders may become more common. Before adopting automatic feeding technology, the needs of the calf must be considered to ensure that calf health, behaviour, growth and over-arching welfare are not affected in a negative way.

Automatic feeders offer a number of advantages in a calf rearing system. It can be a useful tool to detect illness in calves (Johnston et al, 2016) and track animal growth performance (when scale fixture is utilised; Moran, 2012). A healthy calf is imperative for any successful cattle production system, with subsequent performance in later life impacted by its health status as a calf (Lorenz et al., 2011a). Effective management practices are of paramount importance to minimise and control health complications to safeguard the welfare of calves (Sumner et al., 2018). Furthermore, it affords calves an opportunity to express feeding behaviours, including suckling, that mimic natural systems most closely (Medrano-Galarza et al, 2017a), satisfying calf behavioural needs. However, the successful inclusion of an automatic feeder in a calf rearing system is often influenced by management practices used on the farm, rather than the feeder itself. Studies have shown that group-size (Maatje, 1993; Svensson et al, 2003; Svensson and Liberg, 2006), age of introduction to the feeder (Jensen, 2007), quality of milk fed to calves and separation of older and younger stock (Medrano-Galarza et al. 2018a) dictates a calf's health status rather than the feeding system that is implemented.

Automatic feeders may also offer additional benefits for calf growth. Research has shown that the speed by which milk moves through the digestive tract is stimulated by the frequency of consumption, whereby emptying occurs quicker in the abomasum allowing for entrance of new matter (Mylrea, 1966). Although large volumes of milk have been fed to calves with reasonable efficacy (e.g., once-a-day feeding (Saldana et al. 2019)), it is also suggested that the greater the volume of milk offered at each feeding, the longer milk will remain in the abomasum (Burgstaller et al, 2017) and prolonged abomasal emptying may increase rates of digestive disorders (Songer and Miskimins, 2005). For this reason, provided a feeder is programmed to do so, it is possible that automatic feeding systems may utilise milk more efficiently due to the smaller portions being consumed more often. This may stimulate the movement of milk through the digestive system more quickly, perhaps resulting in a higher ADG.

To date, studies regarding labour efficiency in calf rearing have relied on commercial farmers recording (Deming et al, 2018) or recalling information (O'Donovan et al, 2008; Cummins et al, 2016). They have also been either based off estimates (Bostad et al, 2010), or snapshot data collection (Gleeson et al, 2008). Furthermore, the majority of these studies have examined the dairy enterprise as a whole instead of focusing solely on examining the labour associated with calf rearing (O'Donovan, 2008). Although it has been suggested that the costs associated with automatic feeders can be mitigated within two to three years through savings in labour, detail pertaining to this finding is limited (Kung Jr et al, 1997). Previous studies have singularly evaluated the impact of calf feeding systems on health (Maatje, 1993; Svennson et al, 2003; Svennson and Liberg, 2006), welfare (Sutherland et al, 2018) and growth (Kung Jr. et al, 1997; Fujiwara et al, 2014). However, a controlled study which collectively examines how group-housed calf health, behaviour, growth and labour are influenced by feeding system has not been carried out.

To establish modern sustainable farming practices, it is essential to take a balanced approach and ensure that progress is not made at the expense of either the animal or human. Thus, the objective of this study was to compare the effects of automatic and manual feeding systems on calf health, behaviour, growth and labour. We hypothesised that feeding calves using automatic feeders would be more labour efficient and provide greater average daily gains (ADG) than manually feeding calves.

MATERIAL AND METHODS

The study was conducted from January 24 to June 27, 2019 at Teagasc Moorepark Research Farm, County Cork, Ireland. The study population consisted of 60 dairy heifer calves: 44 Holstein Friesian (HF) and 16 HF x Jersey (JE) (HF x JE). Calves were balanced for birth weight (33 ± 4.1 kg), birth date (26 January ± 3.2 days) and breed. Ethical approval to undertake the study was approved by the Teagasc Animal Ethics Committee (TAEC201-2018). Experiments were undertaken in accordance with the European Union (Protection of Animals Used for Scientific Purposes) Regulations 2012 (S.I. No. 543 of 2012).

Pre-experimental management

All births were supervised. Following birth, calves were immediately removed from the cow, as a biosecurity procedure. Calves were weighed (TruTest XR

3000, TruTest limited, Auckland, New Zealand), placed in an individual pen and fed 8.5% of birth bodyweight (BW) of colostrum from a single cow (not specifically their own dam) via bottle and teat. A stomach tube was used if calves refused to consume the colostrum feed using a bottle and teat. Calves were fed colostrum with a quality of ≥22% Brix (>50 g/L IgG), determined using a Brix refractometer (Milwaukee Instruments MA871 Digital Brix Refractometer), which should sufficiently accommodate passive transfer (Bielmann et al, 2010). Following colostrum feeding calves were offered five feeds of transition milk, which were pooled from the second milking post-calving of recently calved cows. Calves were fed two 3 L feeds of transition milk per day using an individual bucket and teat. From approximately three days of age calves were moved to a group pen, offered milk replacer and fed according to their respective experimental treatment group.

Experimental treatments and calf management

The experiment was a randomised block design which included two treatments; i) automated calf feeding system (AFS) and ii) manual calf feeding system (MFS). Each treatment was replicated once. A total of four balanced groups of 15 heifer calves were created. Each group was assigned to one of two treatments. There was no greater than a six day difference in date of birth between calves within each group. At approximately three days of age, calves were assigned to their respective treatment.

Two different locations/houses were used: each location contained both treatments. Treatment groups were located adjacent to one another within each house. No physical contact was possible between the treatment groups, but auditory and olfactory cues could be exchanged.

Each calf was offered 26% crude protein (19.7 ME MJ/kg DM) milk replacer (Volac Heiferlac Instant, Volac, Hertfordshire, United Kingdom) at a rate of 6 L/calf/day. Milk replacer was reconstituted at a rate of 150 g/L. Concentrates (20% crude protein; ingredients: barley, soya meal, sugar beet pulp, distillers grains, rape seed meal, and maize; (Sweet Start Calf Starter Pencils, Southern Milling, Cork, Ireland)), water and hay were offered to all calves for *ad libitum* consumption from three days old. Water was provided using automatic filling drinking bowls and hay was offered in a rack.

Group pens were 35.3 m^2 (2.4 m^2/calf) and contained a concrete feeding area and a lay back area bedded with straw (1.8 m^2/calf). The feeding area of each pen was cleaned in the morning (9:30-10:00) and evening (16:30-17:00) using water and detergent. The lay back area was cleaned, disinfected and re-bedded with fresh straw, to a depth of 15 cm, twice weekly (Monday and Thursday).

Automatic calf feeding system

Each AFS group pen was equipped with an automatic milk and concentrate feeder (Volac Förster Technik Vario, Germany). The automatic milk feeder was computerised, receiving information regarding milk feeding from the RFID in a calf's ear tag. The feeder then mixed milk replacer automatically and distributed it, according to the individual's threshold allowance. A common feeding programme was devised for the AFS calves. Upon entering the treatment pen, milk allocation was increased from 5 to 6 L, remaining at this level until weaning. Each calf was allocated four feeds of 1.5 L spaced evenly throughout the day (24 hr); access to the feeder was granted until the 1.5 L threshold was reached, after this time calves had to wait for four hours until access was allowed for the next 1.5 L to be consumed. Milk was prepared by the machine in units of 750 ml at a temperature of 37 °C. The teat for the automatic feeder was located 68 cm from ground level for each pen, respectively.

Calves assigned to AFS were taught how to use the automatic feeder over a 24-hour period and this was repeated thereafter if necessary. Calves were initially guided to the teat by hand, with the process repeated if the calf broke away from the teat. Training was considered successful after two consecutive days of unassisted feeds were consumed from the feeder. A calf was not required to consume its full allocation in one visit, however, a calf needed to demonstrate its ability to revisit the feeding station voluntarily, without human assistance. All calves were monitored twice-a-day after this time to ensure that further training was not required.

The automatic concentrate feeder granted *ad libitum* access to concentrates for each calf. A fixed quantity of concentrate was manually placed in the feed dispenser. Records were taken of the date, number of calves per pen and the quantity of concentrate, to determine an estimate for concentrate dry matter intake (CDMI). The RFID tag in the feeding station is registered by a computer and stimulates an auger in the dispenser which distributes small 200g quantities of concentrate into the feeding bowl, automatically. Small quantities minimises wastage and increases the accuracy of distribution. Once all concentrate was consumed, the distribution of concentrate into the feeding bowl was repeated again. Calves were not trained to the concentrate feeder.

Manual calf feeding system

The MFS consisted of three plastic compartmentalised five-teat feeders (Wydale, Somerset, England) per group. These feeders were equipped with side partitions between calves and chin protection to minimise the occurrence of bullying. Feeders were not shared between groups. A common feed plan was devised for MFS calves. The milk allocation for manually fed calves was increased from 5 L to 6 L, upon entry into the treatment pen, remaining at this level until weaning. Calves on the MFS were given two feeds of 3 L per day (08:00 and 16:00). When feeding the MFS-calves, the correct volume of warm water (35-38°C) was measured before adding the powder. A whisk was used to mix the milk replacer and water to ensure a homogenous consistency. Milk was fed to calves no more than five minutes after mixing. As each calf moved from their individual pen to the group MFS treatment pen, they were trained to drink from the manual unit. This involved guiding calves to an available teat by hand during milk feeding, with the process repeated if the calf broke away from the teat. The teats were located at 65 cm from ground level for replicate one and two.

Concentrates were offered on an *ad libitum* basis from three days old with one open meal bar concentrate feeder (Birdproof Meal Bar, Milk Bar, McInnes Manufacturing, New Zealand) per group, which allowed up to four calves to feed at any one time. Concentrate consumption was also monitored (as outlined for the AFS above) to determine an estimate of CDMI.

Weaning

Calves were weaned based on weight; the HF calves were weaned once they attained a minimum of 90 kg and the HF x JE calves were weaned once they reached a minimum weight of 85 kg. When a calf on the AFS achieved the minimum target weaning weight, the feeding plan on the computer system was changed. Milk allocation was adjusted to reduce gradually over a period of four days from 6 L to 0 L. This reduced the milk allowance by 1.5 L per day for the calf over the course of the weaning period. Once a calf was fully weaned off milk for one day i.e., 0 L consumed for 24 h, it was moved from the treatment pen (AFS) to a larger group pen. This indoor pen was 79 m^2 and bedded with straw.

When a calf on the MFS achieved the minimum target weaning weight, the calf was removed from the treatment group and placed in a separate group pen with calves at the same stage of weaning. A calf's milk allocation was reduced by 1.5 L per day, from 6 L to 0 L, over the course of four days, similar to AFS.

Measurements

Labour

Labour evaluations were completed for three non-consecutive days per week, until all calves were weaned (final calf weaned 14 weeks after introduction to treatment based on weight). Individual tasks associated with calf rearing were assessed including: training calves to drink from teat feeder or AMS, feed preparation, feeding/ feed inspection ensuring all calves drank milk allocation, cleaning feeding equipment, cleaning pen (wash down in the morning and evening), bedding, and health observations. Each measurement was repeated in the morning and evening and timed using a stopwatch (SW; time is expressed as hh:mm:ss)). The farm tasks related to calf care and start/stop cues for the SW are defined in Table 1. The sum (total hh:mm:ss) of each labour task quantified per day was then divided by the number of calves in the pen on that day.

Table 1. Catalogue of definitions and cues used during labour evaluations to differentiate between tasks involved with automated calf feeding system (AFS) and manual calf feeding system (MFS).

Task	Definition of action	MFS stopwatch (SW) cues	AFS stopwatch (SW) cues
Training calves	All treatments: Guiding calf to find drinking teat	SW started when calf was aided to find teat. SW stopped when calf correctly latched to teat.	SW started when calf was aided to find teat. SW stopped when calf correctly latched to teat.
Milk preparation	MFS: ensuring correct water temperature, adding milk powder, whisking to remove lumps. AFS: Emptying bag of milk replacer into the hopper.	SW started when water first entered bucket. SW stopped when milk allocation for the whole pen was fully prepared (milk powder mixed with water).	SW started when bag was opened. Hopper cover was removed. Bag was emptied into the hopper. SW stopped when the hopper cover was replaced.
Feeding/Feeding inspection	All treatments: Monitoring consumption of milk allocation.	SW started when the first bucket of milk was poured into the manual feeders. Calves observed until all milk was consumed. SW stopped when the last calf finished drinking.	SW started when hand-held automatic feeding monitor attached to feeder was inspected for calf drinking history. SW stopped when all calves' information had been checked.
Cleaning pen/equipment	All treatments: Cleaning of concrete, feeding units and area	SW started when entered pen. Water and detergent used to clean surfaces. SW stopped when pen and each compartmentalised calf feeder was clean	SW started when entered pen. Water and detergent used to clean surfaces. SW stopped when pen and respective feeding unit within the pen were clean.

Health

Individual animal health scores were assigned to calves on a twice-weekly basis. This was carried out independently of the routine daily health inspections, which were completed as part of the labour evaluation. For this reason, the labour associated with health scoring twice-weekly was not recorded. The calf health scoring criteria was developed using a modified scoring system (Supplementary File 1) developed from the Calf Welfare Assessment Protocol published by Barry et al. (2019b). Health factors used from the protocol included the following: overall demeanour, nasal discharge, ocular discharge, ear position, attitude, coughing, faecal hygiene, dehydration, and mobility. An additional factor was included to account for hind quarter cleanliness from faecal matter. Calves were assigned a score on the aforementioned traits from zero to three; zero representing normal and three representing the most severely affected. This meant that numerous health scores were recorded for each health factor related to a calf throughout the study period.

Behaviour

Behavioural observations were undertaken weekly during the pre-weaning period. Prior to data collection, specific behavioural patterns were defined, referring to the calf ethogram reported by Barry et al. (2019b). Individual calf behavioural measurements were taken by a single observer using a scan sampling method for each group once every one minute, for a duration of 15 minutes, five times per day (10:30, 11:30, 12:30, 14:30, 16:30). A five minute adjustment period before observations commenced was adhered to, thereby ensuring calves were accustomed to the observer’s presence. The observer stayed in one position outside of the pen to ensure minimal interference with expressed behaviour. Behaviours related to the ethogram are defined in Table 2.

Table 2. Ethogram adapted from Barry et al (2019a), which categorises and defines various behaviours, used for behavioural observations.

Category of behaviour	Behaviour	Definition
Posture	Standing	Calf is in a static upright standing position with weight placed on all four legs
	Lying	Calf is resting either sternally or laterally with all four legs hunched close to body either awake or asleep.
General	Walking	Calf is actively moving from one point in the pen to another in an active walking motion
	Not visible	Behaviour of the calf is not visible
	Defecating/ Urinating	Calf defecates or urinates
Feeding behaviour	Drinking water	Calf is drinking water
	Eating	Calf eats concentrates or roughage, or other solid feed (proximity of head to feed)
Comfort behaviour	Scratching/ Rubbing/ Stretching	Calf scratches itself with one of their legs (generally hind legs). Calf rubs itself on pen structure Calf stretches itself
Abnormal behaviour	Tongue playing/ rolling	Calf makes repeated movements with its tongue inside or outside its mouth
	Urine drinking / oral manipulate prepuce / cross sucking	Calf drinks the urine of another calf Calf attempts to suck the naval area of another calf. Calf attempts to suck any body part of another calf.
	Orally manipulating pen structure	Calf licks, nibbles, sucks, or bites at the pen structure (barriers, walls, buckets, troughs etc.)

Table 2 continued. Ethogram adapted from Barry et al (2019a), which categorises and defines various behaviours, used for behavioural observations.

Category of behaviour	Behaviour	Definition
Play behaviour	Play behaviour	Calf runs, jumps, changes direction suddenly, bucks, kicks hind legs, twists or rotates body.
	Mounting	Calf mounts, or attempts to mount, a pen mate.
	Head butting	Calf is engaged in head to head pushing with another calf.
Social behaviour	Social interaction	Calf licks another calf in the same area multiple times
		Calf nudges another calf with its nose

Body Weight

Body weight (BW) was measured at birth, weekly until weaning and fortnightly post-weaning (weighing scales described above) until six-months of age.

Data editing

Labour, behaviour and health data were divided into two periods; period one (P1) which was early pre-weaning from week one to seven and period two (P2) which was late pre-weaning from week eight until weaning. This was completed to reflect differences which were observed and associated with calf age during the experimental period. Weight data was not divided into two periods, as it was reported based on age (days). However, the following ages relate to each period; Period 1 = 0-42 days; Period 2 = 43-81 days (based on averages).

Preliminary analysis of labour data showed skewed data from week 13 to 15. Upon investigation it was realised that the labour input was divided among a fewer number of animals towards the end of the study which was incorrectly increasing the time associated with various tasks (week 13 between 39% and 85% of calves weaned depending on replicate and treatment). Furthermore, by only reporting data from week three of the experiment onwards, when all calves were assigned to treatment, a critical period of labour input would have been overlooked, whereby training time would not have been included. Consequently, when analysing labour data, the threshold for inclusion of data points was when 70% of calves were taken off treatment (due to weaning). The resulting labour dataset included measurements that were taken from week one to week 12. Training time to teach the calves to drink from their respective feeding system was recorded on a per calf basis, due to calves being assigned to treatment on an individual basis, based on date of birth, over a period of two weeks. Training time is also omitted from the figure for total labour input, due to its infrequent occurrence at the beginning of the trial period.

Relating to behavioural data, in order to get an accurate representation of the group behaviour, it was important that each treatment group was at full capacity (15 calves). For this reason, behavioural data was analysed from week three to week 11.

Body weight data were arranged based on a calf's age rather than by a calendar date. As all calves were not born on the same date and were weighed every Friday, differences in calf age arose. Average daily gain of each calf was calculated based on the difference between weighing dates and weight values on each respective date. For example, the difference in weight of a calf recorded at 21 days (± 3 days) and 28 days (± 3 days) is taken and divided by the number of days between weighing's, to get an ADG for that period. Average daily gain data was divided into pre and post weaning on a per calf basis. The pre- and post-weaning periods were each approximately 80 days in length. The number of days to achieve weaning weight was calculated by subtracting a calf's birth date from their weaning date.

To create binary data for analysis, health scoring categories were condensed individually, for each health factor, from four possible categories (0, 1, 2, 3) to two categories; category one are calves that scored zero and are of excellent health for a specific health factor, and category two are calves that score anything greater than zero, so have a health issue (mild or severe) related to a specific health factor.

Milk powder intake was calculated on a per calf basis, based on the number of days to achieve weaning weight (accounting for colostrum and transition milk consumption, and a reduction in milk powder consumption during weaning) multiplied by a calf's daily milk powder allocation. Seven days (accounting for three days of colostrum and transition feeding and a four-day weaning period) was subtracted from the number of days to achieve weaning, which resulted in the number of days calves received milk replacer. Calves received 900 g of milk replacer per day (reconstitution rate of 15%), which was multiplied by the number of days receiving milk replacer. To account for the milk replacer consumed over the four-day weaning period (9 L x 150 g) 1.35 kg was added to the resulting figure.

Statistical analysis

Statistical analyses were conducted using SAS software (Version 9.4, SAS Institute Inc., 2002). Linear mixed models (PROC MIXED) were used to determine whether treatment had an effect on the labour, growth (BW and ADG) and CDMI when rearing calves. Dependent variables used in this procedure followed a normal distribution pattern. Significant associations were confirmed at $P<0.05$; least square means assessed and interactions were examined between significant variables in each model. Treatment, breed and replicate were included as categorical variables and calf number and Economic Breeding Index (EBI; single figure profit index related to production, used to identify most profitable dairy herd replacements) as continuous variables. Fixed effects were considered as treatment, replicate, week of treatment (WOT) and period for procedures regarding labour and CDMI. Week of treatment was nested within period due to their close association. When analysing animal variables (i.e., BW and ADG) WOT and period were not included as fixed effects and instead replaced with birthweight, date of birth and breed. To account for the difference in age (days) between the calf's actual age and the mean age of the group on each respective weighing date, a covariate was included in the model. Time of measurement was the repeated measure used in the model.

The frequency procedure (PROC FREQ) was used to report the non-normal distribution of categorical variables related to health scoring including; demeanour, nasal discharge, ocular discharge, ear position, attitude, coughing, faecal consistency, dehydration, mobility and presence of faecal matter. Logistic regression (PROC LOGISTIC) was used to determine the associations between the independent variables; treatment, breed, replicate and period (each of which were dichotomous variables), on the dependent health scores (binary data). The AFS treatment was designated as the reference category (odds ratio (OR) = 1). The HF x JE breed, replicate one and period two were also designated as the reference categories. The frequency procedure (PROC FREQ) was used to establish the distribution of behavioural data. A multinomial logistic regression (PROC LOGISTIC) was used to determine the associations between treatment, replicate and period on the fifteen calf behaviours (non-binary data). The AFS treatment was designated as the reference category, alongside replicate two and period two. 'Standing' was the designated reference category for the dependent variable, behaviour. Oral manipulation and tongue rolling occurred too infrequently to be statistically analysed.

RESULTS

Labour

An interaction was found between treatment and period in terms of total labour input ($P < 0.01$). Total labour for AFS decreased from P1 to P2 (00:09:42 per pen/day ± 00:00:28 and 00:08:56 ± 00:00:25 per pen/day, respectively). Total labour for MFS also decreased from P1 to P2 (00:28:19 ± 00:00:27 per pen/day and 00:21:07 ± 00:00:25 per pen/day, respectively) Labour input for MFS was consistently greater (+00:15:12 per pen/day) than for AFS (Table 3). The labour demand per pen per day for feed preparation, feed inspection and cleaning was higher for the MFS compared to the AFS. However, the labour required for health inspection (+00:03:23 per pen/day) and training (+00:02:06 per calf/day during introduction to treatment), on a per calf basis, were significantly higher for AFS compared to MFS.

Table 3. Mean total labour input (± SEM) and labour input per calf per day (hh:mm:ss) regarding tasks associated with calf rearing for Automatic (AFS) and Manual (MFS) Feeding Systems.

(hh:mm:ss)	AFS	MFS	SEM	P-value	P1	P2	SEM	P-value
per pen/day								
Total time (excl. training)	00:09:33	00:24:46	00:00:21	0.001	00:19:04	00:15:02	00:00:22	0.001
Feed Preparation	00:02:13	00:04:57	00:00:07	0.001	00:03:35	00:03:31	00:00:07	0.674
Feed Inspection	00:01:16	00:15:40	00:00:19	0.001	00:10:13	00:06:28	00:00:19	0.001
Cleaning (incl. pen & equipment)	00:02:41	00:04:09	00:00:06	0.001	00:03:24	00:03:31	00:00:07	0.485
Health Inspection	00:03:23	00:00:00	00:00:04	0.001	00:01:52	00:01:33	00:00:05	0.003
per calf/day								
Total Time (excl. training)	00:00:45	00:01:50	00:00:02	0.001	00:01:17	00:01:17	00:00:03	0.879
Feed Preparation	00:00:11	00:00:22	00:00:01	0.001	00:00:15	00:00:18	00:00:01	0.005
Feed Inspection	00:00:05	00:01:10	00:00:01	0.001	00:00:42	00:00:32	00:00:02	0.001
Cleaning (incl. pen & equipment)	00:00:13	00:00:19	00:00:01	0.001	00:00:14	00:00:19	00:00:08	0.001
Health Inspection	00:00:15	00:00:00	00:00:01	0.001	00:00:07	00:00:08	00:00:01	0.361
Training	00:02:14	00:00:08	00:00:24	0.001	00:01:11	NA	00:00:21	NA

Health

Table 4 shows the distribution frequencies for each of the health scores recorded throughout the study period. For all health scores, regardless of treatment, the majority of calves were scored as 0, i.e., healthy. More calves were categorized as having poor faecal cleanliness than any other health score. Compared to calves in the AFS, calves were more likely to be allocated a faecal score greater than zero in the MFS group (OR = 2.009; CI = 1.463 – 2.759).

Looking at the frequency distribution of health scores, the number of health scores greater than zero reduced in occurrence in P2, compared to P1, with the exception of eyes, cough and interest, which increased during P2 (+1 %, +1.7 % and +0.1 %, respectively).

There were three incidences of illness over the course of the experiment which required medical treatment, one incidence of septicaemia (unrelated to experimental treatment) was found in the MFS while there were two incidences of digestive bloat, one in each of the two treatments.

Table 4. Distribution frequencies (%) of health scores for automatic (AFS) and manual (MFS) feeding systems and early pre-weaning (P1) and late pre-weaning (P2).

	Health Score per Feeding System (%)				Health Score per Period (%)			
	AFS		MFS		P1		P2	
	0	(≥1)	0	(≥1)	0	(≥1)	0	(≥1)
Health Factor								
Demeanour	99.8	0.2	100	0.0	99.9	0.1	100	0.0
Ears	99.5	0.5	99.3	0.7	99.9	0.1	98.9	1.1
Eyes	96.8	3.2	97.5	2.5	95.1	4.9	100	0.0
Nasal	99.0	1.0	98.6	1.4	98.6	1.4	99.1	0.9
Cough	99.0	1.0	98.7	1.3	99.6	0.4	97.9	2.1
Dehydration	100	0.0	100	0.0	100	0.0	100	0.0
Mobility	99.8	0.2	100	0.0	99.9	0.1	100	0.0
Interest	99.8	0.2	100	0.0	99.9	0.1	99.8	0.2
Faecal Hygiene	92.6	7.4	86.4	13.6	85.7	14.3	94.6	5.4

Behaviour

Calves in the MFS had an increased likelihood of defecating and urinating, eating and having (or engaging in) social interactions (Table 5). Calves in the AFS had an increased likelihood of walking. Calves were more likely to lie than stand in P1, compared to P2 (OR= 1.387; CI= 1.301–1.480). Oral manipulation (cross-suckling/urine drinking or manipulation of prepuce) and tongue rolling occurred too infrequently to be statistically analysed. There were nine incidences of oral manipulation (two MFS, seven AFS). This behaviour ceased after week three of treatment. There were three reports of tongue rolling recorded between week six and eight (one MFS, two AFS).

Calf weight

There was no interaction between feeding system and breed. Weaning weight was similar between feeding systems (92.9 kg) and no differences between breeds were observed (92.9 kg). There was no effect of feeding system on the number of days taken to achieve target weaning weight (80.7 days).

There was no effect of treatment on BW at 14 (39.0 kg ± 1.03 kg), 63 (74.3 ± 1.05 kg), 118 (116.0 kg ± 1.05 kg) or 160 (147.5 kg ± 1.05 kg) days of age. There were no significant differences in ADG between treatments (P = 0.277).

Table 5. Likelihoods of automatic (AFS) and manual (MFS) feeding systems exhibiting various behaviours (reference treatment and behaviour are AFS and standing).

Behaviour	Odds Ratio	Confidence Interval		P-Value
Lying	1.055	0.991	1.123	0.162
Walking	0.795	0.683	0.925	0.012
Defecating/ Urinating	1.450	1.080	1.945	0.037
Drinking Water	1.185	0.867	1.620	0.372
Eating	1.281	1.140	1.439	0.005
Scratching/Rubbing/Stretching	0.903	0.760	1.072	0.327
Manipulating Pen	0.935	0.758	1.154	0.599
Playing	0.940	0.769	1.150	0.615
Social Interaction	1.300	1.111	1.521	0.006

Dry matter intake

Milk powder intake per calf was approximately 67.7 kg over the course of the study period. The concentrate dry matter intake (CDMI) per calf/ day was significantly higher for MFS-calves than AFS-calves over the course of the study (1.09 and 0.87 ± 0.070 kg/calf/day, respectively; P<0.05). The CDMI per calf per day increased from P1 to P2 (0.37 kg/calf/day and 1.60 ± 0.072 kg/calf/day, respectively; P < 0.01).

DISCUSSION

Labour

In this study we compared the effects of automatic and manual feeding systems on group-housed calf health, behaviour, growth rates and labour. For the duration of the experiment, the total labour input per pen per day was consistently higher for MFS than AFS; this was mainly attributable to time required for feed inspection (feeding tasks were also found to be laborious in a study by Bostad et al. (2010)). Feed inspection for the AFS was the time spent checking the automatic feeding monitor attached to the feeder for the drinking history of each calf within the pen. For MFS, feed inspection was the time spent pouring milk into the compartmentalised feeders and observing all calves until the last calf in the group finished drinking. The measurement in the present study was done in an experimental setting. On a commercial farm, this figure for feeding inspection is not expected to be as high (demonstrated by Gleeson et al, 2008), because it is likely that farmers would distribute milk to calves and move on to another task, while calves are consuming milk. Although time that is saved by the farmer in doing this may be spent in a positive way towards carrying out other tasks related to calf care, such as cleaning equipment, farmers cannot be sure that each calf has received its full allocation of milk. It is important to note there was an opportunity to overlap tasks with the MFS. Health inspections could be carried out for the MFS in tandem with feeding time (Medrano-Galarza et al (2017a) found this a popular advantage among farmers manually feeding individually housed calves). In order to achieve the same level of health inspection for AFS, it would be necessary to enter the pen at a separate time point during the day, which is advised in association with the inspection of feeding behaviour on the computerised system (Johnston et al., 2016). On a number of occasions, measurements were recorded to evaluate the time required to inspect feeding and leaving when sufficient health inspection had occurred for the MFS. This data indicates that if this practice is used, a labour reduction of approximately 88% could be achieved in time spent inspecting feeding in this study.

Cleaning is another task associated with calf rearing that contributed to the total labour input per pen. The proportion of time spent cleaning was higher for MFS than AFS, because it was necessary to clean the pen as well as each of the compartmentalised feeders used in the MFS. In pens with AFS, only pen cleaning is required because cleaning of the feeding equipment (i.e., teat) is done automatically. Cleaning is an essential management practice that influences calf health (Barry et al., 2019a). It is necessary as it aids in the control of pathogen levels on equipment used for rearing calves (Bazeley, 2003).

Training time was higher for AFS than MFS. There is no clear explanation for this difference in time. However, in the period before being moved into their treatment pen, all calves were fed manually with an individual bucket and teat, which could have meant calves associated humans with the positive reward of milk (Krohn et al, 2001). When calves were moved to their respective treatments, this principle remained the same for MFS at feeding time, whereas with the AFS calves the human factor was reduced significantly. Furthermore, the difference could be related to a time lag which occurred with the AFS between the feeding unit and the transfer of milk to the teat. When a calf in an AFS pen enters the feeding unit, it is identified through its RFID tag. The system then begins mixing the milk allocation for the calf. Once mixed, milk is then transferred through pipes to the feeding station (Hnatiuc & Caracostea, 2017). The difference may also be a result of the ability of calves to learn from each other socially. Social learning has been shown to benefit calves, whereby they learn from one another regarding how to act (Fukasawa et al, 1999). The AFS is an individual feeding system, so as a result, calves may not stimulate or learn from one another as quickly, perhaps, as the MFS calves, who have the ability to carry out feeding in groups.

Although a calf's milk intake was controlled in this study, it is important to note that, if desired, automatic feeders allow farmers to increase the amount of milk given to calves without adversely increasing the labour required (with the exception of increased labour associated with a higher frequency of re-filling the automatic feeder with milk powder).

Calf Health

It was seen from this study that there was a low rate of illness for both treatments. This outcome was potentially reflective of the hygiene management practices used on the farm, whereby emphasis was placed on maintaining high levels of sanitation for feeding equipment and housing (a practice recommended by McGuirk, 2004).

Although, calves in the MFS were more likely to have faecal matter on their hindquarters, it is unclear why this occurred. It is believed that hindquarter cleanliness in this study is a result of loose faecal material, rather than pathogenic diarrhoea, which has been highlighted as an important distinction to make (Jorgensen et al, 2017). As calves in the MFS had a greater CDMI, it suggests that a higher quantity of food matter may be moving through the digestive tract of the calf. This in turn may have caused these calves to either defecate and urinate more frequently, which behavioural data has shown in this study, or have higher levels of faeces and urine to expel from their bodies, compared to their counterparts.

Increased faecal matter on a calf's hindquarters occurred more frequently in the early pre-weaning period. This finding has not been associated with pathogenic infection, which may indicate that this could be due to the ruminal development of a calf. Solid feed intake is a key component in the transition from a pre-ruminant animal to a functioning ruminant (Coverdale et al, 2004). Forage and concentrate consumption is required in a calf's diet for many things including muscular and papillae development in the rumen (Coverdale et al, 2004). The transition process of developing a rumen begins at four weeks and can take up to week 12 to develop fully (Teagasc, 2017). Therefore, although calves in this study had the opportunity to consume forage and concentrates from a young age, their digestive system may not have been developed enough to digest these feedstuffs effectively. This could then have resulted in calves having looser faecal matter in the early pre-weaning period, leading to a hindquarter with a higher level of faecal matter on it. However, this did not result in a greater incidence of pathogenic diarrhoea.

Weight Gain

Research has shown that the speed by which milk moves through the digestive tract is stimulated by the frequency of consumption, whereby emptying occurs quicker in the abomasum allowing for entrance of new matter (Mylrea, 1966). Although large volumes of milk have been fed to calves with reasonable efficacy (e.g., once-a-day feeding (Saldana et al. 2019)), it is also suggested that the greater the volume of milk offered at each feeding, the longer milk will remain in the abomasum (Burgstaller et al, 2017) and prolonged abomasal emptying may increase rates of digestive disorders (Songer and Miskimins, 2005). For this reason, it was expected that AFS would utilise milk more efficiently due to the smaller portions being consumed more often. This could reduce the risk of milk in the rumen and stimulate the movement of milk through the digestive system more quickly, resulting in a higher ADG. However, results from this study show that ADG and the number of days taken to achieve target weaning weight were the same for both treatments. The aforementioned findings could support Mylrea's research (1966) because, although MFS calves had a greater concentrate DMI compared to AFS calves, it was not reflected in the ADG of calves in that treatment. This may be explained by a study which found that large infrequent volumes of milk feeds can have negative effects on calf metabolism and insulin sensitivity (Bach et al, 2013). However, it is important to also consider a study by MacPherson et al (2016) which found that insulin sensitivity was not negatively affected by two large feeds of milk replacer per day (4 L/feed; 15% reconstitution rate).

Behaviour

Behavioural observations are reported on a group level in this study. Although social structure is typically accounted for in behavioural analysis, it is believed that in this circumstance, the treatment has a larger effect compared to calf effect. Treatment differences are large in relation to feeding behaviour. Feeding is at a common time in MFS, leading to synchronised feeding behaviour, whereas calves assigned to the AFS system could choose their own individual feeding time. The stocking rate of the AFS was 50% less than the manufacturer's recommendation (Volac Förster Technik Vario, Germany), resulting in a lower demand for the feeding station. It is possible that other behaviours may be affected by these differences in feeding practices. Furthermore, solid dividers were used between treatment pens ensuring behaviour was not influenced by visual stimulation.

The expression of normal behaviour, such as the time spent lying, recorded in this experiment corresponds with behavioural profiles of calves in previous studies, which found calves had increased frequency of lying in early life (Neja, 2013; Calvo-Lorenzo et al, 2016). Normal behaviour is believed to be actions that allow a calf to satisfy its maintenance needs (Webster et al, 1985). Both feeding systems were offered the same plane of nutrition in terms of milk allowance (6 L/day; approx. 15% of birth BW), concentrates and forage, which was deemed a sufficient amount to satisfy a calf's needs in a previous review (Lorenz et al., 2011). This sufficiency may be reflected by the normal behavioural profile exhibited in this study. Furthermore, the occurrence of abnormal behaviours, such as tongue rolling and oral manipulation, are almost absent in both treatments. The absence of these behaviours suggests that calves in this study had the ability to cope well in their respective environment (Broom, 1991).

As expected, there was a reduction in lying behaviour between P1 and P2 (a reduction found over time also by Neja (2013)). This reduction may be a result of a decrease in the need for low energy expenditure as a calf's digestive system develops to consume solid feed, as well as the desire for fulfilment of other behavioural needs such as play and social interaction (Calvo-Lorenzo et al., 2016; Jensen & Khyn, 2000; Tapki et al, 2006).

Suckling is an important behaviour for calves to express (Margerison et al., 2003), however MFS calves had restricted opportunity to perform this behaviour. Research has shown that calves compensate for lack of suckling by either developing abnormal behaviours or consuming other feedstuff such as concentrates and forage (Margerison et al., 2003; Borderas et al., 2009a). The latter was seen in our study whereby, eating behaviours, including concentrate and forage intakes, were seen more often in MFS-calves than AFS-calves. Furthermore, calves in the MFS also had higher CDMI than their AFS counterparts. This could be due to calves in the MFS experiencing longer intervals between feeds, which may have encouraged them to consume grain between feeds. Research carried out on automatic feeders has shown that when milk intake is controlled, it can result in an increased frequency of unrewarded visits to the feeder (Vieria et al, 2008). However, taking into consideration that calves in the MFS do not have an opportunity to carry out un-rewarded suckling, it is possible that this behaviour was instead re-directed towards other feed related behaviours such as consuming concentrates.

The AFS-calves were more likely to walk than their manual counterparts, this may be due to the feeding system itself. It has been established that calves in each treatment were most likely to be lying compared to standing in this study. Irrespective of treatment, milk was offered at the front of the pen, meaning that a short walk was required to reach the feeders. Once MFS-calves were fed, feeders were removed from the pen, consequently there may have been a reduced incentive for calves to walk from the lying area to the front feeding area. In comparison, the AFS-calves had the opportunity to access the automatic feeder for both rewarded and unrewarded visits at multiple points throughout the day. This, in turn, may have translated into an increase in walking behaviours in the AFS-calves. Alternatively, a study that looked into calf behaviour around restricted and *ad libitum* feeding using an automatic feeder, found that calves with restricted milk allowance (approx. 4 L) had increased levels of unrewarded visits to the feeder, which could be linked to hunger and calf satiety (Vieira et al, 2008). Calves in the AFS were fed smaller volumes of milk more frequently compared to MFS-calves, which may have resulted in calves experiencing hunger more often than their manual counterparts. The AFS-calves may have expressed lower levels of satiety by walking towards the feeder to carry out non-rewarded suckling of the teat. Urinating and defecating were higher for the MFS than AFS. It is possible that this correlated with the poorer faecal hygiene scores of the hindquarters found in MFS calves.

CONCLUSION

Our results showed that calves assigned to both the AFS and MFS exhibited good health and normal behavioural patterns as well as similar growth rates. Automatic feeding systems were consistently more labour efficient than manual feeding systems, despite having higher labour requirements for training and health inspections. Thus when managed appropriately, the saving of labour and facilitation of nature-like feeding behaviours are distinct advantages automated feeding systems have over their manual counterparts when rearing group-housed calves.

ACKNOWLEDGEMENTS

The authors would like to thank Prof. Imke J.M. de Boer for comments on the initial manuscript. The authors would like to acknowledge support given by the Teagasc, Walsh Scholar funding scheme. We also thank the farm staff at Teagasc, Moorepark for their care of the animals and assistance during the study.

SUPPLEMENTARY FILES

Supplementary File 1. Definition of and scoring levels used in the health scoring system adapted from Teagasc (Sayers et al., 2016) and Barry et al (2019a) to assess dairy calf health within the experiment.

Indicator	Definition	Scoring	Score Levels
Demeanour	Combined evaluation of behaviour and responsiveness	4-point scale of 0 to 3	0 = Bright, alert, responsive 1 = Dull, possibly depressed, less responsive 2 = Dull, markedly depressed, markedly unresponsive 3=Unresponsive to any stimulus
Nasal Discharge	Presence of any mucous discharge from the nasal passage	4-point scale of 0 to 3	0 = clear, discharge free 1 = Small amount of cloudy mucous visible 2 = medium amount of bilateral muscous discharge 3 = excessive bilateral mucous discharge
Ocular Discharge	Position, appearance and presence of ocular discharge	4-point scale of 0 to 3	0 = Bright, pronounced 1 = Slightly dull, presence of discharge 2 = Slightly dull, small amount of visible discharge 3 = Dull, sunken, excessive amount of visible discharge
Ear Position	Positioning and activity of ears	4-point scale of 0 to 3	0 = Alert and mobile 1 = Slightly drooped 2 = Drooped 3 = Drooped and limp
Cough	Presence of a cough, increased respiratory rate	4-point scale of 0 to 3	0 = Normal Breathing 1 = Spontaneous coughing 2 = Intermittent coughing 3 = Continuous cough, increased respiration

Supplementary File 1 continued. Definition of and scoring levels used in the health scoring system adapted from Teagasc (Sayers et al., 2016) and Barry et al (2019a) to assess dairy calf health within the experiment.

Indicator	Definition	Scoring	Score Levels
Hydration	Appearance of calf eyes in relation to hydration levels	4-point scale of 0 to 3	0 = Clear bright eyes 1 = Eyes slightly sunken 2 = Eyes sunken 3 = Eyes markedly sunken
Mobility	Ability to stand unassisted and move freely	4-point scale of 0 to 3	0 = Stands unassisted, actively mobile 1 = Slow to stand, limited mobility 2 = struggles to stand, limited mobility 3 = Assistance required to stand, no mobility
Interest in Surroundings	Willingness to interact with observer	2-point scale of 0 to 1	0 = Interactive when approached 1 = Uninterested when approached
Faecal Hygiene	Cleanliness of calf tail area and hindquarters	4-point scale of 0 to 3	0 = completely clean hind quarters with no faecal matter 1 = slight faecal matter around hind quarters 2 = heavier faecal matter around hind quarter 3 = extremely dirty hind quarters and tail


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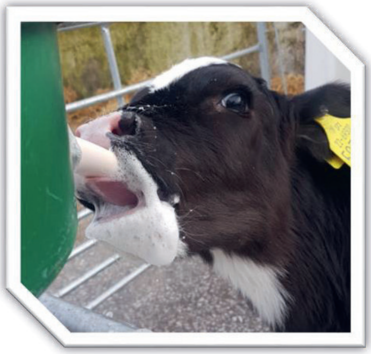

Chapter 4

A comparison of indoor and outdoor calf housing systems using automated and manual feeding methods and their effect on calf health, behaviour, growth and labour

Alison M. Sinnott[ab], Eddie A.M. Bokkers[b], John Paul Murphy[a] and Emer Kennedy[a]

[a]*Teagasc, Animal and Grassland Research and Innovation Centre, Moorepark, Fermoy, Co. Cork, Ireland*

[b]*Animal Production Systems group, Wageningen University & Research, P.O. Box 338, 6700 AH Wageningen, the Netherlands*

Journal of animal science, 100(4): skac079

ABSTRACT

Housing and feeding are integral to calf rearing, and must meet calf needs while remaining functional for the farmer. This study compared health, behaviour, growth and labour requirements of calves housed in groups indoors and fed via an automatic or manual milk feeding system compared to calves manually fed in individual or group hutches outdoors. Seventy-six (49 Holstein-Friesian (HF) and 27 HF x Jersey (JE) dairy heifer calves were balanced for birth weight (35.2 ± 4.95 kg), birth date (1 February ± 7.2 days) and breed. The experiment was a randomised block design with four treatments; i) indoor group housing with automated feeding (IN_AUTO; 12 calves/pen), ii) indoor group housing with manual feeding (IN_MAN; 12 calves/pen), iii) outdoor group hutch with manual feeding (OUT_G_MAN; 8 calves/pen) and iv) outdoor individual hutch with manual feeding (OUT_I_MAN; 6 calves: 1 per pen). Calves in OUT_ treatments moved outdoors at 18 days (± 5.9 days). Each treatment was replicated once. Milk allowance increased gradually from 6 L/day to 8 L/day (15% reconstitution rate) with *ad libitum* fresh water, concentrates and hay offered from three days old. Gradual weaning occurred at eight weeks old. Measurements were divided into period one; before movement outdoors, and period two; after movement outdoors. Health was similar among treatments, regardless of period, with the most frequent score being zero (i.e., healthy). Summarised, standing and lying was observed 24.3% and 29.8%, respectively, in OUT_I_MAN calves, compared to 8.0% and 49.1%, for the other systems, which were similar. No difference in body weight (BW) existed between treatments, except at weaning where BW was lower for OUT_I_MAN (67.4 ± 2.84 kg) compared to IN_MAN (74.2 ± 2.01 kg), and day 102 where OUT_I_MAN (94.1 ± 2.85 kg) were lighter than IN_AUTO (101.1 ± 2.10 kg) ($P=0.047$). Total labour input was greatest for OUT_I_MAN (00:02:02 per calf/day; hh:mm:ss) and least for IN_AUTO (00:00:21 per calf/day) ($P<0.001$). The labour for feeding (00:00:29 per calf/day), feeding inspection (00:00:10 per calf/day) and cleaning equipment (00:00:30 per calf/day) was greatest for OUT_I_MAN. All calves showed good health and growth patterns. Differences in behaviour expressed by calves in the OUT_I_MAN, compared to other treatments, may indicate compromised welfare. Thus, although outdoor group hutches do not negatively impact calves, indoor housing, particularly using automated feeders, can improve labour efficiency.

INTRODUCTION

Quotas previously placed on European milk production were abolished in 2015 and caused a change in dynamic of the dairy sector within the member states. Herd sizes decreased in some countries (e.g., Greece) while in others, such as Ireland and Germany, it increased (Eurostat, 2018a; ICBF, 2019). Extra facilities and housing for expanding dairy herds have been built, but calves are frequently housed in converted, existing farm facilities (AHI, 2021b), suggesting investment in housing specifically built for the purpose of calf rearing has not been prioritised.

Although there are numerous ways calves are housed, the most common types of calf accommodation include outdoor individual and paired hutches, as well as indoor individual and group housing. In Ireland, indoor group housing is the predominant type of calf accommodation (Marcé et al., 2010), with farms often using individual pens indoors after birth, grouping at seven days old (Teagasc, 2017). In addition, compact calving targeting a six week calving rate, due to its association with reproductive efficiency, is applied in Ireland (Shalloo et al., 2014). This further increases requirements for calf accommodation, particularly around peak calving, due to a large number of calves being born in a short time-frame. In contrast, year-round calving systems use calf houses throughout the year and require less accommodation. Outdoor housing structures, such as heavy gauge plastic calf hutches, may offer a potential alternative to permanent indoor facilities (Marcé et al., 2010), particularly when required for relatively short periods of time in seasonal calving systems. However, the impact of outdoor hutches on both calf and farmer in such a system requires examination, in terms of calf health, behaviour, growth and labour efficiency.

Housing environment and management practices have an influence on calf welfare. Calf housing should facilitate a comfortable environment, minimise the requirement for veterinary assistance and labour, and contribute to a low morbidity and mortality (Lorenz et al., 2011c). Rearing calves outdoors, compared to indoor environments, is acknowledged as advantageous in terms of calf health (Lorenz et al., 2011c; Wójcik et al., 2013), weight gain and solid-feed intakes (Wójcik et al., 2013). However, Jorgenson et al. (1970) and Kung et al. (1997) found no difference between indoor and outdoor pre-weaning growth rates. Whether outdoors or indoors, individual housing has also been linked to improved calf health (Marcé et al., 2010), but may lead to abnormal oral behaviours such as tongue rolling (Lv et al. 2021) and excessive oral manipulation of objects and body parts (Bokkers and Koene, 2001). Conversely, paired and group housing encourages social development, particularly in developing feeding behaviours such as learning to select and eat appropriate foods (Costa et al., 2016; Mahendran et al., 2021), leading to less fearful calves than those individually reared (Costa et al., 2016), particularly in relation to novel foods (Whalin et al., 2018). However, it can also result in behavioural issues such as cross sucking of other calves (Jensen, 2003). Furthermore, previous research has reported increased competition surrounding access to milk with group-rearing calves (Miller-Cushon et al., 2014). Individual housing eliminates this, which may further improve calf growth. It should be recognised that differences in feeding and management practices exist between different studies when considering findings related to calf housing, health, behaviour and growth.

Previous research found no differences in labour between indoor and outdoor individual pens fed manually (assumption of feeding system based on the time period of study (1970); four days post-calving until weaning at three, five and seven weeks; Jorgenson et al., 1970). The most recent research into the labour associated with hutches, found indoor individual hutches, feeding calves manually twice-a-day, were more labour intensive than grouping calves indoors with computerised feeders (from four days post-calving until weaning at seven weeks; Kung et al. 1997). They suggest that grouping is more labour efficient than individually rearing calves. This may be due to feeding method rather than housing system. This is confirmed by Sinnott et al. (2021) who showed large differences exist in the labour associated with manual feeding twice-a-day and automatic feeding systems for indoor group-reared calves, indicating labour efficiencies may be closely related to feeding systems, rather than housing system.

Housing and feeding are integral to successful calf rearing operations and must remain functional for the farmer, while meeting the calf's needs. The overall aim of this study was to compare health, behaviour, growth and labour requirements of calves housed in groups indoors and fed via an automatic or manual milk feeding system compared to calves manually fed milk in individual or group hutches outdoors. The primary outcome was to investigate how housing and feeding system influence calf weight gain, and the secondary outcomes included the effects of these systems on calf health, behaviour and labour. The study hypothesis was that calf health, behaviour, growth and labour is affected by the housing and feeding system they are reared in: calves in outdoor systems would have improved health with behavioural profiles displaying increased abnormal behaviours when housed in individual hutches, whereas indoor systems would be more labour efficient (particularly those using automated feeders).

MATERIALS AND METHODS

Experiments were undertaken, and animals cared for, in accordance with the European Union (Protection of Animals Used for Scientific Purposes) Regulations 2012 (S.I. No. 543 of 2012). Ethical approval to undertake the study was approved by the Teagasc Animal Ethics Committee. The study was conducted from January 29 to April 13, 2020 at Teagasc Moorepark Research Farm, County Cork, Ireland.

Animals and experimental treatments

The study population consisted of 76 dairy heifer calves: 49 Holstein Friesian (HF) and 27 HF x Jersey (JE). Calves were balanced and blocked into eight groups (two groups per treatment) based on birth-weight (35.2 ± 4.95 kg), birth date (1 February ± 7.2 days) and breed. There was no more than a 14-day difference in date of birth between calves within each group. The experiment was a randomised block design with four treatments: i) indoor group housing with automated feeding (IN_AUTO; 12 calves per pen), ii) indoor group housing with manual feeding (IN_MAN; 12 calves per pen), iii) outdoor group hutch with manual feeding (OUT_G_MAN; 8 calves per pen) and iv) outdoor individual hutch with manual feeding (OUT_I_MAN; 6 pens). Each treatment was replicated once. Calves were assigned to treatments within approximately three days post-calving. The experimental unit within this study was individual calf. All calves assigned to treatments in this study completed the study protocol and data collected were analysed for both primary (investigating how housing and feeding system influence calf weight at weaning), and the secondary outcomes (investigating the effects of these systems on calf health, behaviour and labour).

Calf management and housing

A schematic of calf flow through treatment housing can be seen in Figure 1. All calves were immediately removed from their dam following calving as a biosecurity measure. Within the first hour of life, calves were weighed (TruTest XR 3000, Tru-test limited, Auckland, New Zealand) and placed in individual pens indoors (1.22 m x 0.82 m) with an over-hanging infrared heat lamp. Calves received 8.5% of birth body weight (BW) of colostrum (Conneely et al., 2014) from a single cow (not specifically their own dam) via a teated bottle. Only colostrum of sufficient quality (measured ≥22% Brix; Bielmann et al., 2010) was fed to calves. Calves received five feeds of transition milk (3L per feed) after colostrum feeding, which was pooled from the second milking post-calving. Feeding occurred at 08:00 and 16:00 with calves receiving the first feed of transition milk at the next feeding time post-colostrum consumption, and twice per day thereafter until treatment allocation and movement into an indoor group pen.

All calves were moved to an indoor group pen at approximately three days old. Calves of the same replicate and treatment were grouped together. Calves assigned to the automated feeding system were fed via automatic feeder (Volac Förster Technik Vario, Germany) and calves assigned to manual feeding systems were fed manually with a compartmentalised teat feeder (Milkbar, New Zealand; regardless of whether they were to be grouped or individually housed at a later stage in the study).

After the first indoor period, at an average 18.4 (± 5.96 days) days old, calves in the OUT_G_MAN and OUT_I_MAN treatment groups were moved to their respective housing outdoors. This reflected a housing situation whereby older calves are moved outdoors due to restricted indoor housing availability, allowing younger calves to remain indoors. In this period, OUT_I_MAN moved from a group to an individual housing system. Treatment groups were located adjacent to one another both indoors (IN_AUTO and IN_MAN) and outdoors (OUT_G_MAN and OUT_I_MAN).

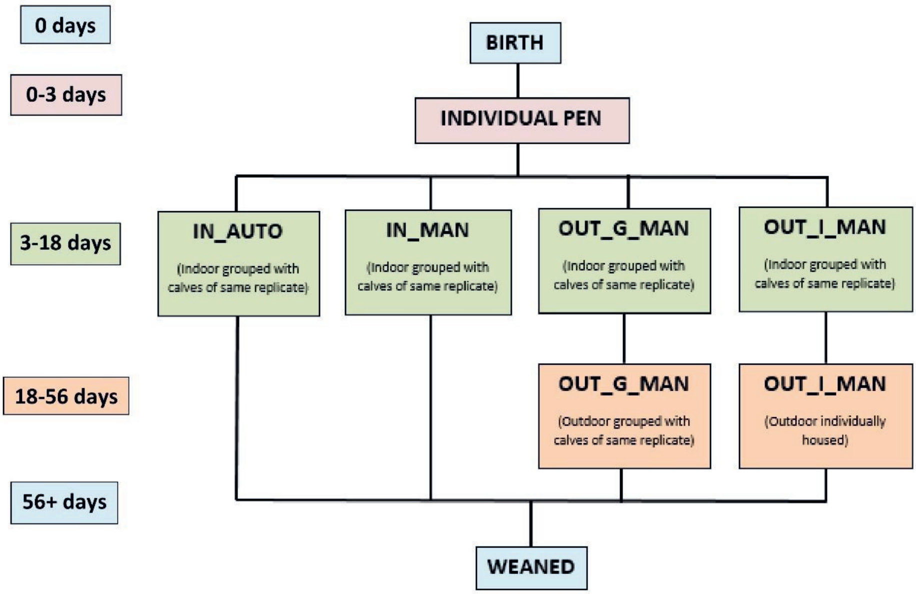

Figure 1. Schematic of calf flow through the study from birth (0 days) until weaning (56 days) for IN_AUTO (fed via automatic feeder from day 3-56), IN_MAN and OUT_G_MAN (both fed manually via compartmentalised multi-teat feeder from day 3-56) and OUT_I_MAN (fed manually via compartmentalised multi-teat feeder from day 3-18 and manually via individual feeder with teat from day 19-56).

Visual and auditory cues could be exchanged between all calves housed outdoors and between all calves housed indoors. No physical contact was possible between treatment groups, with the only exception being calves in the OUT_I_MAN, who could touch between pen structures as per EU (Council Directive 2008/119/EC) and Irish welfare regulations (Planning and Development Regulations, 2001, S124). The treatments housed indoors (i.e., IN_AUTO and IN_MAN) remained in the same group pen throughout the study. Calves in outdoor treatments (i.e., OUT_I_MAN and OUT_G_MAN) in replicate one were moved outdoors on week three of experiment and calves in replicate two were moved to their outdoor housing on week four of experiment.

Indoor housing

The IN_AUTO and IN_MAN treatments were located in a calf rearing shed. Group pens provided a space allowance of 2.9 m^2/calf, and had a concrete feeding area and a separate straw bedded area (1.8 m^2/calf; 15 cm straw depth). Bedding was fully removed weekly, the area disinfected and re-bedded with fresh straw. Straw was replenished mid-way through the week ensuring a clean, dry bed was consistently available. Solid dividers between pens prevented physical contact between groups.

Outdoor housing

Following a period of indoor housing (same housing parameters as IN_MAN and IN_AUTO described above), calves were moved to their respective outdoor hutches. Outdoor group and individual hutches were placed on a concrete surface and positioned north-facing, which protected the hutch entrance from the prevailing wind. Drainage channels collected and removed run-off, from bedding and feeding areas, to appropriate storage facilities. Group and individual hutches were straw bedded; straw was replenished three times weekly; bedding was not removed from the hutches during the experiment. The outdoor concrete feeding area was cleaned three times weekly.

Outdoor group hutches were constructed according to manufacturing guidelines (Super Hutch, JFC AGRI, Galway, Ireland) providing a space allowance (bedded and yard area) of 1.4 m^2/calf. Each pen contained an outdoor concrete feeding area enclosed by gates (JFC AGRI, Galway, Ireland), and a covered bedded area (moulded heavy gauge plastic; 0.9 m^2/calf). Outdoor individual hutches had a space allowance of 4.9 m^2/calf, including an outdoor concrete feeding area enclosed by gates (JFC AGRI, Galway, Ireland) and a covered bedded area (2.6 m^2/calf).

Calf feeding plan

All calves were offered 26% crude protein milk replacer (Volac Heiferlac; Volac, Church St, Portaliff Glebe, Killashandra, Co. Cavan; 26% crude protein, 16% crude oils and fats, 7% crude ash) reconstituted at 15%, using warm water which was fed immediately. From two weeks old, milk allocation was adjusted every 0.5 weeks, based on the age of the calf (Supplementary File 1). The total milk powder allowance for each calf (regardless of treatment) throughout the experiment was 46.4 kg. Calves remained on 6L/day until two weeks old. Daily milk allowance increased on an individual calf basis from 6 to 8L/day gradually, in 0.5L increments every 0.5 weeks. Once a calf was consuming 8L/day for one week (week four to five), milk allowance was reduced by 1L increments every 0.5 weeks until weaning at 8 weeks old (56 days).

Concentrates (20% crude protein; composed of barley, soya meal, sugar beet pulp, distillers grains, rape seed meal, maize; Sweet Start Calf Starter Pencils, Southern Milling, Cork, Ireland), water and hay were offered *ad libitum* from three days old.

Feeding system

Two feeding systems were used; automatic and manual feeding systems.

Automatic feeding system

For the IN_AUTO treatment, group pens were fitted with one automatic milk and concentrate feeding station (one automatic milk feeding unit supplied four feeding stations within separate group pens). The calf to teat ratio was 12 calves to one feeding station. According to individual calf feeding plans, the automatic feeder mixed and distributed milk. Each calf was allocated four feeds spaced evenly throughout the day (24 hr) from four days old; access to the feeder was granted until the allocation for that feed was fully consumed, after this calves waited for four hours until access was allowed for the next allocation. The automatic concentrate feeder provided individual *ad libitum* access, dispensing 200 g of concentrate as required to minimise wastage and increase distribution accuracy.

Manual calf feeding system

Manual calf feeding systems used for IN_MAN and OUT_G_MAN treatments consisted of plastic compartmentalised teat feeders. The OUT_I_MAN were fed using individual bucket teat feeders (2 Gallon Green Bucket, JFC AGRI, Galway, Ireland).

Feeders were not shared between treatments and the calf to teat ratio was one calf to one teat. Calves were offered milk twice-daily in two equal feeds (08:00 and 16:00). Concentrates were offered on an *ad libitum* basis from three days old with one open concentrate feeder (McInnes Manufacturing, New Zealand) per group.

Measurements

Body weight

Body weight was measured at birth, weekly thereafter until weaning and fortnightly post-weaning, using the weighing scale described above. Weighing ceased temporarily once calves were weaned, until calves were approximately 102 days old due to logistical complications resulting from Covid-19 regulations.

Health

Individual health scores were assigned twice-weekly from three days old to weaning (56 d old), in the late morning/afternoon (11:00-12:00). Measurements were carried out by a single experienced observer, with training previously validated via trainer inter-observer reliability. Calf health scoring criteria and methodology outlined by Sinnott et al. (2021) was used (Supplementary File 2). In short, each calf was assessed individually and awarded a health score (four point scale; zero = excellent, no issues; three = severe issues; modified Madison Wisconsin health scoring system), for health factors twice weekly including: demeanour, nasal discharge, ocular discharge, ear position, attitude, coughing, dehydration, mobility and hind quarter cleanliness (faecal cleanliness).

It is important to note that individual health inspections are independent of routine daily health checks carried out by the farmer (seen later as part of the labour evaluation). The labour associated with health scoring twice-weekly was not recorded because it was an in-depth and time consuming process conducted by a researcher, non-reflective of inspections taking place on commercial farms.

Behaviour

Behavioural observations were undertaken weekly during the pre-weaning period (from day three until week seven of replicate one and week six of replicate two, due to Covid-19 regulations). Observations were carried out by a single experienced observer, with training in calf behaviour recognition prior to commencement of this study. Prior to data collection, behavioural patterns were defined referring to the calf ethogram reported by Barry et al. (2019b) (Supplementary File 3). Behaviours included: standing, lying, walking, defecating/ urinating, drinking water, eating, scratching/ rubbing/ stretching, tongue playing/ rolling, urine drinking/ oral manipulate prepuce/ cross sucking, orally manipulating pen structure, play behaviour/mounting/head butting. Data was collected four times per day (10:30, 12:00, 14:30 and 16:30) using methodology outlined by Sinnott et al. (2021). In brief, measurements were taken of each calf, within each treatment, using scan sampling at one minute intervals for 15 minutes.

Labour

Labour evaluations were completed twice-weekly from approximately 18 days of age (i.e., from the moment calves in OUT_ treatments were moved out of the indoor pens), until week seven for animals in replicate one and week six for animals in replicate two (due to Covid-19 regulations) during the trial period. Individual tasks associated with calf rearing described by Sinnott et al. (2021) were assessed including: feed preparation, feeding, cleaning feeding equipment, cleaning pen and health checks. Measurements were repeated in the morning and evening and timed using a stopwatch (SW). The sum (total hh:mm:ss) of each labour task quantified per day was divided by the number of calves in the pen or hutch that day. Specific descriptions of labour cues for each respective task are included in Supplementary File 4. All figures related to labour are reported in the following format: hh:mm:ss.

Transportation was included to record the additional time required to move milk and feeding equipment from the calf rearing shed to the outdoor hutches via a Gator Utility Vehicle (John Deere, Illinois, USA). This time requirement included the moving, loading and unloading of milk and feeding equipment from the preparation area to the hutches, and the return of all equipment for cleaning. Feeding inspection was amended from the protocol by Sinnott et al. (2021) and redefined as the time required to confirm all manually-fed calves were drinking milk during feeding time, and the time required to inspect the hand-held device to ensure that all calves were consuming milk on the automatic feeding system. Feeding inspection and health checks were carried out simultaneously for manually-fed calves, while they were carried out at different times for automated-fed calves. Health checks consisted of an evaluation of each calf to ensure there were no obvious signs of illness, they had a good demeanour, could stand and walk, and that manually fed calves had an interest in consuming their milk allocation.

Temperature and relative humidity

Temperature and relative humidity were measured every 10 minutes during the study using data loggers (Tinytag TGP 4017 Temperature Data Logger; Gemini Data Loggers, West Sussex, United Kingdom). Loggers were positioned inside the lying area, out of calf reach (1.5 m from ground level). A weather station located <1 km from the experimental site recorded external weather conditions (Met Eireann, Fermoy, Cork, Ireland).

Data editing

Measurements were conducted on calves from three days old. This allowed the establishment of baseline measurements such as calf health, behaviour and growth. For this reason, data will be divided into two periods hereafter; period one refers to the time all calves were housed indoors in group pens (approx. 3 to 18 days old) and period two refers to the time after when two treatments (OUT_G_MAN and OUT_I_MAN) moved outdoors to their respective treatments while IN_AUTO and IN_MAN remain indoors, until weaning (approx. 18 days to 56 days old).

Due to complications resulting from Covid-19 pandemic restrictions, the labour and behaviours associated with replicate one are reported until week seven and week six for replicate two. It was also not possible to record weights from 60 days old to 102 days old (post-weaning period) for this reason. Regarding labour, pen cleaning for the

OUT_G_MAN and OUT_I_MAN treatments occurred too infrequently to be accurately included in statistical analysis. As outdoor hutches were previously perceived as labour intensive (Lundell, 2015), particularly for cleaning, it was important to include this task to compare treatments in an unbiased way. Consequently, pen cleaning figures are reported in-text as raw averages for OUT_G_MAN and OUT_I_MAN treatments, furthermore, figures for pen cleaning were omitted from the total labour input for all treatments in Table 1. As all calves in manual feeding systems were housed in similar conditions for period one, labour was not recorded for calves until located in their respective outdoor treatments. Due to incomparable calf numbers across treatment pens, figures referring to labour are on a per calf basis rather than per pen. Additionally, due to incomparable behaviours between replicates for week seven (due to Covid-19 complications), behavioural data is reported until week six across all treatments and replicates.

To analyse health scores binary data was created, individually for each health factor, whereby, four scores for each health factor (0, 1, 2, 3) were re-categorised into two categories; category one are calves that scored zero and category two are calves that scored anything above zero (i.e., indication of health issue). An additional summary parameter was included which divided time (weeks) into two categories; period one and period two. Environmental temperatures from TinyTag data loggers were included in the health data. Average figures were calculated for temperatures recorded between data collection days and divided into two categories; category one are temperatures which fall below the thermo-neutral zone (TNZ) based on age (i.e., lower critical temperature (LCT); ≤10 °C; Davis & Drackley, 1998) and category two, where temperatures fall within the TNZ of the calf (≥11 °C to 24 °C). Orthogonal contrasts were added to compare effects of temperature, period and location on calf health: LCT vs TNZ, period one vs period two and indoor vs outdoor. Contrasts, related to location, were carried out to evaluate the health of calves housed indoors and outdoors.

Table 1. Mean labour input per calf per day (± SEM; hh:mm:ss; mean across treatments) and mean labour input per pen per day (± SEM; hh:mm:ss) for tasks associated with rearing calves for Indoor Automatic (IN_AUTO), Indoor Manual (IN_MAN), Outdoor Group Manual (OUT_G_MAN) and Outdoor Individual Manual (OUT_I_MAN) Feeding Systems from day 18 until weaning at 56 days.

	Indoor		**Outdoor**			
(hh:mm:ss)	**IN_AUTO**	**IN_MAN**	**OUT_G_MAN**	**OUT_I_MAN**	**SEM**	**P-value**
per calf/day						
Total time	00:00:21[a]	00:00:55[b]	00:01:27[c]	00:02:02[d]	00:00:07	0.001
Feed Preparation	00:00:03[a]	00:00:25[c]	00:00:29[b]	00:00:29[b]	00:00:01	0.001
Transport	00:00:00[a]	00:00:00[a]	00:00:23[b]	00:00:24[b]	00:00:01	0.001
Feeding	00:00:00[a]	00:00:08[d]	00:00:06[b]	00:00:29[c]	00:00:01	0.001
Feeding Inspection	00:00:06[a]	00:00:06[a]	00:00:07[a]	00:00:10[b]	00:00:01	0.001
Clean Equipment	00:00:02[a]	00:00:16[b]	00:00:22[c]	00:00:30[d]	00:00:02	0.001
Health Inspection	00:00:11[a]	00:00:00[b]	00:00:00[b]	00:00:00[b]	00:00:01	0.001
per pen/day						
Total time	00:03:55[a]	00:10:40[bc]	00:09:53[c]	00:20:20[d]	00:00:28	0.001
Feed Preparation	00:00:33[a]	00:04:56[c]	00:03:22[b]	00:04:44[c]	00:00:13	0.001
Transport	00:00:00[a]	00:00:00[a]	00:02:33[c]	00:03:49[b]	00:00:04	0.001
Feeding	00:00:00[a]	00:01:32[d]	00:00:41[b]	00:05:05[c]	00:00:07	0.001
Feeding Inspection	00:01:06[a]	00:01:05[a]	00:00:47[b]	00:01:43[c]	00:00:07	0.002
Clean Equipment	00:00:25[a]	00:03:07[b]	00:02:30[b]	00:04:59[c]	00:00:18	0.001
Health Inspection	00:01:52[a]	00:00:00[b]	00:00:00[b]	00:00:00[b]	00:00:07	0.001

[abcd] different letters within row indicate statistical difference $p \leq 0.05$

Although treatment replicates were separate from one another (except OUT_I_MAN, whereby visual and tactile stimulation was possible), we acknowledge that an in-pen influence exists for calf behaviour. Consequently, all results pertaining to calf behaviour in period one and two are reported in a descriptive capacity. The 17 potential behavioural outcomes were condensed into nine categories (Table 2); standing, lying, rumination, feeding related behaviours, comforting, abnormal behaviours, play, tactile social interaction with another calf and other behaviours. All categories were mutually exclusive (e.g., postural behaviours such as standing and lying were superseded by other behaviours, such as rumination, when other behaviours were observed). Grouping allowed for the analysis of behaviours that occurred infrequently (such as behaviours in the abnormal and feeding categories), which may have otherwise went undocumented statistically. An average figure was calculated from temperatures recorded by the TinyTag data logger during the specific date and time that observations were made and divided into two categories (mentioned above) and included as a variable in the data set. Orthogonal contrasts were used to compare the effects of temperature, period and location on behaviour, including comparisons of the following: LCT vs TNZ, period one vs two and indoor vs outdoor.

Body weight data was organised according to calf age rather than calendar date. Calves were weighed on a fixed day every week. For accuracy, data was corrected, allowing for age comparisons among calves. The calf-specific average ADG on each weighing date was calculated based on the difference between weighing dates and weight values. Average daily gain was divided into pre- and post-weaning for each calf individually. The pre- and post-weaning periods were 59 and 93 days, respectively. As all calves were housed indoors for a period, each ADG recorded for this period was summarised and averaged for a common indoor ADG figure. Orthogonal contrasts (indoor vs outdoor) were carried out to determine effects on calf weight gain.

Average figures were calculated from temperature and humidity data, related to indoor and outdoor environments, based on 144 daily environmental measurements. Minimum and maximum temperatures were also noted. The LCT threshold was used as a comparison against average figures to determine whether calves were within their daily TNZ. Average environmental (housing lying area) and atmospheric temperatures were compared to determine differences.

Table 2. Nine mutually exclusive behavioural categories based on various observed behaviours, used for behavioural analysis. Detailed descriptions of the observed behaviours can be found in the study by Sinnott et al. (2021).

Category	Observed Behaviours
Standing	Standing (only)
Lying	Lying (only)
Rumination	Rumination while standing Rumination while lying
Feeding	Drinking milk Drinking water Eating concentrate Eating forage
Comforting	Grooming Scratching/rubbing/stretching
Abnormal	Tongue playing Oral manipulation of the prepuce Oral manipulation of the pen (excessive: continuous and repeated to high frequencies) Cross-suckling
Play	Galloping Bucking/hind leg kicking Body rotations/twisting
Tactile Social Interaction	Licking/allo-grooming another calf Touching another calf Nuzzling another calf
Other	All other behaviours (e.g., walking defecating/urinating)

Statistical analysis

Sample size was calculated based on our primary outcome (namely weaning weight) using existing results from a previous body of work (Sinnott et al. 2021) with 95% confidence interval and 80% power. This sample size would allow for detection of a 2.5 kg difference in weaning weight. Statistical analyses were conducted using SAS (Version 9.4, SAS Institute Inc., 2002). Linear mixed models (PROC MIXED) were used to evaluate whether treatment affected labour input and calf growth (BW and ADG) when rearing calves; multiple comparisons and their interactions were assessed using the PDIFF option in the least square means statement with Tukey adjustment. Dependent variables used, followed a normal distribution pattern. Significant associations were confirmed at $P \leq 0.05$. Categorical variables were treatment, calf number and replicate. Related to labour, fixed effects were treatment, replicate and week-of-treatment. The time parameter, week of treatment, refers to the weeks after all calves are exposed to their treatment, which is after approximately 18 days. Week of treatment number one is therefore the first week after approx. 18 days. For data related to BW and ADG, week-of-treatment was not included as a fixed effect; instead birthweight, date of birth, period and breed were included. An additional covariate was included in the model accounting for the difference in age between individual calves at each weighing date. Time of measurement was the repeated measure used in the model.

The frequency procedure (PROC FREQ) was used to describe the non-normal distribution of categorical variables related to health scoring. Data were sorted according to treatment. Associations between the independent variables, treatment, location, period, temperature and replicate, on faecal health scores was completed using the logistic regression procedure (PROC LOGISTIC; binary distribution with link logit). The following reference categories (odds ratio (OR) = 1) were used: the IN_AUTO treatment, indoor location, thermoneutral temperature (11-16 °C) and replicate one. The model is described using odds ratios, with a 95% confidence interval.

The frequency procedure (PROC FREQ) also described the non-normal distribution of behaviour related to treatment. Data were sorted according to treatment and period. Logistic regression (PROC LOGISTIC) was used to determine the associations between the independent variables: location, temperature and replicate (each of which were dichotomous variables), on calf behaviour (nine behavioural categories with binary outcomes). The indoor environment, thermoneutral temperature (11-16 °C) and replicate one were designated as the reference categories. The dependent variable 'standing' was designated as the reference category for behaviour analysis, meaning each behaviour was compared to the standing variable. The model is described using odds ratios, with a 95% confidence interval.

RESULTS

Body weight and average daily gain

There were no differences in BW for period one (14 and 21 days; 40.6 ± 2.38 kg and 44.9 ± 2.35 kg, respectively). Treatment did not have an effect on BW in period two at 36 (55.5 ± 2.36 kg), 43 (60.3 ± 2.35 kg), post-weaning at 123 (111.7 ± 2.36 kg) or 156 (136.9 ± 2.36 kg) days of age. At weaning, BW of OUT_I_MAN calves was lower than IN_MAN calves (67.4 ± 2.84 kg and 74.2 ± 2.01 kg, respectively; P = 0.050). At 102 days, there was a difference in BW between OUT_I_MAN and IN_AUTO calves (94.1 ± 2.85 kg and 101.1 ± 2.10 kg; P = 0.047; all other treatments were similar).

No differences were found in the ADG for period one (0.52 ± 0.03 kg/day). There were no differences in ADG between treatments at 36, 43, 123 or 156 days of age. The ADG during the weaning period (49 to 56 days) was lower for OUT_I_MAN calves compared to IN_AUTO, IN_MAN and OUT_G_MAN calves (1.3 ± 0.05, 2.5 ± 0.03, 2.2 ± 0.03, 2.9 ± 0.04 kg/day, respectively; P<0.01). Location of calf housing (indoor or outdoor) did not influence calf BW (P = 0.737) or ADG (P = 0.998) throughout the study.

Health

The majority of calves in each treatment were scored as 0, i.e., healthy, for each health score (Table 3). More calves had poor faecal cleanliness than any other health score. Treatment, period, location of the calves (indoor or outdoor) and ambient temperature did not influence faecal health scores (P = 0.092, P = 0.263, P = 0.262 and P = 0.964, respectively).

Behaviour

Results pertaining to behaviour are reported as a percentage based on the number of scans (n) relative to the total number of observations (N) in period one and two. The total number of observations in period one and two for each treatment were as follows: IN_AUTO N = 1325 and 2307, IN_MAN N = 1296 and 2208, OUT_G_MAN N = 624 and 1521 and OUT_I_MAN N = 336 and 1281, respectively. Frequency analysis of behaviour indicates lying was the most common behaviour exhibited among treatments in both period one and two (Table 4). In period two, calves in the OUT_I_MAN expressed lying and tactile social behaviours on average 29.8% and 0.9% of the total observation time, whereas IN_AUTO, IN_MAN and OUT_G_MAN calves expressed these behaviours in a higher proportion (average lying and social tactile for the 3 treatments were 49.1% and 5.1%, respectively).

Table 3. Distribution frequencies (%; N = total number of observations) of health scores* for indoor automatic (IN_AUTO; N = 313), indoor manual (IN_MAN; N = 340), outdoor group manual (OUT_G_MAN; N = 221) and outdoor individual manual (OUT_I_MAN; N = 162) feeding systems.

	Health Score per Feeding System (%)							
Health Factor	**IN_AUTO (N=313)**		**IN_MAN (N=340)**		**OUT_G_MAN (N=221)**		**OUT_I_MAN (N=162)**	
	0	**(≥1)**	**0**	**(≥1)**	**0**	**(≥1)**	**0**	**(≥1)**
Demeanour	100	0.0	100	0.0	100	0.0	100	0.0
Ear Position	100	0.0	99.7	0.3	100	0.0	100	0.0
Eye Secretion	100	0.0	100	0.0	99.5	0.5	100	0.0
Nasal Discharge	100	0.0	100	0.0	99.5	0.5	100	0.0
Cough	100	0.0	100	0.0	100	0.0	100	0.0
Dehydration	100	0.0	100	0.0	100	0.0	100	0.0
Mobility	100	0.0	100	0.0	100	0.0	100	0.0
Interest	100	0.0	100	0.0	100	0.0	100	0.0
Faecal Cleanliness	97.8	2.2	95.3	4.7	94.6	5.4	94.4	5.6

* health parameters assessed using a 4-point scale which was dichotomized and a score of 0 indicated absence the symptom/sign, and a score of 1, 2 or 3 indicated the presence an abnormal symptom.

Furthermore, standing and comforting behaviours were observed more frequently, in the OUT_I_MAN (24.3% and 9.4% of the total time respectively) than IN_AUTO, IN_MAN and OUT_G_MAN, which were similar (approx. 8.0% and 3.4% of the total time, respectively). A decreased level of lying behaviours were seen in OUT_I_MAN calves and despite an overall decrease over time, remained lower than all other treatments (except week four; Figure 2). A similar, but reversed pattern was seen in standing behaviour across the pre-weaning period among OUT_I_MAN calves (Figure 3). In period two, the calves expressed feeding behaviours approximately 3.5% (OUT_G_MAN), 8.5% (IN_AUTO), 8.3% (IN_MAN) and 8.1% (OUT_I_MAN calves) of the total time, respectively. Experience of temperatures below the estimated LCT (≤10 °C) increased likelihoods of lying (OR = 1.81; CI = 1.59 – 2.06), rumination (OR = 2.34; CI = 2.00 – 2.73) and feeding (OR = 1.33; CI = 1.11 – 1.60). Whereas LCT were associated with a decreased likelihood of oral pen manipulation (OR = 0.58; CI = 0.42 – 0.80), tactile social interactions (OR = 0.78; CI = 0.64 – 0.97) and playful (OR = 0.64; CI = 0.47 – 0.88) behaviours.

No incidences of tongue playing were recorded. Oral manipulation of the prepuce occurred twice, both of which were in succession by a single calf in the IN_MAN treatment, during week four of the experiment.

Table 4. Frequency (% based on the number of scans; N = total number of observations) of behaviours exhibited by calves in period one (P1; day three to approx. 18) and period two (P2; day 19 to 56) in indoor automatic (IN_AUTO), indoor manual (IN_MAN), outdoor group manual (OUT_G_MAN) and outdoor individual manual (OUT_I_MAN) feeding systems.

	IN_AUTO (%)		IN_MAN (%)		OUT_G_MAN (%)		OUT_I_MAN (%)	
	P1 (N=1325)	**P2 (N=2307)**	**P1 (N=1296)**	**P2 (N=2208)**	**P1 (N=624)**	**P2 (N=1521)**	**P1 (N=336)**	**P2 (N=1281)**
Standing	11.2	6.3	11.1	8.4	9.9	9.2	14.5	24.3
Lying	60.7	52.7	63.6	46.5	63.4	48.2	57.7	29.8
Rumination	3.4	21.9	2.9	21.7	9.7	25.8	3.5	19.1
General	2.0	1.9	4.0	2.5	2.7	1.6	3.2	3.2
Feed	8.6	8.5	7.3	8.3	2.0	3.5	5.2	8.1
Comfort	3.5	2.6	2.8	3.9	2.9	3.6	6.4	9.4
Abnormal	2.5	1.1	1.1	1.8	0.0	1.0	2.5	2.6
Play	2.7	1.3	3.8	1.3	0.9	1.1	1.3	2.7
Social	5.4	3.8	3.4	5.6	8.5	6.1	5.6	0.9

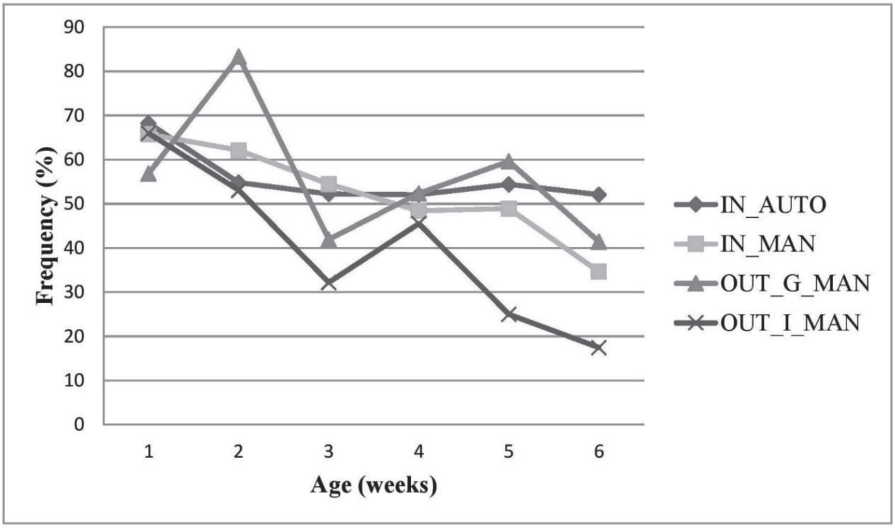

Figure 2. Frequency of lying behaviours (% based on the number of scans) expressed by age (in weeks) for indoor automatic (IN_AUTO), indoor manual (IN_MAN), outdoor group manual (OUT_G_MAN) and outdoor individual manual (OUT_I_MAN) feeding systems

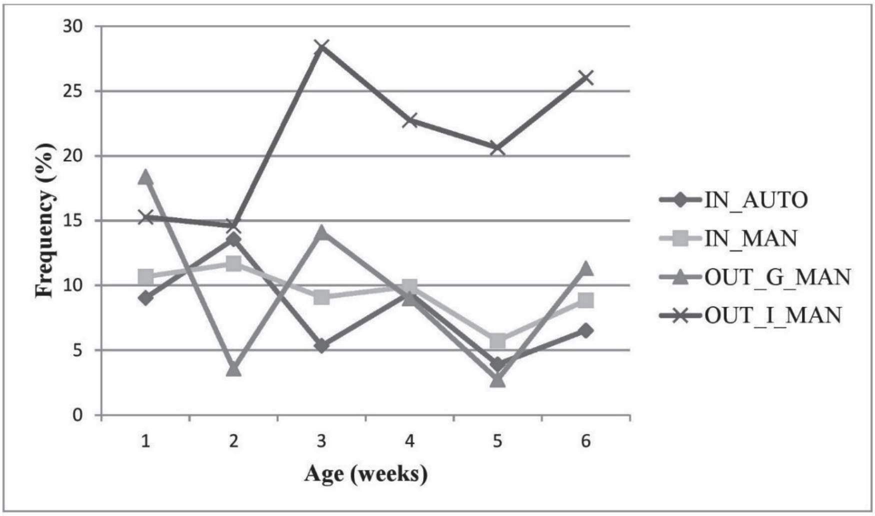

Figure 3. Frequency of standing behaviours (% based on number of scans) expressed by age (in weeks) for indoor automatic (IN_AUTO), indoor manual (IN_MAN), outdoor group manual (OUT_G_MAN) and outdoor individual manual (OUT_I_MAN) feeding systems.

Labour

Total labour input per calf per day, excluding cleaning, was different between all treatments (Table 1). The total labour input was greatest for OUT_I_MAN and least for IN_AUTO. Although not statistically analysed, total labour input, including pen cleaning follows the same pattern and was greatest for OUT_I_MAN (00:03:08 per calf/day of measurement), followed by OUT_G_MAN (00:01:51 per calf/day of measurement), IN_MAN (00:01:01 per calf/day) and IN_AUTO (00:00:28 per calf/day). The labour input (per calf per day) for feeding, feeding inspection and cleaning equipment was greater for OUT_I_MAN than any other treatment. The time taken to prepare milk for feeding, on a per calf basis, was greatest for OUT_G_MAN and OUT_I_MAN. Labour required for health inspection for the IN_AUTO was higher (+00:00:11 per calf/day) than any other treatment.

Temperature and relative humidity

The average atmospheric temperature was 7.1 °C for the 53 days of treatment measurements, with a temperature range from -2.9 to 19.4 °C (consistent with long-term seasonal averages). For period one, when all calves were housed indoors, the average ambient temperature was 8.1 °C, with calves experiencing temperatures outside of their TNZ 11 out of 14 days. Average ambient temperatures for indoor housing, and outdoor group and individual hutches for period two were 9.3 (range from 2.3 to 21.6 °C), 11.0 (range from -2.5 to 34.5 °C) and 9.5 °C (range from -1.3 to 32.8 °C), respectively. Average daily temperatures in period two showed calves housed indoors, in group and individual hutches experienced temperatures outside of their TNZ for 36, 25 and 33 days, respectively.

The average indoor relative humidity when all calves were housed indoors in period one was 88.0%. The average relative humidity for the indoor housing, and inside the outdoor group and individual hutches in period two were 82.0%, 80.0% and 81.2%, respectively. The lowest humidity recorded was 47.2% for the indoor environment, 26.2% for the group and 22.2% for the individual hutches, all of which were in period two. The maximum humidity of 100% was reached by all treatments periodically during the study. Average daily relative humidity experienced by calves in period two housed indoors, in group and individual hutches was >90% for 8, 6 and 7 days, respectively.

DISCUSSION

Behaviour, weight and temperature

Although behavioural data is reported in a descriptive capacity, this study is consistent with numerous others, indicating the most common behaviour expressed by calves in early life is lying (see for example also Calvo-Lorenzo et al., 2016; Sinnott et al., 2021). A positive correlation between levels of rest and growth rates for growing cattle (Mogensen et al., 1997) highlights the importance of lying for the welfare of young growing animals. Previous studies have indicated that calves spend upwards of 50% of the day lying down in early-life, typically decreasing over time (Webster et al., 1985; Chua et al., 2002; Hänninen et al., 2005). Although calves in all treatments displayed similar patterns to the above in early-life (period one), the OUT_I_MAN treatment expressed lying less than any other treatment, particularly after movement from indoors to outdoors. It is possible that deviations in behaviour between period one and period two may be attributable to calves moving outdoors to their respective treatments, particularly with the movement from a group to an individual housing setting. It may be argued that calves were conditioned to stand in the presence of a human during behavioural observations due to positive feed reward associations (Krohn et al, 2001). However in light of this, it would be likely that all manual feeding systems would respond in a similar way, which was not the case. Additionally, in the case of outdoor hutches, conditioning in this study would likely be associated with feeding equipment and vehicles used to transport milk, meaning OUT_G_MAN would exhibit a similar profile for OUT_I_MAN, which also did not occur. With that being said, when calves were lying in their respective individual hutch, visual stimulation from other calves was not possible (unless calves were in the concrete pen outside the hutch). This may not have been favourable for calves, as short-term visual isolation from other calves is reportedly distressing (Bøe and

Færevik, 2003). Calves may have been more alert or easily disturbed because, as herd animals, they lacked the security that grouping offers. In addition to this sentiment, it may also be possible that individually housed calves attempted to interact with a different species (humans), when the opportunity presented itself, in order to satisfy their social needs. Social tactile behaviours were also lower for calves in the OUT_I_MAN group; however this decrease was expected because although some social contact was possible in the outdoor part of the hutch, it was limited substantially, compared to a group housing situation where social contact is readily available. It appears the shortfall of lying and social tactile behaviours is compensated for with an increase in standing and comforting behaviours (self-grooming, scratching, rubbing and stretching), for the OUT_I_MAN calves, which were frequently carried out in the outer pen structure in view of other calves. This suggests that OUT_I_MAN calves have a high motivation for social interaction (suggested also by Færevik et al., 2006). A notable increase in rumination was found from period one to period two across all systems, which is likely attributable to a correlation between increased age and rumen development facilitating this behaviour (Swanson and Harris., 1958). Additionally, an increase in feed related behaviours was also seen across manual feeding systems (consistently high in IN_AUTO relative to manual systems, likely due to the ability to consume milk during observation periods), which may also be attributable to rumen development promoting the digestion of feed, unrelated to milk. Although abnormal behaviour was low among calves housed individually in this study, studies have shown that group housing reduces the incidence of abnormal behaviours such as object licking and increases the opportunity of social interactions compared to individual housing (Chua et al., 2002; Tapki, 2006). Despite studies suggesting competition and social housing increases calf intakes (González et al., 2008; Miller-Cushon and DeVries., 2015), we expected that visual stimulation from other calves consuming concentrate would off-set this and the elimination of feed competition associated with group housing (Miller-Cushon et al., 2014) would lead to better weight gains among individually housed calves. Although we did not study the effect this would have on feeding behaviour specifically, the weight gain of individually-housed calves did not reflect any competitive advantage compared to the other systems.

Studies have shown young calves are motivated to express individual and social play behaviour when their primary needs and thermal comforts are met (Jensen et al., 1998). This is reflected in our findings which demonstrated that calves were less likely to express social and play behaviours when temperatures were outside their TNZ, also notable with the occurrence of pen manipulation increasing with temperature. This can be viewed as exploring the environment, however when expressed extensively or in a stereotypic way it can be considered abnormal (Lauber et al., 2006). Feeding, rumination and lying increased as environmental temperatures decreased. Calves may have responded to a LCT by modifying their behaviour for thermoregulation and energy metabolism (Hänninen et al., 2003). On average, temperatures in the indoor environment and individual hutches were 2 °C greater than the atmospheric temperature, whereas group hutches were 4 °C greater. The higher average daily temperatures recorded in hutches, particularly group hutches, compared to indoor housing indicates hutches are effective in creating micro-climates. However, outdoor housed calves are more exposed to environmental conditions than indoor calves (Nordlund., 2008), due to one hutch side being permanently open, which may lead to the structures heating and cooling quicker than indoor housing facilities. Therefore, it was expected that calves housed outdoors would have a greater difficulty adjusting when moving from indoors to outdoors. This would then necessitate the direction of a higher proportion of feed intake towards maintenance (Hepola et al., 2006), leading to poorer weight gain compared to their indoor counterparts. Although calf intake was not recorded in this study, weight did not reflect impairment of calf growth, due to the possible redirection of feed intake toward maintenance. The OUT_G_MAN calves displayed decreased feeding behaviours, but slightly elevated levels of rumination, suggesting that feeding behaviours may have been carried out at a different time to observations. Indoor housed calves weighed more at weaning, possibly due to gut fill as no differences were observed in ADG or calf weights post-weaning. Thus, housing system, irrespective of location, did not appear to impact calf growth negatively.

Labour and health

The most labour efficient system was the IN_AUTO treatment, similar to that reported by Sinnott et al. (2021), followed by the IN_MAN treatment, suggesting indoor housing is more labour efficient than outdoor. Transport of milk was a large contributor to the difference in labour between the two locations. Transport time is relative to the distance hutches are from the feed preparation and cleaning area, and whether facilities to prepare milk exist in close proximity to the hutches. In this study, hutches were located < 30m from the feed preparation area. However, the breakdown of total labour input for each system indicates that if transportation is removed, the ranking of each system in terms of labour efficiency would remain unchanged. The OUT_I_MAN treatment was least efficient, suggesting that grouping calves is probably more labour efficient than individual housing (a finding supported by Chua et al. (2002)), particularly for outdoor individual housing, in relation to feeding and feeding inspection. It is possible that greater labour efficiencies among all treatments may be seen if carried out on a larger scale, due to economies of scale.

Cleaning equipment was least labour intensive for the IN_AUTO treatment, which is largely attributable to the automatic feeder self-cleaning twice daily. It must be noted that automatic feeders often require additional manual cleaning (in addition to the self-cleaning feature; e.g., cleaning teats and feeding unit) which incur additional labour requirements. In comparison, manual feeders require internal and external manual cleaning of each feeding compartment. The cleaning input for manual feeders used outdoors was greater than indoors. As removing equipment from the indoor environment may introduce potentially pathogen harbouring dirt to equipment from external environments, it was important to ensure that equipment was cleaned thoroughly. As outlined by Van Os et al. (2021), pathogens can be transported from one area of the farm to another in many ways including clothing, tools, and other items and additional care must be taken to eliminate contamination for calf health. Cleaning equipment is a labour intensive, yet necessary process, to help protect calves against illness (Barry et al., 2019a). Similar to Sinnott et al. (2021), although the study size was not designed to detect differences in health problems, the low rates of illness and no difference between treatments for health scores is perhaps in-part reflective of the high sanitisation levels implemented for feeding equipment on the research farm where the present study was conducted, but this might not be the case on all commercial farms. It should be noted that additional cleaning measures (carried out, but not quantified in this present study) to aid in reducing/eliminating harmful bacteria are required and have labour implications associated with the practice. The benefit of these practices is evident (Dietrich, 2015), however the labour implications of its execution are expected to be far less for automated systems due to the absence of physical labour required.

It was not possible to evaluate outdoor pen cleaning using statistical analysis, due to infrequent occurrence. However, outdoor housing is believed to benefit calf health (Lorenz et al., 2011c), so it is possible that external weather conditions, as well as the slightly lower average relative humidity in the outdoor hutches, may have compensated for and led to an infrequent need to clean outdoor pens. This may benefit calf health, because high levels of humidity (>90%) have been linked to bacterial survivability in housing environments (Lago et al., 2006). Although average temperatures were higher in both outdoor housing systems compared to indoor housing, it remained within a calf's upper TNZ threshold (24 °C; Davis & Drackley., 1998).

Automatic milk feeders provide an additional advantage over manual feeding systems by means of monitoring and recording calf intake and feeding behaviour data, which can also be used to identify sick animals (Sutherland et al., 2018). Additionally, individual manual feeding also allows for the efficient quantification of calf intake without substantial human intervention. In a manual group feeding system, in order to quantify calf intake and receive the same information as above, a person would be required to stay at the feeder to ensure all calves consumed their full milk allocation. This has the potential to increase the labour demand for this task considerably (as found by Sinnott et al., 2021). It must be noted, however, that automatic feeders require elevated labour input in the early pre-weaning period in relation to IT training to use such a system, as well as training calves to the feeder (Sinnott et al., 2021; Medrano-Galzara et al., 2018b) and calibration of the feeding system itself.

Practical implications

Indoor housing with automated milk feeders is a labour efficient way of rearing calves, followed by manually feeding indoors. Health, growth and behavioural indicators show that these systems do not appear to impact calves in a negative way in this circumstance. Indoor housing provides shelter from extreme weather for both calf and manager; however, there are high costs associated with building such a structure. Furthermore, automatic feeders are costly, requiring continued maintenance once installed, compared to costs associated with manual feeders. As automated feeding technology progresses, the further adaptation of these feeders to outdoor environments may change the labour efficiency of outdoor systems.

Outdoor group hutches were more labour efficient than individual calf hutches. Transportation of milk and topping up of weather-soiled bedding proved inconvenient with both outdoor systems. Although hutches shelter calves, both calf and manager were more susceptible to prevailing weather compared to indoor housing. This means that in countries such as Ireland, operating primarily spring calving systems, weather will have a considerable influence on the suitability of hutches as housing. This raises the question that if weather conditions such as these persist or worsen, is outdoor housing viable? A concern echoed by producers, whereby the improved working conditions associated with indoor automated feeding and related housing proved more favourable than manual feeding systems, particularly those using outdoor housing (Medrano-Galarza et al, 2017a).

Unlike automatic feeding systems, indoor and outdoor manual systems allowed human interaction with all calves at feeding time to determine a calf's health status relative to milk consumption, which is beneficial for both the farmer in terms of the amalgamation of tasks and labour efficiency, and the calf in relation to health detection. On the contrary, automatic feeders provide additional information regarding calf milk consumption and other feeding behaviours, which can be used as health indicators, without the presence of a human, thus resulting in greater efficiencies in this area. Additionally, individual systems granted high levels of control at feeding time, which allowed calves to consume their full milk allocation.

Although expressed behaviours for IN_AUTO, IN_MAN and OUT_G_MAN prove relatively similar, OUT_I_MAN calf behaviour deviated for their counterparts significantly (potentially through movement from an indoor group-housing system). It is imperative to recognise that commercial farm practices that echo such management practices (moving calves to individual outdoor hutches due to lack of space for new-born calves) may have lasting negative impacts on a calf's welfare particularly in the area of socialisation.

CONCLUSION

Our results showed that after 18 days of age, indoor automatic feeding systems were consistently more labour efficient than indoor manual, outdoor group hutch and individual hutch feeding systems. Health and growth patterns among all treatments were consistent with positive calf development. Differences in behavioural patterns expressed by calves from 18 to 56 days of age in the outdoor individual hutches compared to all other treatments may indicate compromised wellbeing through movement from an indoor group-housing system. Thus, although outdoor group hutches do not negatively impact the calf, indoor housing, particularly when using automated feeders, can provide improved labour efficiency.

ACKNOWLEDGEMENTS

The authors wish to acknowledge support by the Teagasc, Walsh Scholar funding scheme. We thank the farm staff at Teagasc, Moorepark for their care of the animals during the study.

SUPPLEMENTARY FILES

Supplementary File 1. Individual calf milk feeding plan indicating calf milk quantity offered per day (L/day) relative to the age of the calf (in weeks).

Age (weeks)	**0.5**	**1**	**1.5**	**2**	**2.5**	**3**	**3.5**	**4**
Milk Quantity (L/day)	6.0	6.0	6.0	6.0	6.5	7.0	7.5	8.0

Supplementary File 1 continued. Individual calf milk feeding plan indicating calf milk quantity offered per day (L/day) relative to the age of the calf (in weeks).

Age (weeks)	**4.5**	**5**	**5.5**	**6**	**6.5**	**7**	**7.5**	**8**
Milk Quantity (L/day)	8.0	8.0	7.0	6.0	5.0	4.0	3.0	2.0

Supplementary File 2. Definition of and scoring levels used in the health scoring system adapted by Sinnott et al (2021) from Teagasc (Sayers et al., 2016) and Barry et al (2019) to assess dairy calf health within the experiment.

Indicator	Definition	Scoring	Score levels
Demeanour	Combined evaluation of behaviour and responsiveness	4-point scale of 0 to 3	0 = Bright, alert, responsive 1 = Dull, possibly depressed, less responsive 2 = Dull, markedly depressed, markedly unresponsive 3=Unresponsive to any stimulus
Nasal discharge	Presence of any mucous discharge from the nasal passage	4-point scale of 0 to 3	0 = clear, discharge free 1 = Small amount of cloudy mucous visible 2 = medium amount of bilateral mucous discharge 3 = excessive bilateral mucous discharge
Ocular discharge	Position, appearance and presence of ocular discharge	4-point scale of 0 to 3	0 = Bright, pronounced 1 = Slightly dull, presence of discharge 2 = Slightly dull, small amount of visible discharge 3 = Dull, sunken, excessive amount of visible discharge
Ear position	Positioning and activity of ears	4-point scale of 0 to 3	0 = Alert and mobile 1 = Slightly drooped 2 = Drooped 3 = Drooped and limp
Cough	Presence of a cough, increased respiratory rate	4-point scale of 0 to 3	0 = Normal Breathing 1 = Spontaneous coughing 2 = Intermittent coughing 3 = Continuous cough, increased respiration

Supplementary File 2 continued. Definition of and scoring levels used in the health scoring system adapted by Sinnott et al (2021) from Teagasc (Sayers et al., 2016) and Barry et al (2019) to assess dairy calf health within the experiment.

Indicator	Definition	Scoring	Score Levels
Hydration	Appearance of calf eyes in relation to hydration levels	4-point scale of 0 to 3	0 = Clear bright eyes 1 = Eyes slightly sunken 2 = Eyes sunken 3 = Eyes markedly sunken
Mobility	Ability to stand unassisted and move freely	4-point scale of 0 to 3	0 = Stands unassisted, actively mobile 1 = Slow to stand, limited mobility 2 = struggles to stand, limited mobility 3 = Assistance required to stand, no mobility
Interest in surroundings	Willingness to interact with observer	2-point scale of 0 to 1	0 = Interactive when approached 1 = Uninterested when approached
Faecal hygiene	Cleanliness of calf tail area and hindquarters	4-point scale of 0 to 3	0 = completely clean hind quarters with no faecal matter 1 = slight faecal matter around hind quarters 2 = heavier faecal matter around hind quarter 3 = extremely dirty hind quarters and tail

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Supplementary File 3. Ethogram adapted by Sinnott et al (2021) from Barry et al. (2019), which categorises and defines various behaviours, used for behavioural observations

Category of behaviour	Behaviour	Definition
Posture	Standing	Calf is in a static upright standing position with weight placed on all four legs
	Lying	Calf is resting either sternally or laterally with all four legs hunched close to body either awake or asleep.
General	Walking	Calf is actively moving from one point in the pen to another in an active walking motion
	Not visible	Behaviour of the calf is not visible
	Defecating/Urinating	Calf defecates or urinates
Feeding behaviour	Drinking water	Calf is drinking water
	Eating	Calf eats concentrates or roughage, or other solid feed (proximity of head to feed)
Comfort behaviour	Scratching/Rubbing/Stretching	Calf scratches itself with one of their legs (generally hind legs). Calf rubs itself on pen structure. Calf stretches itself.
Abnormal behaviour	Tongue playing/rolling	Calf makes repeated movements with its tongue inside or outside its mouth
	Urine drinking / oral manipulate prepuce / cross sucking	Calf drinks the urine of another calf. Calf attempts to suck the naval area of another calf. Calf attempts to suck any body part of another calf.
	Orally manipulating pen structure	Calf licks, nibbles, sucks, or bites at the pen structure (barriers, walls, buckets, troughs etc.)

Supplementary File 3 continued. Ethogram adapted by Sinnott et al (2021) from Barry et al. (2019), which categorises and defines various behaviours, used for behavioural observations

Category of behaviour	Behaviour	Definition
Play behaviour	Play behaviour/ Mounting/ Head butting	Calf runs, jumps, changes direction suddenly, bucks, kicks hind legs, twists or rotates body. Calf mounts, or attempts to mount, a pen mate. Calf is engaged in head to head pushing with another calf.
Social behaviour	Social interaction	Calf licks another calf in the same area multiple times. Calf nudges another calf with its nose

Supplementary File 4. Catalogue of definitions and cues adapted from Sinnott et al. (2021) used during labour evaluations to differentiate between tasks involved with indoor automatic feeding systems (IN_AUTO), indoor manual feeding systems (IN_MAN), outdoor group and individual hutches (OUT_G_HUTCH and OUT_I_HUTCH, respectively).

Task	IN_AUTO	IN_MAN	OUT_G_HUTCH	OUT_I_HUTCH
Milk preparation	SW start when milk replacer bag opened. Hopper cover removed. Bag emptied into the hopper. SW stop when the hopper cover was replaced.	SW started when water entered first bucket. SW stopped when the last bucket of milk was made (mixed).	SW started when water entered first bucket. SW stopped when the last bucket of milk was made (mixed).	SW started when water entered first bucket. SW stopped when the last bucket of milk was made (mixed).
Transport	NA	NA	SW starts when first bucket lifted to be brought to form of transport. SW stops when housing destination is reached (includes to and from destination).	SW starts when first bucket lifted to be brought to form of transport. SW stops when housing destination is reached (includes to and from destination).
Feeding/Feeding inspection*	SW started when hand-held automatic feeding monitor attached to feeder was inspected for calf drinking history. SW finished when all calves information had been checked.	SW starts when first bucket of milk was poured into feeders. Each calf inspected for obvious signs of ill health, they had a good demeanour, could stand and walk, and were consuming milk. SW stopped when last calf was given health check.	SW starts when first bucket of milk was poured into feeders. Each calf inspected for obvious signs of ill health, they had a good demeanour, could stand and walk, and were consuming milk. SW stopped when last calf was given health check.	SW starts when first bucket of milk was poured into individual feeders. Each calf inspected for obvious signs of ill health, they had a good demeanour, could stand and walk, and were consuming milk. SW stopped when last calf was given health check.

Supplementary File 4 continued. Catalogue of definitions and cues adapted from Sinnott et al. (2021) used during labour evaluations to differentiate between tasks involved with indoor automatic feeding systems (IN_AUTO), indoor manual feeding systems (IN_MAN), outdoor group and individual hutches (OUT_G_HUTCH and OUT_I_HUTCH, respectively).

Task	IN_AUTO	IN_MAN	OUT_G_HUTCH	OUT_I_HUTCH
Cleaning pen°	SW started when entered pen. Water, detergent and disinfectant was used to clean feeding area surfaces. SW finished when pen was clean.	SW started when entered pen. Water, detergent and disinfectant was used to clean feeding area surfaces. SW finished when pen was clean.	SW started when entered pen. Water, detergent and disinfectant was used to clean feeding area surfaces. SW finished when pen was clean.	SW started when entered pen. Water, detergent and disinfectant was used to clean feeding area surfaces. SW finished when pen was clean.
Cleaning equipment	SW starts when begin washing housing specific feeders. SW stops when respective feeders are cleaned	SW starts when begin washing housing specific feeders. SW stops when respective feeders are cleaned	SW starts when begin washing housing specific feeders. SW stops when respective feeders are cleaned	SW starts when begin washing housing specific feeders. SW stops when respective feeders are cleaned
Health check	SW starts when enter pen to inspect calf health. Each calf inspected for obvious signs of ill health, they had a good demeanour, could stand and walk .SW stops when last calf health is inspected	NA *see feeding inspection	NA *see feeding inspection	NA *see feeding inspection

° excluding removal of soiled bedding, disinfection of surfaces and rebedding

Chapter 5

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

Alison M. Sinnott[ab], Eddie A.M. Bokkers[b], John Paul Murphy[a], Sarah McPherson[ab], Katie Sugrue[a] and Emer Kennedy[a]

[a] *Teagasc, Animal and Grassland Research and Innovation Centre, Moorepark, Fermoy, Co. Cork, Ireland*

[b] *Animal Production Systems group, Wageningen University & Research, P.O. Box 338, 6700 AH Wageningen, the Netherlands*

ABSTRACT

Preventing cow-calf contact in rearing systems has been scrutinised recently. This study investigated the effects of full-time contact outdoors on pasture (FT-O), part-time contact housed indoors (PT-I), or no contact housed 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 48h, whereas NC-I calves were separated from cows immediately post-calving, and remained in individual pens for three days before joining the rest of their group. 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 structured feeding plan which offered up to 9.5L/day of milk replacer via an automatic feeder. All calves had *ad libitum* access to water, concentrates and forage. For NC-I calves, weaning started at 44 days and took 12 days whereas for contact calves it started at 58 days and took 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. Part-time contact calves were more likely to have faecal related issues than NC-I (OR = 2.340; CI = 1.554 – 3.523) and FT-O calves (OR = 1.879; CI = 1.218 – 2.900). The PT-I calves were 5.5 (CI = 2.38 - 12.90) and 2.1 (CI = 1.024 – 4.209) times more likely to have eye issues compared to NC-I and FT-O calves, respectively. Illness saw 26% of FT-O calves removed from experiment (no calves removed from NC-I and PT-I). The PT-I calves expressed more abnormal behaviours than FT-O calves late pre-weaning (7.5% vs 3.1% of time, respectively), and more than NC-I at weaning (5.0% vs 2.3% of time, respectively). Contact calves vocalised more at weaning than NC-I calves (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, which were similar. 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 (due to computerised feeder), but 00:02:08 ± 00:00:09 for both 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 ensure the safeguarding of calf and human welfare.

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 are described as providing 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 (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 because incremental changes to an existing system would be easier to implement on-farm. 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 around indoor systems (Johnsen et al., 2021b; 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, nutritional diarrhoea (associated with high milk consumption) can predispose calves to pathogenic invasion, particularly in combination with wet lying conditions (Bazeley, 2003). Furthermore, thermoneutral zones are influenced by weather; cold stress can cause a diversion of energy 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.

Furthermore, to ensure the concept of One Welfare is achieved on-farm, 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 hours 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, being cognisant of the 'One Welfare' approach. 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 examine 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).

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).

Experimental systems

A total of three balanced groups of cow-calf pairs were created and assigned to a randomised block design experiment. The treatments 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 comprised of 39 females and 16 males (higher proportion of female calves related to use of sexed semen). Mean calf birth weight was 34.2 ± 5.75 kg and mean birth date was February 12 ± 16.6 days. Three different calf breeds were enrolled and distributed evenly across the study: 27 HF, eight HF x JE, 20 HF x Aberdeen Angus (AA).

Calving and post-calving management

Cows were moved to a straw bedded group maternity pen approximately five days before calving. When a cow displayed imminent signs of calving, she was moved to an individual straw-bedded calving pen (20.3 m^2), adjacent to the group maternity pen. 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 within the individual pen using a head-lock and calving gate. The cow's udder and each teat surface was cleaned of organic matter (i.e., straw or faeces) using methylated spirits, teat sealant was voided manually from each quarter and the cow was milked (InterPuls, Wiltshire, United Kingdom). 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 during the above process. For cows with calf contact, immediately after parturition the cow's udder and each teat surface was cleaned of organic matter (i.e., straw or faeces) using methylated spirits. Following this, the udder was washed thoroughly with warm water to remove any residues that may act as a taste deterrent for calf suckling. Teat sealant was also voided manually from each quarter and calves remained with the cow. 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 period of 48 hours. During this time, calves were observed for feeding behaviour and cows for signs of aggression. If no signs of colostrum consumption occurred within a six-hour period post-calving, calves were manually fed colostrum collected, via a teat bottle (occurred once during the study), from a single cow not on the study (Barry et al. 2022); colostrum quality was ≥22% Brix (>50 g/L IgG), determined using a Brix refractometer (Milwaukee Instruments MA871 Digital Brix Refractometer). If calves persistently avoided consuming milk from their dam over a period of 24 hours at any point during the study (one occurrence throughout study), or a cow displayed continued aggression towards their calf at any point during the study (did not occur throughout study), the cow-calf pair was excluded from the study. If the bonding process was successful, the pair was then allocated to their respective group (2.4 ± 0.62 days).

Full-time cow-calf contact

Following bonding (2 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) where calves either remained in the paddock until the cow returned post-milking, or accompanied the cow to the milking parlour, were separated and remained in a pen adjacent to the parlour until milking completion, returning to the paddock with their dams thereafter. Paddocks were rotationally grazed, with fresh pasture allocated daily and up to 3 kg DM/day concentrate, such that there were no restrictions on cow diet. Calves had *ad libitum* access to fresh milk (via suckling cow), water, grass and concentrates (straw and silage were offered as forage while indoors). Concentrate (16% 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 environmental 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*.

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, in the morning (08:00). 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, where calves had unrestricted access to their dams. 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 (same 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, ensuring no physical contact between the cows and calves until the designated time-point.

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 contact with their dams possible. 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) 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.

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 were present (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 x 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.

Weaning

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.

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 44 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).

Measurements

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).

Morbidity and removal from system

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

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 minutes, 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). Observations were completed in a similar way to weekly measurements (scan sampling at one minute intervals for 15 minutes; 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.

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

Body weight

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

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.

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, with the quantity, date and number of calves in the pen recorded. Once the feeder was empty, the date was recorded and concentrate replenished, repeating the process. For contact weaning, care was taken to record any weaning group concentrate refusals at the end of their weaning period. This was subtracted from the total concentrate provided to the weaning group calves. 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.

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 further 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 in the 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.

Temperature and relative humidity

TinyTag data loggers were used to record temperature and relative humidity every 10 minutes 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).

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, no statistical analysis was performed and instead 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 minutes) 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 & 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.

Statistical analysis

Statistical 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). The following reference categories (odds ratio (OR) = 1) were used; NC-I system, early pre-weaning period and thermo-neutral temperature (11-16 °C). No other health parameters were analysed this way due to little/no variation between systems over time.

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 significant variables in each model. Significant associations were confirmed at $P < 0.05$. Categorical variables in the behaviour model included; sex, breed, system and period and their interactions. Sex and breed did not influence any behavioural outcomes significantly ($P > 0.05$), 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 and interactions examined between significant variables in each model. Significant associations were confirmed at $P < 0.05$.

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).

RESULTS

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, calves were more likely to be allocated a faecal score greater than one in the PT-I and FT-O groups than NC-I calves (OR = 2.340; confidence interval (CI) = 1.554 – 3.523 and OR = 1.879; CI = 1.218 – 2.900, respectively). Calves in the PT-I group were 5.5 times more likely (CI = 2.38 - 12.90) to have an eye score greater than one throughout the study compared to NC-I and 2.1 times more likely (CI = 1.024 – 4.209) than FT-O calves. There were no differences in eye score for NC-I or FT-O calves (P = 0.779). System did not influence the likelihood of nose related issues (P = 0.140). 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, distribution frequencies show PT-I calves had elevated faecal scores ≥2 compared to NC-I and FT-O calves (+12.9 % and +9.0 %, respectively). In the early post-weaning period, FT-O calves experienced elevated faecal scores compared to NC-I and PT-I calves (+12.1 % and +7.0 %, respectively). Issues related to eyes were found in the PT-I system, with scores ≥2 seen more often in these calves in the late post-weaning period than the NC-I and FT-O systems (+11.5 % and +8.8 %, respectively). In the late post-weaning period, both NC-I and PT-I calves had slight increased frequency of health scores ≥2 for nasal discharge (+8.1 % and +6.1 %, respectively), compared to the FT-O calves, who had no incidence of scores ≥2.

Morbidity and removal from treatment

Of the total number of calves in this study, 21.8 % of the population 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; P < 0.001). Illness associated complications meant 26 % of calves in the FT-O system were removed from the experiment (P < 0.010; no calves from the other systems were removed). Breed or sex did not influence a calf's removal from system (P = 0.235 and P = 0.665, respectively).

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
Faecal	**NC-I**	83.6	16.4	97.5	2.5	95.8	4.2	98.7	1.3
	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
Demeanour	**NC-I**	100	0	100	0	100	0	100	0
	FT-O	97.5	2.5	100	0	100	0	100	0
	PT-I	99.2	0.8	100	0	100	0	100	0
Ears	**NC-I**	100	0	100	0	100	0	100	0
	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
Eyes	**NC-I**	100	0	99.4	0.7	100	0	94.6	5.4
	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
Nose	**NC-I**	95.4	4.6	99.4	0.6	97.9	2.1	91.9	8.1
	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
Cough	**NC-I**	100	0	100	0	100	0	100	0
	FT-O	100	0	100	0	100	0	100	0
	PT-I	100	0	100	0	100	0	100	0
Dehydration	**NC-I**	100	0	100	0	100	0	100	0
	FT-O	98.3	1.7	100	0	100	0	100	0
	PT-I	100	0	100	0	100	0	100	0
Mobility	**NC-I**	100	0	100	0	100	0	100	0
	FT-O	98.3	1.7	100	0	100	0	100	0
	PT-I	97	3	100	0	100	0	100	0
Interest	**NC-I**	100	0	100	0	100	0	100	0
	FT-O	99.1	0.9	100	0	100	0	100	0
	PT-I	99.3	0.7	100	0	100	0	100	0

Weekly behaviour

Results related to weekly behaviour can be found in Table 3. There was no interaction between system and period, relative to lying behaviour. The time spent lying decreased over time (Table 3), decreasing from early to late pre-weaning ($P < 0.050$), and early to late post-weaning ($P < 0.001$). An interaction occurred ($P < 0.050$) between system and period relative to standing. 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 across all systems lay more in LCT (55.5 % of time, compared to 49.1 % of their time when temperatures were within TNZ; $P < 0.050$; Supplementary File 2). The NC-I calves moved less than both contact systems (which were similar) throughout the study (0.5 % vs 1.4 %, respectively; $P = 0.007$).

An interaction between system and period relative to rumination was found. Compared to early pre-weaning, FT-O rumination was greater at all other periods (which were similar). The NC-I calves followed a similar pattern except during late post-weaning, where rumination decreased to early pre-weaning levels. Rumination for PT-I calves was similar among periods, except early post-weaning, where levels increased compared to the early pre-weaning period. Rumination was not influenced by TNZ/LCT ($P = 0.641$). Frequency distributions indicate that 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). An interaction existed between system and period relative to time consuming solids (i.e., forage and concentrate (excl. grazed grass)). Time consuming solids was similar among systems for early and late pre-weaning, weaning and late post-weaning, however in the early post-weaning period, NC-I calves spent less time consuming solids than PT-I calves. As temperature entered the TNZ, time consuming solids increased (7.7 % vs 4.7 % during LCT; $P = 0.008$). The FT-O calves spent twice as much time consuming liquids (i.e., water and milk) than NC-I calves (0.1 % of time; $P < 0.05$).

An interaction existed between system and period for abnormal behaviours: whereby the PT-I system expressed abnormal behaviours more than FT-O calves late pre-weaning (all other periods similar among systems). Comfort behaviour expression was similar among systems. Differences between periods were significant, where comfort behaviours increased between pre and post-weaning, decreased at weaning, but recovered in the early and late post-weaning periods. No differences existed between systems (P = 0.204) and period (P = 0.089) related to time spent playing. The time spent socially interacting with other animals was less (P < 0.010) for NC-I calves (0.09 %) than their contact counterparts, which were similar (0.30 %).

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**		
	NC-I	**FT-O**	**PT-I**	**NC-I**	**FT-O**	**PT-I**	**NC-I**	**FT-O**	**PT-I**
Lying	63.7^{w}	68.8^{w}	69.8^{w}	61.8^{x}	63.2^{x}	54.3^{x}	67.5^{wxy}	48.5^{wxy}	53.8^{wxy}
Standing	35.1^{de}	24.8^{e}	27.5^{de}	36.2^{cde}	33.7^{de}	41.5^{bcde}	31.9^{de}	49.7^{abcd}	45.5^{abcde}
Ruminate	5.2^{c}	5.9^{c}	6.2^{c}	21.7^{ab}	25.0^{ab}	10.0^{bc}	35.5^{a}	27.4^{ab}	16.2^{abc}
Defecate/ Urinate	0.2^{w}	0.1^{w}	0.1^{w}	0.5^{xz}	0.6^{xz}	0.6^{xz}	0.6^{wyz}	0.2^{wyz}	0.3^{wyz}
Eat Solids	3.5^{cd}	1.1^{d}	2.8^{cd}	3.7^{cd}	1.2^{d}	2.1^{d}	8.6^{bc}	9.8^{bc}	12.1^{b}
Comfort	1.6^{w}	1.3^{w}	3.1^{w}	2.8^{x}	4.4^{x}	7.5^{x}	1.8^{wy}	1.7^{wy}	3.6^{wy}
Abnormal	1.0^{b}	1.0^{b}	3.2^{ab}	3.1^{ab}	3.1^{b}	7.5^{a}	1.7^{ab}	2.1^{ab}	6.2^{a}

Differing superscripts within row indicate significance ($P < 0.05$)

$^{a\text{-}e}$ percentages from system x period interaction within a row with a different superscript are significantly different ($P < 0.05$)

$^{w\text{-}z}$ differing superscript indicate significant difference exist between periods ($P < 0.05$)

Table 3 continued. 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 Post-wean			Late Post-wean				P Value		
	NC-I	**FT-O**	**PT-I**	**NC-I**	**FT-O**	**PT-I**	**SEM**	**System**	**Period**	**System x Period**
Lying	56.3^{xy}	53.8^{xy}	40.6^{xy}	27.1^{z}	30.8^{z}	26.4^{z}	5.18	0.238	<0.001	0.109
Standing	41.9^{abcde}	45.8^{abcde}	58.9^{abc}	68.8^{a}	65.9^{ab}	69.2^{a}	5.02	0.243	<0.001	0.050
Ruminate	25.7^{ab}	30.1^{ab}	33.4^{a}	7.9^{bc}	22.6^{ab}	13.3^{abc}	4.09	0.114	<0.001	0.004
Defecate/ Urinate	0.8^{wx}	0.1^{wx}	0.5^{wx}	0.5^{xy}	0.6^{xy}	0.5^{xy}	0.02	0.228	0.007	0.696
Eat solids	9.8^{bc}	16.8^{ab}	34.8^{a}	13.5^{b}	7.2^{bcd}	5.6^{bcd}	2.12	0.099	<0.001	<0.001
Comfort	2.6^{wx}	3.9^{wx}	3.6^{wx}	4.9^{xy}	2.7^{xy}	4.7^{xy}	1.05	0.095	<0.001	0.273
Abnormal	2.5^{ab}	4.3^{ab}	2.9^{ab}	3.4^{ab}	3.0^{ab}	2.4^{ab}	1.09	0.009	0.120	0.004

Differing superscripts within row indicate significance (P < 0.05)

$^{a-e}$ percentages from system x period interaction within a row with a different superscript are significantly different (P < 0.05)

$^{w-z}$ differing superscript indicate significant difference exist between periods (P < 0.05)

Weaning behaviour

Results pertaining to weaning behaviour are outlines in Table 4. No interaction was found between system and stage of weaning, relative to time spent lying or standing. The NC-I calves spent more time lying throughout weaning than both FT-O and PT-I systems (which were similar; 17.1 % more time spent lying). The NC-I calves stood less than both FT-O and PT-I systems (which were similar; 8.7 % less time spent standing). Standing time peaked for all calves in WD 4-5, compared to WD 1-3 ($P = 0.017$) then decreased below initial WD 1-3 levels ($P = 0.027$) during WD 6-7. No interaction was found between system and stage of weaning relative to movement, however movement for all calves was greater in WD 1-3 than WD 4-5 ($P = 0.025$) and WD 6-7 ($P = 0.010$).

An interaction existed between system and stage of weaning for rumination, whereby NC-I calves ruminated more than both FT-O and PT-I calves during WD 1-3. All calves has similar rumination during WD 4-5 and WD 6-7, however PT-I calf rumination in WD 6-7 was less than NC-I rumination in WD 1-3 ($P = 0.012$). An interaction existed between system and stage of weaning, relative to time consuming solids. Although solid consumption duration was similar among systems in WD 1-3, WD 4-5 and WD 6-7, it was less for PT-I calves in WD 1-3 than WD 6-7 ($P < 0.001$). No differences were seen between systems or stage of weaning for consumption of liquids or defecation/urination.

The PT-I calves expressed abnormal behaviours more throughout weaning than NC-I calves, however both systems were similar to FT-O calves. Weaning vocalisations were greater for FT-O ($P < 0.010$) and PT-I ($P < 0.010$), than NC-I calves. The FT-O calves carried out comforting behaviours more than NC-I and PT-O calves ($P < 0.010$). Both FT-O and PT-I systems socialised more than their NC-I counterparts ($P < 0.050$ and $P < 0.010$, respectively).

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				P Value		
	NC-I	FT-O	PT-I	NC-I	FT-O	PT-I	NC-I	FT-O	PT-I	SE	System	Stage of wean	System x Stage of wean
Lying	69.4^{h}	50.8^{i}	64.0^{i}	69.9^{h}	45.7^{i}	46.4^{i}	66.1^{h}	46.9^{i}	54.3^{i}	4.44	<0.001	0.071	0.264
Standing	11.1^{hw}	20.5^{iw}	14.6^{iw}	13.2^{hx}	23.4^{ix}	26.2^{ix}	5.7^{hy}	15.8^{iy}	11.7^{iy}	2.45	<0.001	<0.001	0.267
Rumination	43.8^{ah}	24.6^{bhi}	21.1^{bi}	29.8^{abh}	28.2^{abhi}	27.4^{abi}	33.6^{abh}	30.1^{abhi}	24.8^{bi}	4.10	0.001	0.962	0.040
Movement	0.2^{w}	1.2^{w}	1.0^{w}	0.1^{wx}	0.5^{wx}	0.3^{wx}	0.3^{x}	0.2^{x}	0.1^{x}	0.24	0.172	0.037	0.396
Vocalisation	2.2^{h}	7.4^{i}	5.5^{i}	1.9^{h}	8.6^{i}	12.4^{i}	0.4^{h}	7.8^{i}	5.0^{i}	1.65	0.004	0.102	0.121
Defecate/Urinate	0.3	0.2	0.5	0.8	0.6	0.2	1.2	1.1	0.3	0.27	0.277	0.079	0.188
Consume liquids	2.3	1.2	0.7	2.3	0.8	1.6	1.9	1.1	1.5	0.56	0.070	0.852	0.520

Differing superscripts within row indicate significance (P < 0.05)

$^{a-e}$ percentages from system x period interaction within a row with a different superscript are significantly different (P < 0.05)

$^{h-i}$ differing superscript indicate significant difference exist between systems (P < 0.05)

$^{w-z}$ differing superscript indicate significant difference exist between periods (P < 0.05)

Table 4 continued. 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				P Value		
	NC-I	FT-O	PT-I	NC-I	FT-O	PT-I	NC-I	FT-O	PT-I	SE	System	Stage of wean	System x Stage of wean
Consume solids	10.6^{abcw}	9.5^{abcw}	5.8^{cw}	8.8^{bcx}	15.8^{abx}	12.5^{abcx}	14.1^{aby}	18.0^{aby}	18.9^{ay}	2.21	0.186	<0.001	0.036
Comfort	1.8^{h}	5.8^{i}	4.2^{h}	2.5^{h}	5.3^{i}	2.3^{h}	4.6^{h}	5.6^{i}	2.6h	0.90	0.001	0.354	0.210
Abnormal	1.5^{h}	4.5^{hi}	5.4^{i}	2.3^{h}	3.4^{hi}	5.3^{i}	3.1^{h}	3.3^{hi}	4.2^{i}	0.98	0.004	0.967	0.351
Social	0.7^{h}	2.4^{i}	2.4^{i}	1.8^{h}	2.1^{i}	1.8^{i}	1.1^{h}	2.1^{i}	3.5^{i}	0.65	0.019	0.574	0.308

Differing superscripts within row indicate significance (P < 0.05)

$^{a-e}$ percentages from system x period interaction within a row with a different superscript are significantly different (P < 0.05)

$^{h-i}$ differing superscript indicate significant difference exist between systems (P < 0.05)

$^{w-z}$ differing superscript indicate significant difference exist between periods (P < 0.05)

Growth and linear body measurements

There was an interaction between contact system, calf age and BW ($P < 0.001$). No interactions were found between system, period and health status on calf BW. Calves in the NC-I system weighed less at the end of each period than FT-O and PT-I calves, which were similar weights (Table 5). Calves in the FT-O system weighed more in the carry-over period on day 134 (124.1 ± 2.57 kg; $P < 0.050$) and 189 (174.3 ± 2.57 kg; $P < 0.001$), than both the NC-I and PT-I calves, which were similar (113.7 ± 2.57 kg and 161.3 ± 2.57 kg, respectively).

There was an interaction between period and system for calf ADG ($P < 0.01$; Table 5). 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.

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	P value
Age	Weight (kg)					
28		49.0[a]	54.7[b]	56.2[b]	1.56	0.001
56		69.0[a]	82.1[b]	82.1[b]	2.35	<0.001
70		79.0[a]	87.4[b]	86.8[b]	2.45	0.008
77		81.8[a]	92.2[b]	89.3[b]	2.59	0.005
	ADG (kg/day)					
0-28		0.53[a]	0.73[b]	0.79[b]	0.053	<0.001
29-56		0.69[a]	0.97[b]	0.93[b]	0.066	0.001
57-70		0.68[a]	0.32[b]	0.32[b]	0.09	0.012
71-77		0.41[a]	0.89[b]	0.46[a]	0.15	0.021

[ab] means within a row with a different superscript differ ($P < 0.05$)

There was no interaction between system and age in terms of calf length and height (P = 0.522 and P = 0.280, respectively). A strong positive correlation existed between calf weight and girth (R^2 = 0.91). An interaction was found between system and age for calf girth (P < 0.001; Figure 1); calf girth in the NC-I system was lower than the FT-O from 35 to 84 d (P < 0.05) and PT-I systems from 42 to 84 d (P < 0.050), FT-O and PT-I were always similar. No differences in girth circumference existed between systems at the end of the carry-over period (112 d). Throughout the study, there were no differences between system and calf length (P = 0.203) or height (P = 0.891).

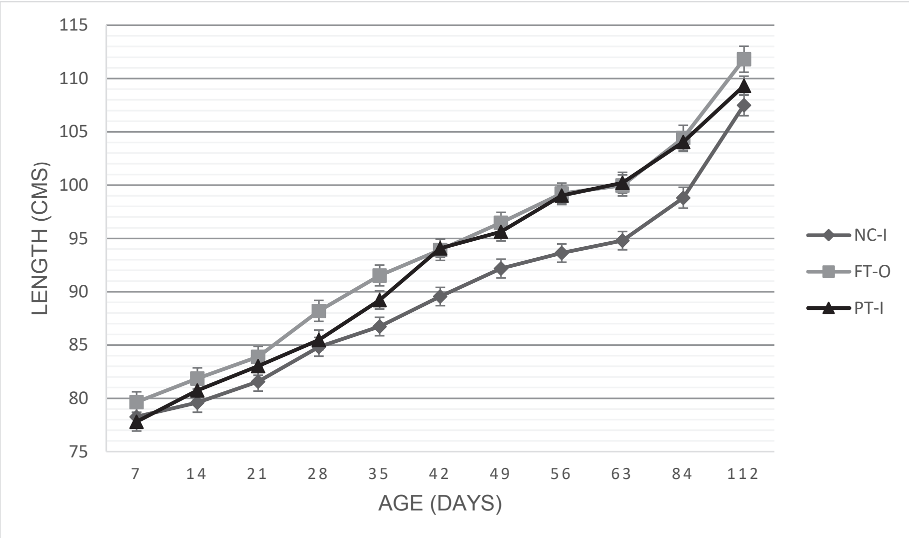

Figure 1. Calf girth (cm ± SEM; represented in the error bars) relative to age (days) for calves with no contact (NC-I), full-time contact (FT-O) and part-time contact (PT-I) with weaning commencing at 58 days for contact calves and 44 days for NC-I calves.

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.

Labour

The NC-I system required the most labour at calving (00:15:56 ± 00:00:35; P < 0.001) 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 (P < 0.001) 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 (P = 0.159; 00:00:47 ± 00:00:05).

The total weekly labour requirement for the FT-O system was greater than both the NC-I and PT-I systems (Table 6). The time to move cow-calf pairs and reunite cow-calf pairs was greater for the FT-O system compared to the PT-I system. Furthermore, the labour associated with calf health inspections was greater for the FT-O system than both NC-I and PT-I systems. The total time required to milk cows differed between each system (P < 0.01, respectively). 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).

No differences existed between FT-O and PT-I regarding the labour associated with weaning; the time required to move cows was 00:01:39 ± 00:00:07 per cow/day (P = 0.951) and to move calves 00:00:35 ± 00:00:03 per calf/day (P = 0.899), respectively.

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**	**P-value**
per calf/day					
Total Labour	00:00:38[a]	00:01:29[b]	00:00:49[a]	00:00:05	0.001
Fill Hopper	00:00:06	NA	NA	00:00:01	NA
Feed Inspection	00:00:04	NA	NA	00:00:01	NA
Cleaning pen/equipment	00:00:22	NA	NA	00:00:02	NA
Separation	NA	00:00:11	00:00:09	00:00:02	0.449
Movement (calf and or cow)	NA	00:00:52[a]	00:00:31[b]	00:00:04	0.001
Reunite	NA	00:00:15[a]	00:00:02[b]	00:00:02	0.001
Health Inspection	00:00:06[a]	00:00:11[b]	00:00:07[a]	00:00:01	0.001

[ab] means within a row with a different superscript differ ($P < 0.05$)

DISCUSSION

Calf health

Cow-contact may influence calf health, as suggested by elevated hindquarter faecal matter for FT-O and PT-I calves, compared to NC-I calves. High volumes of milk consumption is common among CCC systems (Johnsen et al., 2016). Therefore it is possible, particularly for PT-I calves in the early pre-weaning period, that these calves drink in excess and strain their young digestive system (Bazeley, 2003), resulting in nutritional diarrhoea. As the PT-I cows were milked only once per day, it is likely that high volumes of milk were available for calves to consume, which may have facilitated this over-consumption. In addition, environmental exposure to changeable weather (alongside high milk intake) for FT-O calves appears to have impeded calf health (Bazeley, 2003), increasing the number of calves requiring removal from treatment due to illness associated complications. This supports concerns raised by farmers of CCC in seasonal calving pasture-based dairy systems (Neave et al., 2022). Furthermore, 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. While a two-step reduction process was implemented for the nursed calves, the process was still more abrupt process than that of the

NC-I calves. 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 (Costigan et al., 2022). That said, these calves had a high dietary dependency on milk and thus, perhaps a longer period of time is needed for these animals to become fully functioning ruminants. Aside from the dietary aspect of CCC, cows often act as vectors for infections in young stock (e.g., Bovine Viral Diarrhoea (Veterinary Ireland Journal, 2019), Johne's Disease (AHI, 2021a) 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. Indeed, efforts were made to diminish challenges by minimising exposure to cow faecal matter and associated pathogen build-up (i.e., automated scraper, disinfection of cubicles, rotational grazing), however it was impossible to eliminate all associated risks. This is a prominent issue with calves at grass and can lead to growth reduction and respiratory related issues (Teagasc, 2017).

5

Weekly and weaning behaviour

Calves expressed lying most often in the pre-weaning period, reflecting likeness to existing studies (Calvo-Lorenzo et al., 2016; Sinnott et al., 2021; 2022). It is believed that resting behaviour is associated with positive growth rates in cattle (Mogensen et al., 1997). More standing in the two contact systems compared to the NC-I system during weaning may indicate contact calves were more stressed by the weaning process. This is a finding echoed by behavioural 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 increased vocalisations (Newberry and Swanson, 2008) for contact calves, compared to NC-I calves.

The NC-I calves ruminated more than contact calves in the early stages of weaning with Fröberg et al. (2011) finding the same to be true (comparing free-suckling contact calves to milk restricted calves with automatic feeders). It is possible that contact calves were not used to consuming large quantities of solid feed (due to reliance on milk pre-weaning), thus explaining the reduction in rumination. Fröberg et al. (2008) found less solid feed consumption and rumination in restricted suckling system versus artificial rearing. Regulation thereafter may indicate greater consumption of solids 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). Additionally, NC-I calves transitioned from a predominantly concentrate and hay diet to fresh grass in this time, necessitating digestive system adaptation. The FT-O calves grazed most post-weaning, followed by PT-I and NC-I calves suggesting social learning and imitation from the dam may have contributed to this (Fukasawa et al., 1999; Costa et al., 2014; Nicolao et al., 2020). Additionally, this increase in time spent grazing may be due to pre-weaning exposure and familiarity with grass, a tendency also found in a study by Phillips (2004). During weaning, solid feed consumption was similar among calves, however PT-I calves consumed less in days 1-3 than later stages. These calves may not have consumed large quantities of solids due to anticipation of reuniting with dams following restriction (as would be expected with their daily routine). The FT-O calves consumed more liquids than NC-I calves, which was expected given the freedom to consume *ad libitum* milk these calves experienced. Although related to a different behaviour, this echoes a similar pattern highlighted by Jensen (1999), where calves experienced rebound locomotion after periods of confinement (i.e., behaviour performed at greater level following restriction, compared to if they did not experience restriction).

Calves in all three systems performed abnormal behaviours similarly for the most part, however PT-I calves expressed these more during late pre-weaning than FT-O calves and weaning than NC-I calves. As abnormal behaviours can be considered a stress response, partial contact with the cow (repeated separation and reuniting) may have been more stress inducing than being with the cow completely (FT-O) or not at all (NC-I). Weaning also appeared to be more stressful for PT-I calves than NC-I, but similar to FT-O calves. Reductions in abnormal behaviours for FT-O calves is in accordance with Veissier et al. (2013) and Fröberg et al. (2011), indicating unrestricted contact and suckling reduces these behaviours. Social interaction with conspecifics was greater for calves in contact systems than NC-I calves throughout the study which is most likely a result of social learning from the dam. Although studies have indicated socialisation with other calves is comparable to dam socialisation in terms of social development (Krohn et al., 1999; Duve et al., 2012), this study suggests CCC is more socially effective (perhaps due to both cow and calf exposure). That said, the presence of dams in contact treatment groups automatically doubled the number of animals calves could interact with (compared to NC-I calves) which may also be a positive influence on social skill development.

Calf growth and body measurements

Pre-weaning growth was superior for contact calves, which was expected on account of high milk consumption within such systems (Fröberg et al., 2011; Kisac et al., 2011). This dietary advantage appears to be related primarily to weight gain, more so than bone growth and development (length and height) in the 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. In addition to this, cows were milked only once-per-day which may have resulted in more milk being available to PT-I calves, compared to FT-O calves. This could echo rebound behaviour suggestions mentioned previously (i.e., consuming milk/suckling). Contact calf ADG declined considerably during the weaning period, which is likely attributable to dietary, social and environmental changes inducing stress. Although unrestricted concentrates were provided to all calves, 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), particularly FT-O calves who may have also been less reliant on concentrates due to grass being an alternative feed source. It was not possible to account for the proportion of grazed grass in the diet, however 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, where the calf remains at pasture with the group while cows are removed, as is recommended for suckler beef systems (Teagasc, 2014a). However, due to excessive calf distress and absconding from paddocks in search of their dam, similar to issues mentioned by Wagner et al. (2013), an indoor alternative was implemented, resulting in dietary and environmental changes. During the early and late post-weaning periods, PT-I ADG remained low, indicating that pre-existing stress associated with weaning, dietary, social and environmental transitions for these calves 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., 2011c). 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). This post-weaning growth resumption encourages further research into developing viable pasture-based weaning strategies for CCC, while also exploring the introduction of grass pre-weaning for artificially reared calves (which will move to a pasture-based system post-weaning) to minimise growth disturbances associated with weaning (Khan et al., 2011) and also the learning mechanisms underpinning the commencement of grazing behaviours. However, it must be recognised that FT-O calf growth, in this study, may be exceptionally high due to a degree of ‘natural selection’, whereby weaker animals that may have had a lower rate of weight gain were removed from treatment.

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 study was one of the first to evaluate labour in the three rearing systems and quantify the differences. Labour differences between CCC and non-contact calves immediately post-calving are substantial with NC-I calves requiring considerable assistance in the hours after birth (Gleeson et al., 2008). Much of this was attributable to dam colostrum collection for NC-I calves, a method employed in this study to provide feeding consistency among systems. Barry et al. (2022) indicated that colostrum of high quality from a single other dam, which is collected and stored appropriately, is sufficient for calf consumption. As such, the total labour associated with NC-I calves post-calving may be mitigated slightly by collecting and storing a reserve of high-quality colostrum at a time more convenient for the farmer (i.e., at regular milking times). The daily labour of the FT-O system was most intensive, which was 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, safe working environments for farmers are high priority and consideration must be given to the safety risks associated with performance of protective and agitation behaviours by the dam, in relation to the calf. Personal observation found that safety issues related to dams turning suddenly to have their calf in their line of sight can be a threat to the animal handler.

Differences in labour input between contact systems were expected due to once-a-day milking separation and movement of the PT-I system (in addition to known labour benefits of such milking systems; Bewsell et al., 2008) compared to their twice-a-day FT-O counterpart. It must be recognised that labour estimations are likely low for the NC-I and PT-I systems because cow movement around the grazing platform is not accounted for. This would depend on how near/far cows are situated from the milking parlour and thus, is very farm dependent (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 to provide an estimation of time for cow-calf pairs in an outdoor CCC system. These pairs were situated in the grazing block closest to the milking parlour and as such, a movement comparison against the other two systems would be biased and inaccurate. Similarly, provision of forage and concentrate labour is not included as it would also depend on the location of the resource relative to the system pen/paddock. A further labour demand of the FT-O system was the time spent inspecting calf health. This may result from this system occupying a larger space than their indoor counterparts, taking longer to move between and inspect each calf appropriately. Alternatively, it may be related to human avoidance behaviour of calves due to lack of human interactions. This could also be attributable to the morbidity statistics reported herein for this system, whereby the FT-O system required greater intervention for illness, compared to the other two systems. Higher frequencies of health complications would naturally lend itself to spending more time inspecting the health of calves to ensure corrective action was successful. For the weaning period, contact system labour was similar, which was expected due to identical weaning strategies implemented, however this was greater than for the NC-I system. The weaning labour associated with the NC-I system was essentially negligible, due to the pre-programmed automatic feeder managing all feed plans associated with each calf and initiating the weaning process without human intervention (Käck and Jan Ziemerink, 2010).

System opportunities and challenges

When evaluating CCC systems, it is important to be mindful of not only the cow and calf, but also the people implementing these practices on-farm. The daily labour involved with calf care increased with the full-time CCC as applied in the present study, which would challenge farmers during an already 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). Appropriate facilities for cow-calf bonding, milking separation, as well as fencing for weaning are integral to the successful handling of animals for the farmer. That said, the cost of an automatic milk feeder and associated milk replacer (provided this is the milk fed to calves) is eliminated with this system.

Calf growth is an undeniable benefit of CCC. That said, PT-I calves faced challenges during weaning and thereafter. Here, these calves experienced three primary stressors; environmental (a long-term change from indoor to outdoor), social (de-bonding) and diet (primarily milk and concentrate substitution to grass-based and concentrate substitution). These challenges around weaning had long-lasting effects, emphasised by stunted calf weight-gain post-weaning. Although FT-O calves experienced similar stressors, environmental changes were short-term (calves moved indoor for weaning period only). Upon returning outdoors post-weaning, growth rates indicate that pre-weaning grass exposure mitigated the remaining weaning stressors, and facilitated a return to higher growth rates.

Calf health for the PT-I system, although challenged, was less affected than for the FT-O system. Health difficulties faced by FT-O calves raises welfare concerns. Removal from treatment data suggests approximately one quarter of calves in this type of system would succumb to life-threatening health complications. As health issues, likely outdoor and age related, are an issue for young calves in full-time outdoor systems, a hybrid model between this and the PT-I system may be better for the calf. This could see calves remain indoors for an extended period until older with a greater ability to cope in outdoor spring environments.   This urges further research and improvements for rearing calves in pasture based CCC systems as this is a new and much understudied area of calf rearing.

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

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 compromises calf health and human welfare in terms of daily labour. Similarly, PT-I calf behaviour patterns, such as abnormal behaviour expression, and stunted growth post-weaning highlight challenges faced before, during and after weaning. Thus, CCC in pasture-based dairy systems require further research to ensure the safeguarding of calf and human welfare.

ACKNOWLEDGEMENTS

The authors would like to thank Fiona Guinan and Gort Gerrit for comments related to statistical analysis within this manuscript. The authors would like to acknowledge support given by the Teagasc, Walsh Scholar funding scheme and Vistamilk. We also thank the farm staff at Teagasc, Moorepark for their care of the animals and assistance during the study.

SUPPLEMENTARY FILES

Supplementary File 1. The start and stop cues for the stopwatch (SW) for each labour related task associated with each management system; no cow-calf contact (NC-I), part-time cow-calf contact (PT-I) and full-time cow-calf contact (FT-O).

	NC-I	PT-I	FT-O
Calf movement	SW starts when calf is moved after weighing/ move calf to individual pen/ SW stops when door of individual pen is closed	N.A.	N.A.
Cleaning cow udder	SW starts when enter pen to clean/ SW stops when each teat and udder surface is cleaned sufficiently for colostrum collection	SW starts when enter pen to clean/ SW stops when each teat and udder surface is cleaned sufficiently for suckling	SW starts when enter pen to clean/ SW stops when each teat and udder surface is cleaned sufficiently for suckling
Dipping navel and ear tagging	SW starts when individual pen opened / tag and iodine navel / SW stops when individual pen is closed	SW starts when enter pen/ tag and iodine navel/ SW stops when leave pen	SW starts when enter pen/ tag & iodine navel/ SW stops when leave pen
Colostrum collection	SW starts when clusters are placed on teats / milked fully/ SW stops when clusters are removed from teats Note: if clusters fall off they are reapplied and this is included in this time	N.A.	N.A.
Colostrum feeding	SW starts when approach calf to feed/ colostrum fed / SW stops when sufficient colostrum consumed	N.A.	N.A.
Filling hopper	SW starts when bag opened. Hopper cover removed. Bag emptied into the hopper. SW stopped when the hopper cover replaced.	N.A.	N.A.
Feeding inspection	SW started when hand-held automatic feeding monitor attached to feeder inspected for calf drinking history. SW stopped when all calves' information checked.	N.A	N.A

Supplementary File 1 continued. The start and stop cues for the stopwatch (SW) for each labour related task associated with each management system; no cow-calf contact (NC-I), part-time cow-calf contact (PT-I) and full-time cow-calf contact (FT-O).

	NC-I	PT-I	FT-O
Clean pen and equipment	SW started when entered pen. Water and detergent used to clean surfaces. SW stopped when pen and respective feeding unit within the pen were clean	N.A	N.A
Separation	N.A.	SW starts when entering pen/paddock to begin separation. Cows and calves separated. SW stops when all cows and calves successfully separated.	SW starts when entering pen/paddock to begin separation. Cows and calves separated. SW stops when all cows and calves successfully separated.
Reuniting	N.A.	SW starts when gate around yard opened to move cows from yard to calf shed. SW stops when gate locking cows into shed with calves is closed.	SW starts when gate opened to move cows from yard to calves in parlour collecting pen. SW stops when pairs reunite to begin movement to paddock.
Health inspection	SW starts when enter pen. Inspect all animals' health status. SW stops when sufficient health inspection of all animals carried out	SW starts when enter pen. Inspect all animals' health status. SW stops when sufficient health inspection of all animals carried out	SW starts when enter pen. Inspect all animals' health status. SW stops when sufficient health inspection of all animals carried out
Weaning separation	N.A.	SW starts when entering pen/paddock to begin separation. Cows and calves separated. SW stops when all cows and calves successfully separated.	SW starts when entering pen/paddock to begin separation. Cows and calves separated. SW stops when all cows and calves successfully separated.
Weaning reuniting	N.A.	SW starts when gate opened for calves to move into cow weaning pen. SW stops when all calves moved into cow pen and gate closed between cows and calf pen.	SW starts when gate opened for calves to move into cow weaning pen. SW stops when all calves moved into cow pen and gate closed between cows and calf pen.

Supplementary File 2. Average regional weather conditions (2021) and the 10 year average (2010-2020), when calves were in their respective system during the pre-weaning period

	Mean Air Temp (°C)		Max Air Temp (°C)		Min Air Temp (°C)		Precipitation (mm)		Mean Wind (knot)		Max Wind (knot)	
	10 Year	2021	10 Year	2021	10 Year	2021	10 Year	2021	10 Year	2021	10 Year	2021
Jan	5.08	4.97	11.98	8.11	-4.21	1.84	99.24	48.40	5.62	5.67	38.83	18.97
Feb	5.71	6.31	13.65	9.27	-3.65	3.36	91.61	189.90	6.93	8.73	42.64	26.44
Mar	5.88	7.47	13.82	11.19	-3.13	3.75	66.75	52.70	5.78	6.45	37.00	21.63
Apr	8.05	7.44	16.54	12.33	-1.70	2.53	65.53	22.50	5.76	5.32	35.17	17.99
May	10.48	9.82	19.62	14.23	0.97	5.41	56.41	130.80	5.62	6.38	29.67	20.67

Supplementary File 2 continued. Weather

This table shows the regional weather conditions during the experiment and of the 10 year average (2010-2020). Average temperatures were lower in 2021 during January, April and May (-0.1, -0.6 and -0.7 °C, respectively) and higher in February and March (+0.6 and +1.6 °C, respectively), compared to the previous 10 year average. Total precipitation in 2021 was less for January, March and April (-50.8, -14.1 and -43.0 mm, respectively), but greater during February and May (+98.3 and +74.4 mm, respectively) than the previous 10-year average. Average wind speed in 2021 was greater during February, March and May (+1.8, +0.7 and +0.8 knots, respectively), whereas wind in April 2021 was less than the 10 year average (-0.4 knot, respectively).

Average ambient temperatures for indoor housing (i.e., NC-I and PT-I) during the pre-weaning period was 8.5 °C (range from 0 to 20.0 °C) with temperatures outside TNZ during 83 out of 122 d. The average atmospheric temperature for calves outdoors (i.e., FT-O) was 10.9 °C (range from -5.3 to 20.1 °C), with temperatures outside TNZ during 97 out of 122 d. The average relative humidity for calves housed indoors and outdoors was 83.9% (range of 39.4 to 100%) and 82.9% (range of 55.9 to 98.5%), respectively.


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Chapter 6

General Discussion

INTRODUCTION

The European dairy sector has been reformed in recent years following milk quota abolition in 2015. While a number of countries have faced production restriction or decline (France and Greece, respectively), Ireland has seen an increase in milk production (+41% from 2015 to 2019; Shalloo et al., 2020), more new entrants into dairy farming (Forde, 2021) and increased herd size (Brodam, 2021). As herd size increases, so too does the number of calves being born on-farm. Seasonal compact calving systems are employed in Ireland, meaning cows calve in a condensed period during spring, with a target of 90% of the herd calving within six weeks (Teagasc 2016). To facilitate exploitation of grazed grass, a low-cost feed resource (Doyle et al., 2022), synchronisation of lactation commencement and grass growth occurs (Dillon et al., 1995). Farm labour reflects spring pressures, with spring being the most labour intensive period on dairy farms (Deming et al., 2017), placing additional strain on farmers due to hired labour costs and difficulties sourcing additional labour (Eastwood et al., 2018; Kelly et al., 2017). With calf care highlighted as one of the most labour intensive processes on-farm (O'Donovan et al., 2008) and trends showing improved six-week calving rates (ICBF, 2022) calving is likely to become even more compact in future, therefore, avenues for reducing workload must be explored for calf rearing (e.g., technology usage and alternative management strategies). However, management decisions made on-farm heavily influence a calf's welfare status in terms of their health (Svensson and Liberg, 2006; Lorenz et al., 2011a), behaviour (Sutherland et al., 2014; Costa et al., 2016) and growth (Fröberg et al., 2011; Kisac et al., 2011). Thus, when adapting calf management systems, the welfare of both the farmer and the calf need careful consideration.

Therefore, the main aims of this thesis were to evaluate labour inputs required for various calf management systems and housing strategies and examine how these systems and strategies employed on-farm affect calf health, behaviour, growth and overarching welfare. I will first discuss the impact management and housing systems have on labour. Next, the implications of management and housing systems on calf welfare will be addressed. Calf-welfare promoting management strategies will be discussed in relation to One Welfare and recommendation for future research and practice are described. Finally, the main conclusions of the thesis are given.

Labour implications

This thesis saw vastly different calf management and housing systems evaluated, with considerably different outcomes in terms of labour efficiency. On a surface level, ranking across chapters by order of most to least efficient, in relation to their overall total daily labour input figure, the systems are as follows: indoor group housing with automatic feeder (Chapter 3, 4 and 5), part-time cow-calf contact (CCC) indoors (Chapter 5), indoor group housing with manual feeding (Chapter 4), outdoor group hutch with manual feeding (Chapter 4), full-time cow calf contact outdoors (Chapter 5), and outdoor individual hutch (Chapter 4). Despite their ranking, each system has both positive and negative aspects, which will be outlined in the following section.

One important aspect, in relation to labour and calf rearing, is the management surrounding colostrum feeding. In recent years, there has been huge progression in research and knowledge surrounding colostrum feeding and management (McGrath et al., 2016, Barry et al., 2022), with it being well recognised as the first tool to build immunity and aid in a calf's defence against infectious agents (Yang et al., 2015). To achieve appropriate levels of immunity, sufficient volumes of good quality colostrum must be fed (Godden, 2008). From findings in Chapter 2, it is clear that commercial dairy farms most commonly interrupt the natural process of a calf suckling colostrum from the dam because of immediate separation, in lieu of manually feeding colostrum to calves. Chapter 5 illustrates very notable differences in labour implications in how a calf is managed in the time immediately post-calving, when either a natural or artificial rearing system is employed. Compared to the intervention of farmers in this process, assuming the role of the dam (collecting and feeding colostrum) which has direct implications on their own labour, facilitating dam colostrum consumption via calf suckling is more labour efficient.

Furthermore, artificial intervention means round-the-clock assistance is required due to the relative unpredictability of calving. While most farms have a team of calf rearers, hired labour or otherwise (i.e., family) (Chapter 2), there are also a large number of other tasks on-farm in the spring besides calf rearing, such as milking, grassland management and animal health provisions (Hogan et al., 2022a). For the most-part, farmers were unconcerned about the workload associated with the upcoming calving season (Chapter 2), however a considerable proportion were somewhat to extremely concerned about the associated workload. It is possible that these farmers anticipate long spring working hours and stressful conditions, which can lead to exhaustion as well as burn-out. Such stressors can have detrimental effects on human welfare and mental health (Schaufeli et al., 1996). Problems related to this may be expected to worsen among farmers if this tendency of increasing herds and number of calves continues in the near future.

Obvious downsides in electing to leave a calf with their own dam to suckle following calving are the inability to determine the quantity of colostrum consumed as well as colostrum quality variability from cow to cow. While colostrum is available from the dam on a relatively *ad libitum* basis (depending on the volume of colostrum a heifer/cow can produce), if this is not of sufficient quality, or the calf is unable to suckle independently, calf welfare is threatened as a result. That said, most farmers admittedly do not test colostrum quality on-farm and if they do, some do not test the quality of all samples (Chapter 2). In this case it is impossible to determine if the colostrum manually fed to calves is of good quality anyway. As such, an advantage of a suckling system would be that calves have more access to colostrum/transition milk with less associated labour.

Future opportunities exist to either fuse both natural and artificial practices (Chapter 5) or create a system that is more efficient for the farmer (being mindful of biosecurity measures to minimise the spread of diseases e.g. Johne's disease). Research shows colostrum from a single other dam of sufficient quality is as beneficial as own dam colostrum (Barry et al., 2022). In this case, it may be possible to test own-dam colostrum quality and if inadequate, intervene with milk from a single other dam. However the importance of testing colostrum quality, including samples from all cows, needs to be stressed to farmers in this case

(Chapter 2). Similarly, in Chapter 5, own-dam colostrum was collected and immediately fed to calves. Considering the above research, a colostrum management system where own-dams are not milked immediately post-calving, instead utilising milk from one other dam stored appropriately, may reduce labour of artificial rearing immediately post-calving (Barry et al., 2022). A labour reduction might be seen, depending on the volume of colostrum provided, because colostrum collection labour would be spread across multiple calves, reducing the labour on a per calf basis.

Immediately following calving in artificial rearing systems, calves are frequently housed in groups (Chapter 2). Automatic milk feeders are a technology used in group housing systems as a method of reducing calf rearing labour, as demonstrated in Chapter 3, 4 and 5. While there is variation between the total labour associated between automatic calf feeders across Chapter 3, 4 and 5, this is largely down to the data handling during each study. For example, total daily labour in Chapter 4 includes pen cleaning across all systems. This is reported in-text so as not to bias one system or another due to infrequencies in the data (Chapter 4), whereas Chapter 3 and 5 include this in total labour figures. Including this would contribute to a higher total labour figure in Chapter 4, meaning total labour figures derived from Chapter 3 and 5 are the most accurate labour depictions for automatic milk feeders.

There is a low uptake of automated feeding technology on commercial farms, with farmers favouring manual feeding practices instead (Chapter 2; similarly found by Medrano-Garlaza et al., 2017b). No details as to why farmers elected not to use automatic feeders were collected (Chapter 2), but offers an avenue for potential research. While this thesis has outlined the labour saving benefits of this technology (Chapter 3, 4 and 5), the costs of these feeding systems is a notable barrier to implementation (Medrano-Galarza et al., 2017a), as well as determining the number of systems required to cater for calf numbers. Another reason for low uptake, not referred to in literature, may be due to automatic feeders being used for a limited period of time in compact seasonal calving systems, such as Ireland (approx. 5 months). In comparison, a system with year-round calving would see feeders being used throughout the year, with a lower demand due to fewer calves being born in a compact timeframe.

While automatic feeding systems are most labour efficient overall, various other systems also had their own advantages, relative to calf care tasks. An advantage of the manual feeding system was the ability to amalgamate tasks for efficiency. For example, during feeding inspection, it is possible to carry out health inspection simultaneously (Chapter 3 and 4). Similarly, during separation of contact systems, it was possible to also inspect calf health at the same time (Chapter 5). With the automatic feeding system, while the hand held computer can provide information regarding drinking behaviour, it does not give a physical indication of calf health (Chapter 3, 4 and 5). As such, it is necessary to enter the group pen at a different time to carry out appropriate health inspections. This would also be a beneficial practice to build human animal relationships for less fearful calves, because unlike using automatic feeders, the positive association of food provision with humans for the manually reared calves is a very effective way to do this (Jago et al., 1999). A drawback of the manual feeding system is high levels of labour associated with the preparation of milk replacer and feeding this milk to calves (Chapter 3 and 4). In comparison, contact systems limit this issue entirely (Chapter 5), whereas automatic milk feeders reduce it significantly (Chapter 3, 4 and 5; with the exception of filling the hopper with milk replacer powder). A benefit to contact systems is the elimination of the need to wash feeding equipment entirely (Chapter 5), whereas this is still a requirement for manual and automated feeding systems (Chapter 3, 4 and 5).

An obvious difference among the systems evaluated throughout this thesis is where calves were located; either indoors or outdoors. Although management decisions vary immensely between each system, it must be highlighted that indoor systems (Chapter 3, 4 and 5; indoor group housed calves fed via automatic or manual feeder and part-time CCC indoors) appear to rank better in terms of total daily labour than all outdoor systems (Chapter 4 and 5; Outdoor individual and group hutches fed manually and full-time CCC outdoors). Containing calf-rearing operations to confined spaces indoors undoubtedly minimises the movement required to perform tasks such as milk transportation and feeding equipment as well as health inspections of calves. Furthermore, working in farming environments that have direct exposure to outdoor elements and weather conditions, can lead to job dissatisfaction (in winter environments; Medrano-Galarza et al., 2017a).

Calf management practices and housing systems that promote welfare

The environments calves are exposed to, and the management decisions made in relation to rearing practices, have a direct impact on calf health, behaviour and growth, all three of which are indicators of calf welfare (Lorenz et al., 2011a), which will be discussed in-depth in the following section.

Health

Rearing calves in relatively regulated environments (i.e., either indoors or in protective calf hutches; Chapter 3, 4 and 5) appears to be beneficial for calf health, compared to a paddock-based alternative (Chapter 5). Full-time cow contact outdoors (Chapter 5) increased calf morbidity and required the removal of a number of calves from the system due to illness associated complications, compared to indoor systems (both part-time cow contact and artificially reared calves; Chapter 3, 4 and 5). As a hybrid of indoor and outdoor systems, paddock access is a popular calf rearing approach among commercial farmers (Chapter 2). Although there was a poor health outcome among calves in the outdoor system investigated in Chapter 5, I believe there are a number of factors related to this. Due to cows moving outdoors to graze soon after calving (Dillon et al., 1995), providing full-time cow contact meant calves also moved outdoors at young ages (5 ± 3.3 days old). At this age, a calf's regulatory systems may not be developed sufficiently to cope with outdoor environments (Marcato et al. (2022), this highlighted potential for moving calves outdoors at an older age when they have improved adaptive immunity (28 vs 14 day)). In comparison, calves in Chapter 4 moved outdoors successfully from three weeks old and similarly, calves were commonly only moved outdoors from three weeks onwards on commercial farms also (Chapter 2). Inter-changeable spring weather patterns (i.e., fluctuations in temperatures including relatively low temperatures between -5.3 and 20.1 °C, rainfall and wind speeds) may have also challenged young contact calves, which was not something indoor housed calves, or hutch managed calves experienced to the same extent. While the cow was present with the calf outdoors, offering an *ad libitum* resource of fresh, warm milk, large volumes of milk consumption likely led to nutritional diarrhoea for these calves. This, alongside changeable weather patterns, may have resulted in calves being immunocompromised, pre-disposing them to acquiring additional pathogens, leading to infectious diarrhoea (Bazeley, 2003).

For the most part, when comparing indoor automatic (Chapter 3 and 4) to both indoor and outdoor manual feeding systems (Chapter 3 and 4), calves were scored as healthy. The comparison of indoor systems alone (Chapter 3) saw greater faecal scores in manually fed calves, an indicator of diarrhoea related issues. Although not significant, in Chapter 4 when comparing indoor and outdoor systems, manually fed calves had a slightly higher frequency distribution of faecal related health scores. Similarities in distribution frequencies across indoor and outdoor housing systems with manual feeding systems, suggests that faecal related issues may be more related to the volume and frequency of milk fed to calves rather than the location of the calves. For example, larger volumes of milk less frequently may cause a level of digestive strain on the calf (Songer and Miskimins, 2005; Burgstaller et al, 2017). That said, when the milk volume fed to calves reaches *ad libitum* levels, this leads to even greater incidence of faecal related issues, as seen in cow-contact systems (compared to calves using automatic feeders on a relatively restricted milk diet; Chapter 5). These large volumes of milk are linked to the presence of nutritional diarrhoea. Research suggests that when provided a choice with *ad libitum* feed resources (including *ad libitum* milk), calves selected diets that led to low levels of non-nutritive oral behaviours and increased chewing and rumination (Webb et al., 2014). However, this research was conducted with artificially reared calves, where the incentive for dam bonding and socialisation would not have been a contributing factor to milk consumption.

Group size on commercial farms (Chapter 2) and the research farm (Chapter 3, 4 and 5) were larger than recommended, for the most part (recommendation groupings of < 10 calves; except outdoor group hutches which were in groups of 8), with no obvious health complications associated with this as a result. Thus, perhaps group sizing is more of a risk for calf illness if management decisions on-farm do not reflect best practice (e.g., farm hygiene). High levels of sanitisation were employed on the research farm where possible (Chapter 3, 4 and 5) which appeared to prove effective, due to low levels of illness experienced, namely in artificial rearing systems. While efforts were made to reduce health challenges experienced by contact calves (cow faecal matter is high-risk due to associated pathogens; Pelan-Mattocks et al., 2000), it was impossible to eliminate all associated risks in these systems (Chapter 5). This may be reflected in the higher instances of illness in these calf groups. The common practice of cleaning calf feeders daily and use of a cleaning agents at least once a week on most farms, according to farmers, may also lend itself to larger calf groupings (Chapter 2).

Behaviour

Providing animals the opportunity to express natural behaviours is vitally important for their overall welfare (von Keyserlingk et al., 2009). Out of all calf management and housing systems evaluated within this thesis, the full-time CCC outdoor system (Chapter 5) offers the closest alternative to what would occur naturally for cow and calf, followed by the part-time CCC indoor system. The full-time system enables calves to perform unlimited suckling behaviours, as desired, in the pre-weaning period in an outdoor environment, which promotes exploratory behaviours (Kerr and Wood-Gush, 1987). Unlike their full-time counterparts, suckling for the part-time calves is confined to specific time-points during the day. That said, both of these contact systems facilitate the element of social learning from the dam, which artificial rearing systems cannot provide (Chapter 3, 4 and 5), which is highlighted as valuable developmentally for the calf (Costa et al., 2014; Nicolao et al., 2020). In artificial rearing practices when comparing manual and automatic feeding systems (Chapter 3 and 4), automatic feeders echo a contact system most closely. These feeders allow for smaller and more frequent feeds, while also mimicking natural feeding and suckling practices (Medrano-Galarza et al, 2017a), but lack the social contact and maternal care of the cow.

Manually feeding calves limited amounts twice per day, then a reduction to once per day over time, is common practice, which limits a calf's ability to express said suckling behaviours as desired.

The expression of abnormal behaviours, such as tongue rolling and excessive oral manipulation of objects and body parts, are indicators for welfare problems (Bokkers and Koene, 2001; Lv et al., 2021). While it could be assumed that fulfilment of natural behaviours for cow-contact calves would be sufficient to eliminate the presence of abnormal behaviours in a calf's life, results from Chapter 5 indicate this, in-part, to be incorrect. Compared to their full-time and artificially reared counterparts, the part-time system expressed elevated levels of abnormal behaviours. This may be interpreted as an expression of calf frustration in response to elements of this management system, potentially linked to repeated separation from the cow. Aside from this, low levels of abnormal behaviours (including tongue rolling, urine drinking, oral manipulation of objects and body parts, cross sucking) were seen throughout this body of research (Chapter 3, 4 and 5). Despite influencing a calf's ability to perform natural suckling behaviours artificially (automatic and manual feeding systems), abnormal behaviours did not appear to increase considerably in response to these conditions (when comparing frequency of abnormal behaviour to contact systems). However, while artificial management systems did not appear to negatively influence calf welfare in this way, quality of life is also determined by positive experiences (Webb et al., 2019). Management decisions made on farm with artificial rearing systems provide a certain level of positive experiences such as facilitating socialisation (group housing with peers only), exploratory behaviours (straw as bedding), play behaviours (adequate space allowance per calf) and access to forage and concentrates (many provisions of which are also commonly seen on commercial farm level (Chapter 2)). However, the basic level natural and positive experience of CCC (provided sufficient bonding has occurred) is denied in these systems, and this cannot be ignored.

As cows and calves are herd animals by nature, socialisation plays a huge role in their day-to-day lives. Although it may appear obvious, calf socialisation levels were higher in group housing (Chapter 3, 4 and 5), than an individual housing setting (Chapter 4). While behaviour was not studied specifically on commercial farms (Chapter 2), individual housing was not used on a long-term basis (<5 days), suggesting socialisation occurred following this period. A notable disruption to calf standing behaviour was found among individually housed calves, whereby standing was increased considerably for these animals (compared to their group housed counterparts) (Chapter 4). This appears to highlight the behavioural effects of inhibited socialisation. These calves stood more frequently in the outer gated enclosure area, which provided visual, auditory and a level of tactile contact with other calves. Social security of conspecifics is extremely important to herd animals, with distress signals evident upon separation (Færevik et al., 2006). Retirement to lie in the hutch structure meant the elements of physical, visual and auditory social security were impacted, meaning this was potentially undesirable for the calves, further supporting previous research indicating the positive impact of group housing on the calf compared to individual housing (Costa et al., 2016; Mahendran et al., 2021). Socialisation also aids calves in the decision making process surrounding feed and diet (Whalin et al., 2018; Mahendran et al., 2021). Contact calves (Chapter 5) had the highest levels of social interaction, compared to artificial rearing (automatic feeders specifically in Chapter 5, however socialisation levels were similar among all artificial group rearing systems in Chapter 3 and 4). This indicates that contact calves benefitted from levels of dam learning and socialisation. It is important to acknowledge that while calf numbers remained the same among groups (Chapter 5), cow numbers doubled the number of animals within the system for contact calves (compared to artificially reared calves). This may have impacted socialisation considerably, as these calves were provided with twice the number of animals to interact with, thus leading to twice the level of socialisation exposure to other animals. It also diversified calf social interactions due to experiences with dam, other dams and calves of varying ages. This in itself would be important, as exposure to more animals of different ages may lead to better socialisation skills among calves. However, it must be remembered that that also increases the risk of contracting disease.

Weaning behaviour was not studied in Chapter 2, 3, and 4, however deviations in behavioural patterns among calves in Chapter 5 during weaning indicates stress within these systems. Despite using a stepped approach to reduce milk consumption and initiate de-bonding, calves in the contact systems displayed increased standing and vocalisations, compared to calves reared in an artificial setting (i.e., automatic feeder), indicating stress. Additionally, contact calves ruminated less at the beginning of the weaning process, suggesting a level of diet dependency on milk (a finding reported also by Fröberg et al. 2011). It is important to consider the three stressors contact calves experience during weaning; environmental (a long-term change from indoor to outdoor), social (de-bonding) and diet (primarily milk and concentrate substitution to grass-based and concentrate substitution). While artificially reared calves experience environmental and dietary stressors, these calves experienced separation immediately post-calving. It is evident that the weaning strategy for contact calves does not mitigate calf stress effectively, which affects calf welfare negatively.

Growth

While calf growth should not be considered a sole determinant of welfare, it can be utilised as an indicator for wellbeing (growth used as a benchmarking tool for calf welfare; Sumner et al., 2020). Calf growth rates varied among systems evaluated in this thesis, however this is most likely attributable to diets these calves experienced. *Ad libitum* milk allowances in Chapter 5 demonstrates that exceptional calf weight gains can be achieved, particularly when milk is derived from the dam in this case. While a small number of farms provide *ad libitum* milk to their calves, restricted milk allowances are generally provided on commercial Irish dairy farms (Chapter 2). As seen from specific calf weight gains under these types of systems (Chapter 3, 4 and 5), calf growth rates are lower. That said, a restricted milk policy facilitates rumen development, where the effective transition to solids based diet may compensate for lower milk allowances (Khan et al., 2011), yet this transition may be too early for these calves. In comparison, calves that experience cow contact have a high reliance on milk resulting in low solid feed consumption pre-weaning. As such there are considerable growth checks associated with contact systems around weaning (indicated by average daily gains (ADG) in Chapter 5), which may also be attributed to weaning being too early from a biological perspective for these calves. It must be recognised, however, that contact calves experience a number of additional stressors during weaning, for this reason the importance of minimising dietary strain around weaning is heightened. In comparison, the growth check associated with weaning is not as severe in artificial rearing systems (namely automatic feeding systems (Chapter 5), but also manual feeding systems (Chapter 3 and 4)). Adaptation of calves to their intended post-weaning environment during the pre-weaning period may mitigate this weaning growth check. Pre-weaning exposure to grass is common practice on commercial farms (Chapter 2), with calves generally granted access to grass after 21 days. Tracking calf growth post weaning (Chapter 5) indicates that pre-weaning exposure to grass appears to alleviate the weaning growth challenges, evident in calf growth within the full-time contact system. This may be valuable moving forward, because any management practices that reduce dietary stress around weaning would lend itself to improving calf wellbeing overall.

Individual feeding systems do not appear to offer any growth advantage over group feeding calves (Chapter 3), similarly, automatic feeders do not improve calf growth rates (Chapter 3 and 4) over their manual feeding counterparts (in a restricted feeding capacity). This research shows, that feeding calves manually in a group housing system, a system most commonly employed on Irish dairy farms (Chapter 2), can be done, without reducing calf growth. Furthermore, whether a calf was managed inside or outside (namely in an artificial rearing system (including Chapter 5)), growth was not significantly influenced in any negative way. Instead, the volume of milk provided to calves appears to dictate calf growth more than the management/feeding system employed on-farm.

One Welfare in calf rearing strategies

This thesis highlights the inter-relationship between the farmer and animal when rearing calves, but also the inter-dependence that exists between calf and carer on-farm. Chapter 2 identifies how farmers are concerned about the spring workload associated with calf rearing in Ireland. This is a valid worry, because as labour increases, elevated levels of stress, working hours required and the risk of burn-out are also often experienced. Each of these labour concerns can influence a farmer's ability to rear calves appropriately, thus directly affecting calf wellbeing. For the future, it is crucial to find the balance between farmer and calf needs in order to guarantee good welfare for both. However, decisions made on-farm related to housing structures (Chapter 2 and 4) as well as management systems implemented (Chapter 2, 3, 4 and 5) have the ability to dictate calf welfare immensely.

Practical recommendations

The on-farm proportion of this research has provided reassurance that information dissemination related to calf welfare appears to have been successful to-date, namely in response to feeding waste milk to calves and overcrowding of calf houses. This study also identified what currently happens on Irish dairy farms and areas of calf housing and management systems that may require attention into the future, such as colostrum management and structural improvements to existing calf houses. Combining findings related to artificial calf rearing systems, this research has highlighted automatic milk feeders to be the most efficient way of rearing calves, while also promoting nature-like feeding and suckling behaviour in calves. That said, the merits of manual feeding systems indoors are also highlighted in terms of illness identification, amalgamation of tasks, as well as similarities between systems for calf health and growth patterns. While rearing calves in group hutches outdoors will impact farm labour, it does not influence calf welfare in any apparent negative way, meaning it is a potential alternative to building a permanent calf house. In contrast, individual hutches outdoors are labour intensive and compromise calf welfare making it an unviable housing system. In relation to pasture-based CCC systems, the part-time system was more labour efficient than the contrasting outdoor system, however calf behaviour and post-weaning growth rates indicate elevated calf stress in this system. The full-time system had exceptional growth rates and normal behavioural patterns, but calf morbidity was a huge issue in this system. Thus, moving calves outdoors, even if with cows, at less than one week old is not recommended in a seasonal compact calving system, instead a hybrid indoor/outdoor model may better cater for farmer and animal needs.

Future research areas

- *Improving labour efficiency immediately post-calving*
  Future research should explore how labour improvements can be made when managing colostrum on-farm while emphasising calf health. Areas include; developing a practice that fuses both natural and manual colostrum feeding practices. This would mean allowing natural suckling to occur when colostrum quality and calf vigour is sufficient, and when this is not possible, manually feed colostrum from another dam instead, allowing dam-calf contact to occur thereafter (being mindful of biosecurity measures to minimise the spread of diseases e.g. Johne's disease). A colostrum storage system that integrates quality testing, but also remains labour efficient, should be developed to reduce the labour of artificial rearing immediately post-calving.
- *Explore the economics of automatic calf feeders*
  While labour efficiencies are evident through use of automatic milk feeders, a detailed breakdown of the economics associated with this system is needed.
- *Examine the value of pre-weaning grass exposure*
  A link between grazing grass pre-weaning and improved post-weaning average daily gain has been identified (in contact rearing systems). It is unclear if this was because these calves were accustomed to being outside (so a degree of acclimatisation occurred), or whether previous grazing experience allowed for more efficient digestion of grazed grass. Specific research must now determine if the above is true, and if pre-weaning exposure to grass would also be beneficial for artificially reared calves.
- *Establish viable pasture-based cow calf contact systems*
  The relative high morbidity level means full-time pasture based CCC is not viable as applied in this thesis. A system where a later turn-out date is applied to calves may be better (e.g., turn-out after three weeks common on commercial farms, but also proved successful in Chapter 4).

- *Develop improved weaning strategies for CCC systems*
  The weaning strategy as applied in this thesis does not mitigate calf stress effectively. Weaning strategies must find ways to reduce environmental, social and dietary stressors for these calves. Furthermore, practical and effective ways to wean contact calves in pasture-based systems must be further explored.

Conclusions

- Commercial farmers demonstrated sufficient spring planning, providing appropriate housing and space allowances for calves that facilitated group housing post-birth, influencing calf welfare positively. Planning was also apparent by the lack of concern among farmers regarding upcoming spring workloads.
- Large proportions of sheds are converted for calf housing, so emphasis must be placed on modifying sheds appropriately so provisions are made to safeguard animal and farmer welfare
- Management components of rearing systems appear in-line with current sectoral recommendations, and improvements have been made, however areas such as testing colostrum quality and extended working hours require further attention on many farms, to protect calf welfare and reduce associated workloads.
- Calves in both automatic and twice per-day manual feeding systems exhibited good health, normal behavioural patterns and similar growth rates. Automatic feeding systems were consistently more labour efficient than manual feeding systems, despite having higher labour requirements for training and health inspections.
- When managed appropriately, the saving of labour and facilitation of nature-like feeding and suckling behaviour are distinct advantages automated feeding systems have over manual counterparts.
- After 18d old, indoor automatic feeding systems were consistently more labour-efficient than indoor manual, outdoor group hutch, and individual hutch feeding systems. Health and growth patterns were consistent among all calves, however behavioural patterns expressed by calves in outdoor individual hutches may indicate compromised well-being through movement from an indoor group-housing system.
- Cow-calf contact pre-weaning enables exceptional calf growth rates and reduced labour demands around calving.
- Pre-weaning cow contact and grass exposure benefitted full-time calves but compromised calf health and farmer welfare (due to daily labour). Part-

time calf behaviour patterns, and stunted post-weaning growth highlights challenges in this system.

- Cow-calf contact in pasture-based dairy systems require further research to ensure the safeguarding of calf and human welfare.

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SUMMARY

Decisions made surrounding calf rearing such as early-separation, housing, feeding system, hygiene practices, health treatment plan, feeding and weaning, among others, influences calf health, growth, behaviour and over-arching welfare considerably. As such, continual research and examination is required to ensure that the decisions made on-farm, related to calf rearing, promote animal welfare in a positive way. It also must be recognised that oftentimes farmer welfare, in relation to adapting and adopting these welfare promoting systems, is something that is acknowledged in-text, but over-looked relative to the logistics of what is involved and how changes can be implemented. As the dairy sector evolves, increasing emphasis is being placed on farming sustainably, therefore it is necessary to weight human and animal welfare with analogous importance moving forward, when developing calf rearing strategies.

The general aim of this thesis was to 1) evaluate labour inputs required for various calf management systems and housing strategies and 2) examine how these systems and strategies employed on-farm affect calf health, behaviour, growth and over-arching welfare.

Rearing facilities directly affect the viability and suitability of calf rearing systems on-farm, however it is unknown whether facilities in the Republic of Ireland are fit for purpose, or sufficiently consider calf and farmer welfare. In Chapter 2, current calf-housing facilities and management practices on Irish farms were reviewed to determine if calves are reared in structurally appropriate facilities with management decisions that safeguard calf and farmer welfare. Fifty-one farms were visited twice; 1) Pre-calving (December-January; farmer interview and housing structural evaluation) and 2) During peak-calving (January-March; short farmer interview and housing environmental evaluation). Results showed farmers demonstrated sufficient planning for spring, providing appropriate housing and space allowances for calves that facilitated group housing post-birth, influencing calf welfare positively. Planning was also apparent by the lack of concern among farmers regarding upcoming spring workload. On-farm housing, not purpose built for calves, is frequently converted for calf housing, meaning emphasis must be placed on modifying sheds appropriately so provisions are made to safeguard

animal and farmer welfare (e.g., drainage and slopes and facilitate cleaning out). Management components of rearing systems appear in-line with current sectoral recommendations (e.g., advice against feeding waste-milk), and improvements have been made, however several areas require further attention on many farms (e.g., colostrum testing and extended working hours), to safeguard calf welfare and reduce associated workloads. This showed calf housing provisions are sufficient for calf numbers born on-farm in Ireland, however structural components and management decisions made should be continually reviewed to ensure that calf and farmer welfare is considered.

It has been suggested that the integration of automatic feeding systems into calf rearing programmes has the potential to improve calf welfare and the associated labour. In Chapter 3, the effects of automatic and manual feeding systems on calf health, behaviour, growth and labour were studied in a controlled experiment. Sixty dairy heifer calves were enrolled in this study. The two experimental systems were; i) automated calf feeding system and ii) manual calf feeding system. Results showed that calves assigned to both the automated feeding system and manual feeding system exhibited good health and normal behavioural patterns, as well as similar growth rates. The automatic feeding system was consistently more labour efficient than the manual feeding system, despite having higher labour requirements for training and health inspections. This demonstrates, when managed appropriately, nature-like suckling behaviour and the saving of labour are distinct advantages automated feeding systems have over their manual counterparts when rearing group-housed calves.

Housing and feeding systems are important components when rearing calves, and must meet calf needs while remaining functional for the farmer. However, research has yet to identify the impact of housing and feeding system on both calf and farmer welfare. In Chapter 4, the health, behaviour, growth and associated labour of calves housed in groups indoors and fed via an automatic or manual milk feeding system compared to calves manually fed in individual or group hutches outdoors was examined. Seventy-six dairy heifer calves were enrolled in this study, with outdoor systems moving outdoors at 18 days. Results indicate that after 18 days of age, the indoor automatic feeding system was consistently more labour efficient than indoor manual, outdoor group hutch and individual hutch feeding systems. Health and growth patterns among all treatments were consistent with positive calf development. Differences in behavioural patterns expressed by calves from 18 to 56 days of age in the outdoor individual hutches compared to all other treatments may indicate compromised wellbeing. This indicated that although outdoor group hutches do not negatively impact the calves, indoor housing, particularly when using automated feeders, can provide improved labour efficiency.

Preventing cow-calf contact (CCC) in rearing systems has been scrutinised recently due to increased societal attention and the associated welfare concerns with current rearing practices. Studies examining CCC systems at pasture are limited, particularly those which evaluate system effects on the calf and farmer collectively. Chapter 5 investigated the effects of full-time contact outdoors on pasture, part-time contact housed indoors, or no contact housed indoors on calf health, behaviour, growth and labour in a pasture-based dairy system. Seventy-three calves were enrolled in this study (55 with dam access for respective contact system; 18 had no dam-contact). Results show CCC pre-weaning enables exceptional calf growth rates and reduced labour demands around calving. Although pre-weaning cow contact and grass exposure was beneficial for full contact calves, the current system compromises calf health and human welfare in terms of daily labour. Similarly, behaviour patterns of part-time contact calves, such as abnormal behaviour expression, and stunted growth post-weaning highlight challenges faced before, during and after weaning. This indicates that CCC in pasture-based dairy systems requires further research to ensure the safeguarding of calf and human welfare.

In the final chapter (Chapter 6), the inter-relationships of the previous four chapters are discussed and the implication their results have on the agricultural and greater scientific communities. The labour implications of each management and housing system are outlined and systems promoting calf welfare were concluded. Finally, the inter-relationship and inter-dependency between the farmer and animal when rearing calves is acknowledged under the umbrella of One Welfare.

In conclusion, although farms are wide-ranging in relation to calf housing and management practices employed, this thesis describes how it is possible to improve labour efficiency and promote animal and human welfare collectively when developing calf rearing strategies on-far

ACKNOWLEDGEMENTS

I would like to acknowledge the opportunity provided to complete this thesis with Teagasc and Wageningen University and Research. I am grateful to Dr. Pat Dillon and Dr. Laurence Shalloo, the Moorepark administration team and Grassland Research Department for making the necessary facilities available to me throughout my PhD. Many thanks also to the Walsh Scholar programme and Vistamilk for funding my research and providing me with this opportunity.

The sentiment ‘it takes a village’ is most definitely something that rings true for me this past four years while completing my PhD, and there are many, many people I owe thanks to.

Firstly, I would like to extend my sincere gratitude to both my supervisors, Dr. Emer Kennedy and Dr. Eddie Bokkers. Emer, your help, guidance, mentoring, friendship and support for the past four years has been extraordinary. Although you have an ‘open-door’ policy, it was more of a revolving door with the way I was in and out to your office for discussions, opinions or just an old chin-wag. Although I struggled often, the confidence I have in my work and my ability to argue for what I believe in, is with thanks to your encouragement (I still believe 11 pages of results was necessary in that instance!). Eddie, you have to be commended for your positive attitude towards the endless email correspondence we had, where I was always looking for something, in one way or another. Thank you for supporting and pushing me to take a step outside of Ireland, be it the Netherlands or otherwise. As terrified as I was, it helped me to grow as a person more than I could have imagined. To you both, thank you for taking a chance on me all of those years ago, and for having the patience to let me grow into the researcher I have become. I think this thesis is evidence enough to say we made a great team!

A special word of thanks to all of the technical, farm staff and students who helped me complete all of my trial work in the calf shed, on the road and in Flagstaff. Ger, for always starting the day with a smile and never having a second thought regarding my random and constant requests. Pat, for your constant level-headedness and willingness to go out of your way to give a lift when I was stranded in the rain at the far end of the farm. JohnPaul, for your never ending patience and support, no matter the time of day. Kieran and Des, for the laughs, the messing and the work that we eventually got done. Mikey, for testing my hearing from across the milking parlour and reminding me not to make pets out of the heifers. A massive thank you also to Andy, Dick, Brian, Bernie, Terrance, Tim and Eddie for all of the chats and laughs down in the yard. Bumping in to you all throughout the day was always a sure fire way to put a smile on my face, or at least reassure me that nothing is ever quite as bad as it seems. You all made my time here unforgettable, mostly because we now have a suckler dairy cow on a beef and tillage farm in Wexford!

To my Canadian (and not so Canadian) friends across the pond at UBC, I am so unbelievably lucky to have met you all. A special thanks to Eamonn, Megan, Jennifer, Tommy, Bianca, Rodrigo, Caily, Ellynn, Malina, Negar, Hannah and Joey for looking after me so well and for creating memories with me to last a lifetime. Moreover, a sincere appreciation goes to Nina and Dan for allowing me to join the Animal Welfare Programme at UBC. It was an honour to collaborate and work with you and your team during my time in Canada. To the PhD students in Moorepark who have went before me and came after me, you bring the colour to Teagasc Moorepark. The socialising, ranting, advising, gossiping, partying, reviews of canteen lunches, help and the affirmation that we are all in the same boat, made all of the long days a little bit shorter!

Ellen Fitzpatrick, I have never in my life met someone quite as kind, caring, selfless, strong or as resilient as you. You have all the qualities that anyone could ever hope to find in a friend and I couldn't have been luckier for our paths to have crossed all those years ago. There is no way that I could have gotten through these last four years without you, be it the chats, debriefs, endless treats or lazy days in the apartment in Moorepark. You are one in a million! Mossy and David (and of course Socks!), you had my heart broke and my sides burst from laughter. The devilment and dinners from you will be unmatched. You are two absolute gentlemen in every sense of the word and I couldn't have asked for better housemates, or friends here in Fermoy. Hazel, Fionnuala and Orlaith, your house and company have been a safe-haven for Ellen and I for the past four years. The times spent across the length and breadth of Ireland with my gals are some of the fondest memories I will ever have. Between antipasti spreads, Hanna's birthday cakes and sipping prosecco in Jacuzzis up the north, we have done alot.. but we have more left to do still!

A huge thank you goes out to my family. Thomas, Julie and James; there is no better trio on this earth to keep a girl grounded in reality, let me tell ya, which I am very grateful for. Thank you for always being there for me through thick or thin. You three have been rocks in my life, supporting me in everything that I do and are the best role models a youngest sibling could ask for. To Hollie-Mae and Roree, thank you for keeping me sane and well entertained during endless covid lockdowns, you both bring so much joy to our family, so thank you for simply being you. Noelle and Kayleigh, for always rooting for me from the side lines regardless of what I do, despite having no interest in agriculture – you are the best! To Oscar, you can't read, but I love you to the moon and back again!! To baby Evie, welcome to the family, I hope you always know how loved you are by us all!! Fiona Guinan, I may as well lump you in here too, for what we have experienced together you are nothing short of family. You have been a life-line for me throughout college and this PhD, and your kindness knows no bounds. You are loyal to the bone and the best side-kick a girl could ask for. No matter the ledge we find ourselves on, I will always know there are two of us in it! James

McCabe, your patience, calm and reassurance has been invaluable to me throughout this experience. Thank you for your encouragement, kindness, endless and company… hopefully it hasn't run out by the time I finish this thing! Here's to the future and all the adventures we find ourselves on.

To Mammy and Daddy, I don't even know where to begin, only that I've taken the ball, and this is exactly what I could do with it (I may go find another one now!). It goes without saying that I consider myself very lucky to be your daughter. You have always led by example and I am so grateful that you taught me the value of hard work, dedication and above all else, kindness. Even more importantly, your outlook on life has encouraged me to always find the positive and good in the world.. and that having a sense of humour can solve an awful lot of problems in life! You put everything into giving me every opportunity imaginable, supporting me every step of the way and pushing me to achieve my dreams. There aren't enough words in the world to say how grateful I am for you both.

Unfortunately, not everyone who saw me set out on this PhD journey, have been able to see me submit my final thesis - one such person being my grandmother, Granny Phil. To describe granny: she was a woman before her time and a forward thinker, but had kindness by the buckets, a caring heart for animals and people, and a warmth that would never see you cold again in your life. Whether it was a place to heat your toes after a chilly Saturday morning on the farm, or seek refuge from the hustle and bustle of the world, granny Phil's door and heart were always open. If you think I love calves, you should have seen granny working with them and the requited love that they had for her. Granny always rooted for the runt of the litter, which I obviously didn't lick off a stone.. and I know she would have had a great laugh at the prospect of trekking my little 14 kg calf across Ireland in the back of my car (featured on the front cover of this thesis!). In one of my last conversations with granny, she said, "I am so proud of you and the work that you are doing. You will be the tops of the top. Unfortunately I won't be here, but I sure as God will be looking down on you." I know this to be true granny, because you have never felt too far away and I am sure you are keeping good company with Nan and Uncle James.

So finally, I dedicate this thesis to my parents, Maime and Vincent, and my late grandmother, Philomena. You instilled a love of agriculture and helped me believe the possibilities in life are endless. You showed me that although education is important, approaching the world and people around you with kindness, empathy and consideration is a truer testament of character than any qualification could be. Moreover, you have shaped me to be the woman I am today, and for that I am eternally grateful.

ABOUT THE AUTHOR

Alison Sinnott was born in Wexford, Ireland, in 1995. She has been immersed in the agricultural sector from a young age, having grown up on her parents beef and tillage farm, nestled in the foothills of Mt. Leinster. Alison has always had a keen interest in animals, making pets of all sorts, any chance that she could. She developed a particular soft spot for calves and calf rearing, which inspired her to pursue a career as an agricultural scientist.

Alison obtained her Bachelor degree in Agricultural Science, with a major in Animal Science at University College Dublin in 2018. During her undergraduate studies, Alison developed a passion for research and decided to take the next steps in forging her career in this area. Following graduation, she became a PhD Walsh Scholar, working in conjunction with Teagasc Moorepark and the Animal Productions System Group at Wageningen University. Under the supervision of Dr. Emer Kennedy in Ireland, and Dr. Eddie Bokkers in the Netherlands, Alison's research focuses on evaluating calf housing and management systems and their effects on calf and human welfare.

Alison was also fortunate to have been selected by the British Society of Animal Science for the Steve Bishop Early Career Award in 2021. This afforded her the opportunity visit and work with the Animal Welfare Programme at the University of British Columbia, Canada, in 2022. This collaborative experience, facilitated by Dr. Marina von Keyserlingk and Dr. Dan Weary, allowed Alison to gain invaluable insight into animal welfare in global food systems.

Findings of this thesis were presented at international conferences, research centre open days, discussion groups, invited lectures and published in peer-reviewed scientific journals.

PUBLICATIONS

Refereed scientific journals

Sinnott, A.M., Kennedy, E. and Bokkers, E.A.M., 2021. The effects of manual and automated milk feeding methods on group-housed calf health, behaviour, growth and labour. *Livestock Science*, *244*, p.104343.

Sinnott, A.M., Bokkers, E.A.M., Murphy, J.P. and Kennedy, E., 2022. A comparison of indoor and outdoor calf housing systems using automated and manual feeding methods and their effect on calf health, behavior, growth, and labor. *Journal of animal science*, 100(4), p.skac079.

Conference proceedings and abstract

Sinnott, A.M., Bokkers, E.A.M., Murphy, J.P. and Kennedy, E., 2021, August. A comparison of calf housing and feeding methods and its effect on calf welfare, growth and labour. In *8th International Conference on The Assessment of Animal Welfare at Farm and Group level* (pp. 178-178). Wageningen Academic Publishers.

Sinnott, A.M., Bokkers, E.A.M. and Kennedy, E., 2022. An evaluation of fulltime and part-time pasture-based cow-calf contact systems compared to no cow-calf contact on calf health, growth and labour. In *WIAS Annual Conference 2022* (pp. 15-15).

McPherson, S.E., Riaboff, L., Dissanayake, O., **Sinnott, A.M**., Cunningham, P. and Kennedy, E. 2022, August. Effect of separation at weaning on the activity of cows and calves reared in a cow-calf contact system measured with accelerometer sensors. In *10th European Conference on Precision Livestock Farming* (pp. 241).

Sinnott, A.M., Bokkers, E.A.M., McPherson, S., and Kennedy, E., 2022, September. Impact of prolonged cow-calf contact on dairy cow production in a pasture-based system. In *73rd annual meeting of European Federation of Animal Science* (pp. 387).

McPherson, S., Webb, L.E., **Sinnott, A.M.**, Bokkers, E.A.M, Kennedy, E., 2022, September. Pasture based cow calf contact: effects of fulltime, part-time and no contact on calf growth. In *73rd annual meeting of European Federation of Animal Science* (pp. 241).

Technical articles

Sinnott, A.M., Murphy, JP., Kennedy, E. (2021). Which is the more labour efficient — manual or automatic calf milk feeding?. *Moorepark Open Day Booklet*, pp. 178-179.

Sinnott, A.M., Kennedy, E. (2021). Calf housing on commercial farms in Ireland. *Moorepark Open Day Booklet*, pp. 180-181.

Sinnott, A.M., Murphy, JP., Kennedy, E. (2021). Calf Hutches: a viable housing alternative? *Teagasc Moorepark Open Day Booklet,* pp. 182-183.

Sinnott, A.M, Murphy, JP.,Hanrahan, G., Fogarty, W., Kennedy, E. (2019). Are automatic calf feeders more labour efficient than manual feeders? *Teagasc Moorepark Open Day Booklet*, pp. 166-167.

EDUCATION CERTIFICATE

Completed training and supervision plan[1]

The Basic Package	**2 ECTS**
WIAS Introduction Day	2018
Scientific Integrity	2021
Ethics and Animal Sciences	2021
Disciplinary Competences	**12 ECTS**
WIAS Proposal	2019
Laboratory and Animal Science Training (LAST) course	2019
Fundamentals of Animal Emotion	2021
Professional Competences	**12 ECTS**
WGS Course - Project and Time Management	2020
UCC Course - Leadership Skills for Agri-food Sector	2021
UCC Course - Career Management	2021
Presentation Skills	**3 ECTS**
WAFL (Poster Presentation)	2021
WIAS Science Day (Oral Presentation)	2022
EAAP (Theatre Presentation)	2022
Teaching competences	**4 ECTS**
Supervise BSc Internship - William Fogarty (Munster Technical University)	2019
Supervise BSc Internship - Kevin O Connor (Munster Technical University)	2020
Supervise BSc Internship - Kevin Hassett (Munster Technical University)	2021
Supervise BSc Internship - Pauline Lambert (L'institut Agro France)	2020
Education and Training Total	**32 ECTS**

[1] with the activities listed the PhD candidate has compiled with the educational requirements set by the Graduate School of Wageningen Institute of Animal Sciences (WIAS). One ECTS credit equals a study load of 28 hours.

Colophon

The research described in this thesis was financially supported by the Walsh Scholarship Programme, Teagasc, and in part by Vistamilk.

Cover design and thesis lay-out by Alison Sinnott

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