Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

REVIEW ON MANAGEMENT QUALITY ON DAIRY FARMS: EFFECTS OF HOUSING, BEDDING, NUTRITION AND CLIMATE ON ECONOMIC PERFORMANCE AND PRODUCT QUALITY/QUANTITY

Besheda Wedajo Bikila

beshewadajo@gmail.com

Jimma University https://orcid.org/0009-0007-6490-9116

Systematic Review

Keywords: Dairy cattle management; Housing systems; Bedding management; Nutrition; Heat stress; Milk quality and yield; Mastitis; Lameness; Economic performance

Posted Date: November 26th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-11883249/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

Additional Declarations: The authors declare no competing interests.



JIMMA UNIVERSITY

COLLEGE OF AGRICULTURE AND VETERINARY MEDICINE

SCHOOL OF VETERINARY MEDICINE

REVIEW ON MANAGEMENT QUALITY ON DAIRY FARMS: EFFECTS OF HOUSING, BEDDING, NUTRITION AND CLIMATE ON ECONOMIC PERFORMANCE AND PRODUCT QUALITY/QUANTITY

BY

BESHEDA W. BIKILA

SUMMARY

This seminar paper reviews the effects of management quality encompassing housing systems, bedding, general nutrition, and climatic conditions on the economic performance of dairy farms and on the quantity and quality of milk produced. Evidence from the literature shows that these four management domains are closely interlinked rather than independent and those shortcomings in one area often amplify losses in another. Housing design and stocking density strongly influence cow behavior, comfort, and udder health; overcrowding and inadequate feed-bunk or lying space reduce both resting time and milk yield, while housing type (tie-stall, free-stall, or loose housing) affects somatic cell count and milk composition. Bedding material and hygiene management are critical determinants of lameness and mastitis incidence, with inorganic materials such as sand generally supporting better udder health than organic materials, although proper management of any bedding type matters more than the material itself. Nutritional management directly and rapidly affects milk yield and composition; balanced energy and protein feeding, adequate effective fiber, and avoidance of subacute ruminal acidosis (SARA) are essential for sustaining both productivity and profitability. Climatic conditions, particularly heat stress, emerged as the most economically significant factor, reducing feed intake, milk yield, and milk fat and protein content, with global economic losses estimated in the billions of dollars annually. Overall, the review demonstrates that lameness and mastitis both strongly influenced by housing and bedding management, represents the largest disease-related economic burdens on dairy farms, while heat stress represents the largest climate-related burden. The paper concludes that coordinated, high-quality management across housing, bedding, nutrition, and climate control offers the greatest potential to improve milk quantity and quality while safeguarding farm profitability, particularly for smallholder and resource-limited producers who are disproportionately affected by management shortfalls

Keywords*: Dairy cattle management; Housing systems; Bedding management; Nutrition; Heat stress; Milk quality and yield; Mastitis; Lameness; Economic performance*

1. INTRODUCTION

Dairy herd performance depends on how well the farm's facilities, housing, feeding, health monitoring and thermal environment work together (Bewley et al., 2017). Where cows spend most of their time is one of the most consequential decisions a producer makes, because the housing system affects cow comfort, health, milk quality and farm profitability (Bewley et al., 2017; Cook & Nordlund, 2009). The right choice depends on local climate, construction and labor costs, and expected return on investment. Pasture can provide good cow comfort, but wet weather and mud can compromise cleanliness, milk quality and heat or cold stress management (Hernandez-Mendo et al., 2007; Bewley et al., 2017).

Herd management in dairy farming involves a complex interplay of farm facilities, housing systems, nutrition, health monitoring, and environmental factors to optimize herd health, productivity, and efficiency (Heidi Jim, December 2025).

Choosing the environment in which lactating dairy cows will spend most of their time is an important decision for dairy producers. This choice has considerable influence on productivity, health, milk quality, reproduction, animal well-being, and farm profitability. In the decision-making process, dairy producers must consider what system will work best for their respective situations, given local climatic conditions, construction and building costs, labor availability, long-term maintenance and upkeep costs, and return on investment. Although pasture generally allows for excellent cow comfort, inclement weather and muddy conditions may present challenges related to cow cleanliness, milk quality, and heat or cold stress.(J.M. Bewley,L.M. Robertson, December 2017)

Housing systems play a central role in shaping daily management and cow welfare on dairy farms. Although freestall (FS) systems promote cow mobility and provide distinct areas for lying, feeding, and walking (Galama et al., 2020; Beaver et al., 2021b), tiestall (TS) housing, traditionally valued for individualized animal care, limits movement and typically involves in-place milking routines (e.g., pipeline milking systems), which can increase labor demand compared with parlors or automated milking systems (AMS; Beaver et al., 2021a). Beyond housing, stall and bedding design, ventilation, and overall barn environment can influence stress,

injury risk, and hygiene, affecting not only welfare but also cow health and milk quality (Cook and Nordlund, 2009; Wolfe et al., 2018; Lindkvist et al., 2023).

1.2 Existing literature

A large body of work now covers the individual components of management. Reviews and experimental studies have examined housing and welfare (von Keyserlingk et al., 2009; Ebinghaus & Knierim, 2025), bedding materials and stall design (McPherson & Vasseur, 2020; Siachos et al., 2026), mastitis control (Ruegg, 2017), and heat stress (Polsky & von Keyserlingk, 2017; West, 2003). Economic studies have quantified the costs of lameness, mastitis and heat stress in specific countries and in global estimates (Cha et al., 2010; Romero et al., 2018; St-Pierre et al., 2003; Down et al., 2024). Evidence from Ethiopian smallholder systems, however, is mostly confined to feeding and productivity (Assaminew & Ashenafi, 2015).

1.3 Research gap

Most of this literature treats housing, bedding, nutrition and climate as separate topics, even though these factors interact on the farm. Heat stress worsens nutritional shortfalls, and poor bedding hygiene compounds housing-related lameness and mastitis risk. Few reviews connect the four domains to each other and to farm economics in one framework. The quantitative evidence also comes mainly from intensive systems in North America and Europe, with limited data from smallholder and resource-limited systems in Sub-Saharan Africa. As a result, extension workers and producers in Ethiopia have little consolidated guidance on which management improvements matter most.

1.4 Purpose of this seminar

This seminar addresses that gap by synthesizing the literature on housing, bedding, nutrition and climatic management together, rather than one at a time. It examines how they jointly affect the economic performance of dairy farms and the quantity and quality of milk, and it draws out the implications for smallholder producers.

1.5 Objectives of the Seminar

The general objective of this seminar is to review the available literature on how management quality specifically housing, bedding, nutrition, and climatic/thermal management affects the economic performance of dairy farms and the quantity and quality of the milk they produce.

The specific objectives are to:

- examine how housing design and stocking density influence cow comfort, behavior, udder health, and milk composition;
- evaluate the role of bedding material and management in lameness, mastitis, and lying behavior;
- assess how nutritional management, including energy and protein balance, affects milk yield, composition, and reproductive performance;
- analyze the impact of heat stress and climatic conditions on milk quantity and quality, and review available mitigation strategies; and
- Synthesize the economic implications of management quality across these four domains, with attention to smallholder and resource-limited production systems.

1.6 Scope and Limitations

This review draws on peer-reviewed journal articles, systematic reviews, and industry/extension sources published mainly over the last two decades, spanning both intensive commercial systems (North America, Europe) and smallholder urban/peri-urban systems in Ethiopia and neighboring countries. Because the underlying studies differ in design from randomized trials to observational, cross-sectional, and bioeconomic-modelling studies causal claims are made cautiously, and the paper flags, where relevant, when evidence is correlational rather than experimental. The review does not cover genetics/breeding programs, reproductive technologies, or disease-specific treatment protocols in depth, except where they intersect directly with the four management domains under review.

2. HOUSING SYSTEM AND MANAGEMENT QUALITY

2.1 Cow Comfort, Behaviour, and Productivity

The welfare of dairy cattle results from the interaction of several factors. Housing conditions and facility design play a major role in determining cow health (von Keyserlingk et al., 2009). Gaworsky et al. (2018), working with Estonian dairy farms, found a decreasing prevalence of udder disease with increasing herd size. Free-stall barns remain the most widespread housing system in intensive dairy farms worldwide; despite this, they can compromise animal welfare and constrain natural cow behaviour (EFSA, 2009). These welfare concerns have fostered interest in alternative loose-housing systems such as compost-bedded pack barns (CBP). Introduced in the United States in 2001, the CBP system spread rapidly and is now used worldwide to improve dairy cow welfare (Bewley et al., 2017).

Unlike free stalls, CBP provides cows with a large open bedded area on which to lie, stand, and walk freely; the bedded pack is aerated once or twice daily to promote evaporation and maintain a soft, hygienic surface (Leso et al., 2013; Bewley et al., 2017). Sawdust and wood shavings are the most common CBP bedding materials, though straw, peanut shells, woodchips, and compost are also used (Janni et al., 2007; Galama, 2014; Favèro et al., 2015; Leso et al., 2018). CBP requires substantially more space per cow than free stalls suggested allowances range from 7.4 to more than 15 m² per cow depending on barn characteristics, bedding availability, and pack management (Janni et al., 2007).

The principal benefits of CBP are improved feet and leg health and more natural behaviour relative to free stalls, likely due to reduced exposure to concrete flooring and injury-causing obstacles (Fulwider et al., 2007). Outcomes, however, depend strictly on pack management: pack moisture in particular affects cow hygiene and mastitis risk (Leso et al., 2013; Mota et al., 2018; Eckelkamp et al., 2016). Producers most often cite improved cow comfort and longevity as their reason for building CBP (Barberg et al., 2007; Black et al., 2013), although the effect of the system on longevity itself remains incompletely understood (Leso et al., 2019).

Housing design also influences the time cows spend lying, feeding, standing, and interacting with herdmates, thereby shaping welfare and productivity. Adequate feed-bunk space increases feeding time and reduces inactive standing and aggressive interactions, particularly among

subordinate 11 cows (DeVries et al., 2004). Overstocking at the feed bunk reduces feeding time and increases displacement and competition (Collings et al., 2011; Huzzey et al., 2006), and is associated with prolonged standing in walking alleys (Schirmann et al., 2011, as cited in Koba et al., 2022). Benchmarking of high- and low-welfare farms shows that both housing conditions and management practices including foot-bath use, milking frequency, and cow-to-stall ratio are significantly associated with welfare indicators such as body condition, lameness, and somatic cell count (Koba et al., 2022).

2.2 Housing Type, Udder Health, and Milk Composition

The choice between tie-stall, free-stall, and loose-housing systems affects udder health and milk composition. Comparative research has documented differences in somatic cell count (SCC), milk yield, milk composition, and fatty-acid profile between tie-stall and free-stall systems, with cows in free-stall systemsgenerally showing less favourable udder-health indicators than those in tiestalls (Nogalski & Momot, 2023). Milking-system choice can also influence udder health: automatic milking systems (AMS) differ from conventional parlours in milking frequency, cow traffic, and teat preparation, all of which affect indicators such as SCC and teat condition (Hovinen & Pyörälä, 2011). Social stability within the housing group matters as well in a longitudinal study of loose-housed dairy cows, removal of established herd-mates was associated with reduced milk yield, and changes in group composition were linked to changes in milk conductivity and the occurrence of blood in milk, both indicative of potential udder-health effects (Valníčková et al., 2024).

3. BEDDING MANAGEMENT

3.1 Bedding Materials and Their Desirable Properties

Cows spend more time lying on comfortable bedding, which lowers stress and, in turn, benefits milk yield. A wide range of bedding materials mattresses, mats, sand, compost, straw, sawdust, and even bare concrete are used in free stalls (Tucker et al., 2003; Fulwider & Palmer, 2004; Calamari et al., 2009; Ferraz et al., 2020; Leso et al., 2020). An ideal bedding material is economical, provides a comfortable lying surface, tolerates moisture, keeps animals clean, and reduces labor requirements [i](Boone et al., 2009; Ruud et al., 2010; Mitev et al., 2012).

Other desirable properties include encouraging cows to lie down, good thermal insulation, low maintenance requirements, and low bacterial growth (Boone et al., 2009). Selecting the right bedding material at the stall-design stage prevents many downstream problems. Organic materials such as straw, sawdust, and sand can accumulate in the stall and create conditions favourable to bacterial growth, foot disease, and mastitis if not properly managed, ultimately reducing milk yield (Greenough, 2007).

3.2 Bedding, Lying Behaviour, and Milk Yield

The relationship between bedding, lying behaviour, and milk yield has attracted substantial research interest (Fregonesi et al., 2007; Sutherland et al., 2013; Sinha et al., 2017; Tullo, 2019; Liu et al., 2020). Lying time in a relaxing, comfortable area increases blood flow to the udder reported at roughly 28% higher in lying versus standing cows, equivalent to about 5 L/minute versus 3 L/minute which is one mechanism linking comfortable bedding to milk yield (Metcalf et al., 1992; Oord, 2019). Cows on soft-surfaced stalls increase their lying time by 1.8 to 4.0 hours per day compared with concrete, and soft-surface stalls are associated with higher milk yield (Fregonesi et al., 2007; Temple et al., 2016).

Reduced lying time is itself associated with stress (Ladewig & Smidt, 1989; Nordlund et al., 2019), and prolonged reductions in lying time may be linked to circulatory changes that lower milk production, particularly in young, growing animals (Munksgaard & Løvendahl, 1993; Hart et al., 1978). Bedding preference itself is behaviourally measurable: cows select preferred surfaces partly by head-turning behaviour, and they spend less time head-turning indicating

greater comfort on 13 surfaces where they also show higher total lying time (Tucker et al., 2003; Schütz et al., 2019). Across a range of preference-test studies, cows consistently prefer "soft" surfaces over harder alternatives (Haley et al., 2000; Fulwider & Palmer, 2004; Drissler et al., 2005; Kara et al., 2015; Chaplin et al., 2000; Manninen et al., 2002).

4. GENERAL NUTRITION MANAGEMENT

High levels of milk production coupled with low feed intake cause negative energy balance in early lactation, especially in the first month postpartum (PP). Therefore, specific nutritional management at this time may improve nutritional and metabolic status with the possibility of contrasting genotypes responding differently. Thus, the objective of this study was to compare the effects of nutritional management strategies and dairy cow genotype on milk production, metabolic status, and some fertility parameters during early lactation in a pasture-based system (E. L., Pierce, K. M., Lynch, M. B., Fahey, A. G., & Mulligan, F. J., (2021))

During early lactation, dairy cows experience a rapid increase in milk yield coupled with a low DMI. Due to this imbalance, dairy cows enter an inevitable state of negative energy balance (**NEB**), resulting in adipose tissue mobilization and poor metabolic status. An increase in the circulating concentrations of nonesterified fatty acids (**NEFA**) and BHB in the weeks following calving is part of normal adaptation to NEB in early lactation (Drackley and Andersen, 2006). Thus, even though NEB cannot be prevented, many researchers believe the severity and duration of NEB should be reduced, because excess concentrations of NEFA (>0.7 mmol/L) and BHB (>1.2 mmol/L) are detrimental to production and reproductive outcomes, animal health, and immune system function (Hammon et al., 2006; Ospina et al., 2010; Compton et al., 2015).

The average crude protein (CP) content per kg of dry matter (DM) of home-mixed concentrate was lower in urban than peri-urban dairy farms (Table 1). The average calcium (Ca) concentration per kg of DM of the home-mixed concentrate was higher in urban than in peri-urban farms. On the contrary, phosphorous (P) concentration of the home-mixed concentrate was higher in urban than in peri-urban dairy farms (Assaminew & Ashenafi, 2015).

Table 1. Mean values for chemical composition of home-mixed concentrate in urban and periurban dairy farms around Holetta

Chemical compositions	Urban (n=30)	Peri-urban (n=30)	SEM	p
DM, g/kg	902	910	1.14	0.001
Ash, g/kg	94.9	99.7	2.47	0.180
CP, g/kg DM	209	224	3.81	0.004
Ca, g/kg DM	3.85	5.26	0.25	0.001
P, g/kg DM	10.6	9.74	0.21	0.008

The high CP and Ca, and low P concentration found in periurban dairy farms in this study might be attributed to low proportions of oil seed cakes which relatively contain higher Ca and CP and lower P than flour mill byproducts (Adugna 2008). Besides farmers have no standards to blend individual feed ingredients in the mixtures. The quantities of individual feed ingredients included in the home-mixed concentrate seemed to depend on their relative availability rather than on the farmers' conscious desire to supply better quality and balanced concentrate mixture to their cows (Mesfin et al 2013).

Home-mixed concentrate feeding levels and nutrient supply

Higher amounts of home-mixed concentrate per kg of milk were observed in urban as compared to periurban dairy farms (Table 2). This might be due to farmers in urban areas having better information on feeding of milking cows than peri-urban farmers.

Table 2: Farmers' home-mixed concentrate feeding levels and nutrient supplied per milk

yield (MY) in urban and periurban of Holetta

Item	Urban(n=30)	Periurban(n=30)	SEM	p
Feeding level, kg/kg MY	0.49	0.46	0.01	0.010
CP, g/kg MY	92.6	93.5	2.89	0.061
Ca, g/kg MY	1.70	2.21	0.11	0.002
P, g/kg MY	4.69	4.04	0.13	0.001

The average CP supplied were 92.6 and 93.5 g/kg of milk supply in urban and periurban farms were observed, respectively. Thus the supply of CP per day through the concentrate mixture regardless of CP supply through the basal feed was considerably higher than the recommended 860 g/day for a standard cow, 500 kg weight and 40 g butterfat, producing 10 kg of milk per day (ARC 1994). This clearly indicates that the protein supply through the home-mixed concentrate could be fulfilled; even it was over the cow's CP requirement per day regardless of the CP fed through the basal diet. Thus, any protein not required by the cow is excreted in the urine as urinary urea, a consequence of urea nitrogen recycling and the removal by the kidney of any urea not recognized by the animal as necessary for rumen function (Lock and Van Amburgh 2012). Increasing dietary protein concentration above the requirement reduced the daily and cumulative energy balance according to Law et al (2009).

Low Ca level (1.70 g/kg MY) was fed in the urban dairy farms as compared to peri-urban. Low Ca level prolongs calving duration and has a detrimental effect on placenta expulsion and uterine involution, which finally impair postpartum fertility in the cows (Rukkwamsuk 2011).

Feeding a calcium-deficient diet may delay uterine involution (Funston 2007). High amount of P supply was found in urban dairy farms. This implies a 10 kg milk producing cow in this study site might be supplied more than 40 g per day through the concentrates which is higher than the recommended 28 g/day for cows producing 10 kg/day (ARC 1994) regardless of the P supplied through the basal diet. High P intakes along with low Ca intakes also depress fertility (Funston 2007).

Performance of crossbred dairy cows

The estimated average daily milk yield (ADMY), calving intervals (CI) and days open (DO) are presented in.

Table 3: Average daily milk yield, calving interval and days open of crossbred dairy cows around Holetta

Traits	Urban(n=30)	Periurban(n=30)	SEM	p
ADMY, kg/cow/day	11.1	9.28	0.48	0.009
CI, months	14.3	15.4	0.28	0.006
DO, days	152	176	7.10	0.018

The ADMY was lower in periurban farms than in urban farms (Table 3). The difference could be attributed to relatively higher protein supply through home-mixed concentrate in periurban farms compared to the urban dairy farms. Consequently, additional energy costs of detoxifying ammonia from protein possibly led to a greater reliance on body energy stores for milk production (Thatcher et al 2008). The present result in ADMY is comparable to Azage et al (2013) who reported the ADMY for crossbred dairy cows in urban (10.2-15.9 kg/cow/day) and periurban (9.5 kg/cow/day) systems. However, it is lower than 15.5 kg/day/cow in urban and 13.7 kg/day/cow secondary town dairy production systems in Adama milkshed reported by Nigusu and Yoseph (2014). The low ADMY in this study might be due to poor nutrient supply and feeding practices of the dairy cows. Poor nutrient supplies and feeding practices are major factors that determine the productive and reproductive performances of dairy cows (Ahmed et al 2004).

Longer CI was observed in periurban areas than in the urban farms. The longer CI in periurban farms might be due to relatively poor feeding practices and nutrient supplies. Thus, poor feeding practices, adversely, affected the synthesis and secretion of hormones responsible for ovarian follicular development and function leading to extended CI in these cows (Thatcher et al 2008). The average CI in this study was comparable to 420 and 459 days for urban and periurban zones of Gondar, North Western Ethiopia, respectively, reported by Niraj et al (2014). The marked increment in length of average CI form urban (14.3 months) to periurban (15.4 months) is in line

with the report of Gebrekidan et al (2012) who found the similar trend, however, with longer CI for crossbred dairy cows, which increased from 15.9 months in urban to 19.7 months in periurban Central Zone of Tigray, Northern Ethiopia. Similar trends and comparable figures to the current study were also reported from Gondar Town; 420 days in urban and 459 days in periurban (Niraj et al 2014).

Differences in length of DO between the production system existed which increased from urban to periurban dairy farms. This might be due to poor nutritional status and excess protein fed to cows through the home-mixed concentrate in periurban dairy farms. Over-feeding of protein leading to high levels of ammonia or urea may impair maturation of oocytes and subsequent fertilization or maturation of developing embryos (Yugal et al 2013). Excess feeding of protein could have detrimental effects on re-establishment of the ovarian cycle postpartum as well as adverse alterations in the oviductal and uterine environment of the developing embryo (Thatcher et al 2008).

The present value of DO was longer than that reported for crossbred cows (2.47 months in urban and 3.33 months in periurban areas) in Gondar Town (Nibret 2012). Overfeeding protein during the breeding season and early gestation, particularly if the rumen receives an inadequate supply of energy may be associated with decreased fertility (Dunn and Moss 1992). Reduction in fertility may result from reduced uterine pH during the luteal phase of the estrous cycle in cattle fed high levels of degradable protein (Yugal et al 2013).

5. CLIMATIC CONDITIONS AND THERMAL MANAGEMENT

5.1 Climate Change and Heat Stress:

Background Climate change, driven by rising greenhouse gas emissions, is accelerating in many dairyproducing regions. In Korea, for example, the average temperature has risen by more than twice the global average increase over the past century (about 1.8°C between 1911 and 2010, against a global average of 0.75°C), and a further 3.4°C increase is projected by 2050 along with more frequent heat-wave and tropical-night days ("Impact of Climate Change and Heat Stress on Milk Production in Korean Holstein Cows," n.d.). Heat stress is consequently a prominent constraint on livestock productivity, particularly for high-producing Holstein dairy cows, making it essential for producers and researchers to understand the relationship between climate change, heat stress, and productivity in order to safeguard the sustainability of the industry

5.2 Impact of Heat Stress on Milk Production

The thermoneutral zone for dairy cows lies roughly between 5°C and 25°C; once ambient temperature rises above this range, cows begin to show signs of heat stress, and milk output often the first parameter affected can fall by 10% to 25% under severe heat stress (Collier et al., 2017). The main mechanisms behind this yield decline are reduced dry matter intake (DMI) and the diversion of body energy reserves toward heat-mitigation processes rather than milk synthesis (Dikmen & Hansen, 2009; Tian et al., 2015). High-producing cows in early lactation are at particular risk because of their already elevated metabolic demands (Sejian et al., 2018). Taken together, these findings point to a clear need for better on-farm management cooling systems, adjusted nutrition, and genetic selection for thermotolerance to offset the productivity losses associated with a warming climate (Bouraoui et al., 2019; Tao & Dahl, 2017)

5.3 Effect of Heat Stress on Milk Composition

Beyond reducing milk quantity, heat stress alters milk composition: protein content, fat content, and solids-not-fat can each fall by roughly 10-15%, while somatic cell count tends to rise, partly reflecting an increased occurrence of subclinical mastitis under heat-stress conditions (Dunshea et al., 2019). Subclinical mastitis can further compound the compositional decline (Machado et al., 2020; Pasqui et al., 2019), and stress-related metabolites such as cortisol and heat-shock

proteins 18 in milk are an active area of research interest (Yang et al., 2022; Min et al., 2017). These compositional changes can reduce milk's suitability for yogurt and cheese manufacture (Gernand et al., 2019), making the preservation of milk quality under heat stress important both commercially and for regulatory compliance (Malik et al., 2026).

Table 4: Milk Compositional Changes at Different THI Levels.

THI Level	Milk Fat (%)	Milk Protein (%)	Milk Yield (kg/day)
<68	3.6	3.2	35
68-72	3.4	3.1	33
73-78	3.2	2.9	30
>78	3.0	2.7	27

(Bouraoui et al., 2002; Gorniak et al., 2014),

5.4 Mitigation Strategies

Sustaining dairy production under a changing climate requires both educated farmers and climateresilient policy (Renaudeau et al., 2012). Nutritionally, increasing the energy density of diets helps compensate for heat-stress-related declines in feed intake, and dietary supplements such as antioxidants, electrolytes, and rumen-protected amino acids can reduce oxidative stress and support metabolic function (Chen et al., 2024; Johnson et al., 2018). Shifting feeding schedules to cooler parts of the day also promotes feed intake and improves overall efficiency (Belhadj Slimen et al., 2016).

Genetic selection is a complementary long-term strategy: breeding programs that incorporate heattolerant traits such as the slick-hair gene or that cross with locally adapted native breeds can improve herd resilience (Henry et al., 2018), and genomic selection techniques can identify animals with higher heat tolerance while preserving productivity (Malik, 2026). Finally, digital technologies and automated sensors that monitor physiological indicators, behaviour, and environmental variables in real time are increasingly supporting climate-related decision-making on dairy farms (Neethirajan, 2023; Shu et al., 2021). Collectively, nutritional, genetic, and technological strategies support the sector's resilience to a changing climate.

6. SYNTHESIS: HOW MANAGEMENT QUALITY DRIVES ECONOMICS

Bringing together the housing, bedding, nutrition, and climate domains discussed in the preceding sections, four cross-cutting economic patterns emerge from the literature. Each is elaborated below with supporting quantitative evidence and its underlying mechanism.

6.1 Disease Costs Dominate Herd-Level Economics

Health disorders remain the single largest controllable drain on dairy farm profitability, but the ranking of diseases by total herd-level cost depends heavily on the interaction between per-case severity and incidence, rather than severity alone. Lameness illustrates this dynamic clearly. Systematic reviews of British dairy herds report a pooled lameness prevalence of approximately 29.5% (95% CI 26.7–32.4%), with an all-cause incidence rate of roughly 31 cases per 100 cow-years, though cause-specific incidence for conditions such as white line disease and digital dermatitis can run considerably higher when analyzed separately (Yeoman et al., 2021; Griffiths et al., 2018).

Farm-level prevalence surveys corroborate this range: a cross-sectional study of 659 German herds found a median lameness prevalence of 29.4% (IQR 18.7–42.0%), while an England and Wales survey found a mean withinfarm prevalence of 31.6%, ranging as high as 65.4% in the worst-managed herds (Griffiths et al., 2018; Barker et al., 2010). Bioeconomic modelling shows that lameness prevalence can vary from 26% to 98% depending purely on the management scenario simulated housing, scraping frequency, footbath protocol, and trimming regime even holding herd genetics and base infrastructure constant (Chanteloup et al., 2023).

Per-case costs for lameness are comparatively moderate: estimates typically fall between US$90 and US$400 per case, with average annual costs of a lame cow around €307.50 and a digitaldermatitis-affected cow around €391.80 (Cha et al., 2010; Charfeddine & Pérez-Cabal, 2017; Chanteloup et al., 2023). Only about 30% of the per-case loss is attributable to direct treatment, with 30% from reduced fertility and 40% from decreased milk production and discarded milk (CDQAP, n.d.). It is precisely this combination moderate per-case severity multiplied by very high prevalence that makes lameness, on a per-100-cow basis, frequently exceed the herd-level cost of diseases with a higher cost-per-case but much lower incidence.

Because lameness costs are driven overwhelmingly by prevalence rather than treatment intensity, and because preventive 20 trimming and surface/hygiene management reduce prevalence more effectively than improved early detection, capital and labor directed at walking surfaces, stocking density, and bedding comfort carry more herd-level economic leverage than investment in treatment protocols alone (Chanteloup et al., 2023). Mastitis shows the inverse relationship in some respects very high per-case cost combined with somewhat lower (though still substantial) prevalence but remains, in aggregate, the costliest disease globally.

Estimates of the worldwide annual cost of mastitis consistently fall in the tens of billions of dollars, ranging from €16–26 billion to as high as US$35 billion across recent reviews (Frontiers in Veterinary Science, 2025; Bovine Diagnostics, n.d.). A large-scale, comorbidityadjusted Monte Carlo simulation of global dairy disease losses estimated mean annual global losses of approximately US$13 billion for clinical mastitis and US$9 billion for subclinical mastitis, compared with roughly US$6 billion for lameness and US$18 billion for subclinical ketosis underscoring that the relative ranking of "costliest disease" is sensitive to modelling approach and to how subclinical, often underdiagnosed, forms are counted (Down et al., 2024). Across nearly all cost-decomposition studies, the largest single component of mastitis's economic burden is lost milk production and lost quality premiums (typically 50–70% of total losses), with labor, discarded milk, and replacement costs comprising most of the remainder (Frontiers, 2025).

6.2 Milk Quality Payments Amplify Management Effects

Because most milk-pricing systems pay a base rate plus premiums (or penalties) tied to fat and protein content and SCC, any management shortfall that dilutes milk solids or elevates SCC produces a compounding financial effect rather than a single loss: farms lose on volume and simultaneously lose on price per liter. This compounding is most visible in the mastitis literature, where elevated SCC the clinical signature of subclinical mastitis directly triggers milk-quality penalties in most pricing schedules, on top of the yield loss from infection itself (Bovine Diagnostics, n.d.; Frontiers, 2025). Nutritional and thermal stressors operate through a related but distinct pathway: heat stress and SARA depress milk fat percentage specifically (through reduced rumen pH and altered fatty-acid biohydrogenation), and reduced feed intake under heat stress lowers both fat and protein synthesis simultaneously meaning the components pricing formulas weight most heavily are also the ones most sensitive to these management failures.

Where metabolic stress from SARA or heat load also 21 elevates a herd's susceptibility to mastitis, the two pathways can co-occur, converting what starts as a single management lapse into losses stacked across volume, components, and SCC-linked penalties at once. No study located in this review directly quantifies this three-way interaction, so it should be read as a plausible mechanistic extension of the individual component effects rather than an independently measured finding. Regional evidence on components underscores the stakes: comparative studies of Kosovo dairy farms found mature-equivalent fat and protein yields roughly 50% higher on large, betterresourced farms than on small and medium farms (p

6.3 Cheap Fixes with Good Management Can Rival Costly Infrastructure

A recurring theme across the housing and welfare literature is that management execution hygiene routines, stocking-density control, ration consistency, footbathing frequency, prompt lesion treatment explains a large share of the variation in health and economic outcomes between farms, sometimes as much as or more than the underlying capital investment in infrastructure. The clearest quantitative support comes from the bioeconomic lameness model referenced above, in which prevalence ranged from 26% to 98% purely as a function of the management scenario simulated on an otherwise-fixed housing platform (Chanteloup et al., 2023) a spread far larger than what is typically reported between different bedding materials or barn designs holding management constant.

Welfare-benchmarking studies point in the same direction: a study of 63 conventional zero-grazing farms in Northern Germany found high between-farm variability in welfare indicators and identified specific management practices glove use during milking, footbath and scraping frequency, cubicle management as differentiating high- and low-welfare farms independent of barn design (Springer et al., 2022). Similarly, systematic reviews comparing compost-bedded-pack, freestall, and conventional-bedded-pack systems, and comparisons of deep-litter versus cubicle housing, have found that management practices not housing category alone are the operative variable in welfare outcomes.

It is worth flagging that most of these findings come from observational benchmarking and

crosssectional comparisons rather than randomized or controlled variance-decomposition studies that formally partition outcome variance into "management" versus "capital" components. The bioeconomic model (Chanteloup et al., 2023) is the strongest quasi-experimental evidence in this set because it simulates management scenarios on a fixed housing platform; the observational welfare-benchmarking studies are correlational and cannot fully rule out confounding by unmeasured herd or resource factors.

A defensible framing for a seminar-level claim is therefore that several independent lines of evidence one quasi-experimental, several observational are consistent with management execution explaining a comparable or larger share of outcome variation than infrastructure category, rather than a stronger claim that this has been established through pooled quantitative variance decomposition across the literature.

6.4 Small-Scale and Resource-Limited Farms Are Disproportionately Exposed Regional studies converge on the finding that the financial consequences of management shortfalls are not evenly distributed across farm sizes, but fall disproportionately on small and medium operations. In Colombia, a stratified cross-sectional study of the Bogotá plateau dairy region (55 farms, approximately 12,000 cows in the sampling frame) found subclinical mastitis prevalence of 55.2%, with significant differences by farm size (Romero et al., 2018). A related economic analysis estimated the annual impact of milk losses from subclinical mastitis at over US$800,000 for the study region and US$70.3 per cow per year, reporting explicitly that the financial impact was greater on small- and medium-sized farms than on large farms attributed to large farms' more homogeneous, standardized management relative to the more variable practices on smaller operations (Romero et al., 2018, as cited in Fernández et al., 2023). In Kosovo, comparative production studies similarly found mature-equivalent milk, fat, and protein yields roughly 50% higher on large farms than on small and medium farms ($p<0.01$), with the lowest-performing quintile of farms operating at a substantial daily loss per cow even while the herd average remained modestly profitable indicating that the downside tail of poor management outcomes is concentrated among smaller, less-resourced operations rather than spread evenly across the sector. The proposed mechanism in both cases is consistent: smaller operations tend to have fewer financial buffers to absorb a bad month or disease outbreak, less consistent access to veterinary and extension advisory support, and less capacity to standardize protocols across the

herd than larger operations can achieve via dedicated staff or automation. This pattern is best described as "documented in these specific regional studies" rather than asserted as a universal law of dairy economics the evidence base here (Colombia and Kosovo) is real but geographically narrow, and a stronger claim would benefit from additional studies from other smallholder contexts, including Sub-Saharan Africa, where similar dynamics are frequently asserted but less rigorously quantified.

7. CONCLUSION AND RECOMMENDATIONS

Across housing, bedding, nutrition, and climate, the evidence reviewed points to a consistent conclusion: the quality of management execution hygiene, stocking density, ration precision, and responsiveness to thermal stress is at least as important as the underlying capital investment in determining both the quantity and quality of milk produced and the resulting farm profitability. Because these domains interact (for example, heat stress amplifies nutritional shortfalls, and poor bedding hygiene amplifies housing-related lameness risk), the most cost-effective improvements tend to come from coordinated management strategies rather than single-factor fixes. Because milk-pricing systems increasingly reward composition (fat and protein) as well as volume, management practices that stabilize milk composition not just yield are becoming an increasingly important economic lever for producers, and this is particularly true for smallholder and resource-limited producers, who are disproportionately exposed to the costs of management short falls.

Housing and bedding: prioritize adequate stocking density, feed-bunk space, and consistent bedding hygiene over material choice alone; where feasible, invest in alternatives such as compost-bedded packs that improve leg health and comfort.

Nutrition: formulate concentrate mixtures against measured nutrient requirements rather than ingredient availability alone, with particular attention to Ca:P balance and avoidance of excess protein relative to energy.

Climate/heat stress: combine low-cost behavioral measures (shifting feeding to cooler hours) with cooling infrastructure and, where resources allow, genetic selection for thermo tolerance.

Economic strategy: because lameness and mastitis prevalence are driven more by management execution than by capital investment, extension programs for smallholder and resource-limited farms should prioritize low-cost management training (hygiene, foot bathing, and ration consistency) alongside any infrastructure support.

Further research: additional quantitative studies from Sub-Saharan African and South/Southeast Asian smallholder dairy systems are needed to test whether the management-versus-infrastructure and farm-size disparities documented in Colombia and Kosovo generalize to other resource-limited contexts, including Ethiopia.

REFERENCES

Assaminew, S., & Ashenafi, M. (2015). Feed formulation and feeding impact on the performance of dairy cows in Central Highland of Ethiopia. Livestock Research for Rural Development, 27(4).

Barker, Z. E., Leach, K. A., Whay, H. R., Bell, N. J., & Main, D. C. J. (2010). Assessment of lameness prevalence and associated risk factors in dairy herds in England and Wales. Journal of Dairy Science, 93(3), 932–941.

Baumgard, L. H., & Rhoads, R. P. (2013). Effects of heat stress on postabsorptive metabolism and energetics. Annual Review of Animal Biosciences, 1, 311–337.

Bewley, J. M., Robertson, L. M., & Eckelkamp, E. A. (2017). A 100-year review: Lactating dairy cattle housing management. Journal of Dairy Science, 100(12), 10418–10431.

Brscic, M., Cozzi, G., Lolli, S., Gottardo, F., Contiero, B., & Guatteo, R. (2015). Management factors affecting dairy cow welfare in free-stall housing systems. Animal, 9(12), 1980–1988.

Cha, E., Hertl, J. A., Bar, D., & Gröhn, Y. T. (2010). The cost of different types of lameness in dairy cows calculated by dynamic programming. Preventive Veterinary Medicine, 97(1), 1–8.

Charlton, G. L., Haley, D. B., Rushen, J., & de Passillé, A. M. (2014). Stocking density, milking duration, and lying times of lactating cows on Canadian freestall dairy farms. Journal of Dairy Science, 97(5), 2694–2700.

Charlton, G. L., & Rutter, S. M. (2017). The behaviour of housed dairy cattle measured using electronic technology. Animal, 11(10), 1869–1876.

Charfeddine, N., & Pérez-Cabal, M. A. (2017). Effect of claw disorders on milk production, fertility, and longevity, and their economic impact in Spanish Holstein cows. Journal of Dairy Science, 100(1), 653–665.

Cook, N. B., & Nordlund, K. V. (2009). The influence of the environment on dairy cow behavior, claw health and herd health indices. Veterinary Journal, 179(3), 360–369.

DeVries, T. J., & von Keyserlingk, M. A. G. (2006). Feed stalls affect the social and feeding behavior of lactating dairy cows. Journal of Dairy Science, 89(9), 3522–3531.

Down, P. M., et al. (2024). Global losses due to dairy cattle diseases: A comorbidity-adjusted economic analysis. Preventive Veterinary Medicine.

Ebinghaus, A., & Knierim, U. (2025). Welfare of dairy cows in open-sided loose housing systems under temperate conditions—A review of potential challenges. Journal of Dairy Science, 108(6), 6034–6051

Fregonesi, J. A., & Leaver, J. D. (2001). Behaviour, performance and health indicators of welfare for dairy cows housed in strawyard and cubicle systems. Livestock Production Science, 68(2–3), 205–216.

Fraser, D. (2008). Understanding animal welfare. Acta Veterinaria Scandinavica, 50(Suppl. 1), S1.

Henry, B. K., Eckard, R. J., & Beauchemin, K. A. (2018). Review: Adaptation of ruminant livestock production systems to climate changes. Animal, 12(S2), s445–s456.

Hernandez-Mendo, O., von Keyserlingk, M. A. G., Veira, D. M., & Weary, D. M. (2007). Effects of pasture on lameness in dairy cows. Journal of Dairy Science, 90(3), 1209–1214.

Huzzey, J. M., DeVries, T. J., Valois, P., & von Keyserlingk, M. A. G. (2006). Stocking density and feed bunk management affect the feeding patterns of dairy cattle. Journal of Dairy Science, 89(1), 126–133.

Kadzere, C. T., Murphy, M. R., Silanikove, N., & Maltz, E. (2002). Heat stress in lactating dairy cows: A review. Livestock Production Science, 77(1), 59–91.

Kamberi, M. A., et al. (n.d.). Economic assessment of dairy farm production in Kosovo.

Kamberi, M. A., et al. (n.d.). The impact of feeding factors on Holstein dairy farm costs in Kosovo.

Kolver, E. S. (2003). Nutritional limitations to increased production on pasture-based systems. Proceedings of the Nutrition Society, 62(1), 1–8.

Kotsampasi, B., Karatzia, M. A., Tsiokos, D., & Chadio, S. (2024). Nutritional strategies to alleviate stress and improve welfare in dairy ruminants. Animals, 14(17), 2573.

Krasniqi, F., Kamberi, M. A., Kastrati, R., Emiri-Sallaku, E., & Tafaj, M. (2018). Investigation on feeding level and milk production of Holstein dairy cows under farm conditions in Kosovo. Bulgarian Journal of Agricultural Science, 24(3), 450–459.

López-Baca, M. A., et al. (2022). Heat stress in dairy cattle with emphasis on milk production and feed and water intake habits. Revista de Ciencias Agrícolas.

Malik, M. A. (2026). Effect of climatic stress on behavior, milk production and milk composition of dairy cattle: A bird's eye view. The Progress: A Journal of Multidisciplinary Studies, 7(1), 1–9.

McPherson, S. E., & Vasseur, E. (2020). Graduate Student Literature Review: The effects of bedding, stall length, and manger wall height on common outcome measures of dairy cow welfare in stall-based housing systems. Journal of Dairy Science, 103(11), 10940–10950

National Research Council. (2001). Nutrient requirements of dairy cattle (7th rev. ed.). National Academies Press.

Neethirajan, S. (2023). Artificial intelligence and sensor technologies in dairy livestock: Charting a digital transformation. Animal Behavior and Welfare, 1–15.

Norring, M., Manninen, E., de Passillé, A. M., Rushen, J., Munksgaard, L., & Saloniemi, H. (2008). Effects of sand and straw bedding on the lying behavior, cleanliness, and hoof and hock health of dairy cows. Journal of Dairy Science, 91(2), 570–576.

Nordlund, K. V., Cook, N. B., & Oetzel, G. R. (2006). Investigation strategies for laminitis problem herds. Journal of Dairy Science, 89, E11–E19.

Polsky, L., & von Keyserlingk, M. A. G. (2017). Invited review: Effects of heat stress on dairy cattle welfare. Journal of Dairy Science, 100(11), 8645–8657.

Rajala-Schultz, P. J., Gröhn, Y. T., McCulloch, C. E., & Guard, C. L. (1999). Effects of clinical mastitis on milk yield in dairy cows. Journal of Dairy Science, 82(6), 1213–1220.

Romero, J., Benavides, E., & Meza, C. (2018). Assessing financial impacts of subclinical mastitis on Colombian dairy farms. Frontiers in Veterinary Science, 5, 273.

Ruegg, P. L. (2017). A 100-year review: Mastitis detection, management, and prevention. Journal of Dairy Science, 100(12), 10381–10397.

Siachos, N., Smith, R. F., & Neary, J. M. (2026). Review: Free-stall bedding management for enhanced dairy cow health and welfare. Applied Animal Science, 42(3), 203–214.

Sordillo, L. M., & Aitken, S. L. (2009). Impact of oxidative stress on the health and immune function of dairy cattle. Veterinary Immunology and Immunopathology, 128(1–3), 104–109.

Sova, A. D., LeBlanc, S. J., McBride, B. W., & DeVries, T. J. (2013). Associations between herd-level management practices, feeding practices, and milk production in dairy cattle. Journal of Dairy Science, 96(8), 5329–5337.

Springer, A., et al. (2022). Effects of housing and management factors on selected indicators of the Welfare Quality® protocol in loose-housed dairy cows. Veterinary Sciences, 9(7), 353.

St-Pierre, N. R., Cobanov, B., & Schnitkey, G. (2003). Economic losses from heat stress by US livestock industries. Journal of Dairy Science, 86, E52–E77.

Tucker, C. B., & Weary, D. M. (2004). Bedding on geotextile mattresses: How much is needed to improve cow comfort? Journal of Dairy Science, 87(9), 2889–2895.

Tucker, C. B., Weary, D. M., & Fraser, D. (2004). Free-stall dimensions: Effects on preference and stall usage. Journal of Dairy Science, 87(5), 1208–1216.

van Gastelen, S., Westerlaan, B., Houwers, D. J., & van Eerdenburg, F. J. C. M. (2011). A study on cow comfort and risk for lameness and mastitis in relation to different types of bedding materials. Journal of Dairy Science, 94(10), 4878–4888.

Vasseur, E., Gibbons, J., Rushen, J., & de Passillé, A. M. (2012). Qualitative behavior assessment of dairy cows in 3 housing systems. Journal of Dairy Science, 95(9), 5225–5235.

von Keyserlingk, M. A. G., Rushen, J., de Passillé, A. M., & Weary, D. M. (2009). The welfare of dairy cattle—Key concepts and the role of science. Journal of Dairy Science, 92(9), 4101–4111.

Wang, F. X., Shao, D. F., Li, S. L., Wang, Y. J., Azarfar, A., & Cao, Z. J. (2016). Effects of stocking density on behavior, productivity, and comfort indices of lactating dairy cows. Journal of Dairy Science, 99(5), 3709–3717

Weary, D. M., & Taszkun, I. (2000). Hock lesions and free-stall design. Journal of Dairy Science, 83(4), 697–702.

West, J. W. (2003). Effects of heat-stress on production in dairy cattle. Journal of Dairy Science, 86(6), 2131–2144.

Whay, H. R., Main, D. C. J., Green, L. E., & Webster, A. J. F. (2003). Animal-based measures for the assessment of welfare state of dairy cattle, pigs and laying hens: Consensus of expert opinion. Animal Welfare, 12, 205–217.

Welfare Quality®. (2009). Welfare Quality® assessment protocol for cattle. Welfare Quality Consortium.