

THESIS

INDIVIDUAL QUARTER DRY-OFF PROCEDURE IN DAIRY COWS

Submitted by

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In partial fulfillment of the requirements

For the Degree of Master of Science

Colorado State University

Fort Collins, Colorado

Spring 2025

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ABSTRACT

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Mastitis, defined as inflammation of the mammary gland, has a major impact on the dairy industry, affecting profitability and animal welfare due to reduced milk production, increased antibiotic use, and pain and discomfort in the affected animals. This health disorder concerns researchers, producers, and consumers worldwide. The “*individual quarter dry-off*” procedure, which consists of stopping milking the affected quarter is an alternative to the use of antibiotic treatment in unresponsive cases. Understanding the relationship between the multiple factors involved in the disease and this procedure is crucial. Through an extensive review of mastitis and a descriptive statistical analysis of this dry-off practice, this thesis focuses on understanding the dynamics of this procedure within a lactating dairy herd.

Chapter 1 includes a literature review on mastitis, and the possible management practices conducted by the dairy industry to mitigate the problem. Due to the limited information available on individual quarter dry-off, the information provided in this chapter consists of a discussion of the anatomy of the mammary gland, physiology, pathology of mastitis disease, and management practices. Once general knowledge of the root of the problem is established, technical implications regarding the *individual dry-off procedure* are explained in the following chapter.

The objective of chapter 2 is to describe the dynamics of individual quarter dry-offs in certified organic dairies. The data were collected from PCDart (©DRMS) spanning from 2018 to 2023 from four organic dairies in CO, USA. The dataset included 2,881 cows with at least one dried quarter (QDO), of which 769 cows (26%) had a second dried quarter (QDO2). The variables considered in this study were quarter location, parity, days in milk (DIM), season, and survival

after the first quarter dry-off (QDO). The statistical analysis was completed in SAS (SAS Institute Inc.), employing chi-square goodness of fit, logistic regression, and ANOVA. The results showed that QDO was more prevalent in front quarters among both primiparous (PP) and multiparous (MP) cows, with higher frequencies observed during winter across both parity categories. The mean \pm SE of days in milk at QDO was smaller for primiparous cows compared to multiparous cows, and it took approximately one year to have a second dried quarter to occur. Parity category had no effect on the likelihood of QDO2, and the number of days to culling after QDO were not significantly different between parities, averaging around 365 days. Additionally, cows with QDO had lower actual and projected 305 milk yield compared to healthy cows (597 kg [PP] and 436 kg [MP] less for actual 305 milk production; 628 kg [PP] and 495 kg [MP] less for projected 305 milk production). Overall, milk yield was consistently lower in cows with QDO compared to their herdmates. These findings provide valuable insights into the dynamics of quarter dry-off, contributing novel information to support the control of mastitis in certified organic dairies.

Chapter 3 explores the dynamics of milk yield following the individual dry-off of quarters (QDO) in dairy cows. The study focused on cows that had one quarter dried off due to a chronic mastitis event and had milking records available for 30 days post-procedure. Data were collected from 144 cows on an automatic milking system (AMS) dairy farm in Colorado, of which 79% (n=144) were multiparous and 21% (n=30) primiparous. Information was sourced from DelPro and DairyComp on-farm software, and linear mixed models with repeated measures and estimated marginal means (emmeans) were generated using RStudio. Although the sample size of primiparous cows was limited, results showed a slight decrease in milk production following QDO. Conversely, multiparous cows displayed increased production in the opposite quarters, with an overall milk yield rising over the 30-day period after the dry-off. Total milk production following

QDO was higher in cows ≤ 120 days in milk (DIM) compared to those with >120 DIM. Additionally, cows experienced greater milk yields when the dry-off procedure was performed on rear quarters versus front quarters. Of the variables analyzed, the number of days in milk after the procedure showed the most statistically significant relationship with milk production, while presence of other diseases did not exhibit a significant effect. These findings offer valuable insights into milk yield dynamics and implications for management strategies in dairy herds.

ACKNOWLEDGEMENTS

I would like to thank my advisor Dr. Pablo Pinedo for this opportunity, his guidance and support throughout the program. I would also like to thank my lab mates for their friendship and support during these two years. Additionally to USDA-NIFA OREI for the award number #2022-51300-3788.

TABLE OF CONTENTS

ABSTRACTii

ACKNOWLEDGMENTSv

LIST OF TABLESviii

LIST OF FIGURES ix

CHAPTER 1: LITERATURE REVIEW1

 Anatomy and physiology of the mammary gland1

 Mastitis pathogenesis and classification6

 Mastitis management and control10

REFERENCES19

CHAPTER 2: DYNAMICS OF INDIVIDUAL QUARTER DRY-OFF PROCEDURE IN
CERTIFIED ORGANIC DAIRIES25

 Summary25

 Introduction26

 Materials and methods27

 Results29

 Discussion33

 Conclusion37

REFERENCES38

CHAPTER 3: MILKING BEHAVIOUR AFTER INDIVIDUAL QUARTER DRY-OFF
PROCEDURE IN AN AUTOMATIC MILKING SYSTEM40

 Summary40

 Introduction41

 Materials and methods42

 Study population42

 Statistical analysis43

 Results44

 Discussion70

Conclusion	72
REFERENCES	73

LIST OF TABLES

TABLE 2.1: Mean, standard deviation, and p-values for actual milk 305, projected milk 305, herdmate deviation, and days dry in previous lactation by parity and level (0=healthy, 1=QDO).....	33
TABLE 3.1: Number of animals per parity category, quarter position, and stage of lactation.....	43

LIST OF FIGURES

FIGURE 1.1: Extracted from Nickerson (2011). Diagrammatic cross section of the four quarters of the udder illustrating the gross anatomy.	2
FIGURE 1.2: Extracted from Nickerson (2011). (a) Diagram of a mammary quarter illustrating the glandular tissue (alveoli are drawn out of scale), ducts, gland and teat cisterns, and teat canal. (b) Diagrammatic cross section of an alveolus illustrating mammary epithelial cells, myoepithelial cells, and capillary network.	2
FIGURE 2.1: Frequency (%) of localization of individual quarter dry-off and parity group in primiparous (PP) and multiparous (MP) cows (left rear [LR], right rear [RR], left front [LF], and right front [RF]).	29
FIGURE 2.2: Frequency (%) of localization of individual quarter dry-off and parity group in primiparous (PP) and multiparous (MP) cows (left rear [LR], right rear [RR], left front [LF], and right front [RF]).	30
FIGURE 2.3: Frequency (%) of individual quarter dry-off by parity group in primiparous (PP) and multiparous (MP) cows (left rear [LR], right rear [RR], left front [LF], and right front [RF]).....	30
FIGURE 2.4: Frequency (%) of individual quarter dry-off by parity group in primiparous (PP) and multiparous (MP) cows (left rear [LR], right rear [RR], left front [LF], and right front [RF]).....	31
FIGURE 2.5: Count of DIM for individual quarter dry-off 1 by parity group in primiparous (PP) and multiparous (MP) cows.	32
FIGURE 3.1: Least square means (SE) for quarter milk yield when one rear quarter was dried-off within 120 DIM (left rear [LR], right rear [RR], left front [LF], and right front [RF]).	45
FIGURE 3.2: Least square means (SE) for quarter milk yield when one rear quarter was dried-off with more than 120 DIM (left rear [LR], right rear [RR], left front [LF], and right front [RF])...	47
FIGURE 3.3: Least square means (SE) for quarter milk yield when one rear quarter was dried-off within 120 DIM in primiparous cows (left rear [LR], right rear [RR], left front [LF], and right front [RF]).	48
FIGURE 3.4: Least square means (SE) for quarter milk yield when one rear quarter was dried-off within 120 DIM in primiparous cows (left rear [LR], right rear [RR], left front [LF], and right front [RF]).	49
FIGURE 3.5: Least square means (SE) for quarter milk yield when one rear quarter was dried-off within 120 DIM in multiparous cows (left rear [LR], right rear [RR], left front [LF], and right front [RF]).	50
FIGURE 3.6: Least square means (SE) for quarter milk yield when one rear quarter was dried-off with more than 120 DIM in multiparous cows (left rear [LR], right rear [RR], left front [LF], and right front [RF]).	51

FIGURE 3.7: Least square means (SE) for quarter milk yield when one front quarter was dried-off within 120 DIM (left rear [LR], right rear [RR], left front [LF], and right front [RF]).	.....52
FIGURE 3.8: Least square means (SE) for quarter milk yield when one front quarter was dried-off with more than 120 DIM (left rear [LR], right rear [RR], left front [LF], and right front [RF]).	.....53
FIGURE 3.9: Least square means (SE) for quarter milk yield when one front quarter was dried-off with more than 120 DIM in primiparous cows (left rear [LR], right rear [RR], and left front [LF]).	.....54
FIGURE 3.10: Least square means (SE) for quarter milk yield when one front quarter was dried-off within 120 DIM in multiparous cows (left rear [LR], right rear [RR], left front [LF], and right front [RF]).	.....56
FIGURE 3.11: Least square means (SE) for quarter milk yield when one front quarter was dried-off with more than 120 DIM in multiparous cows (left rear [LR], right rear [RR], left front [LF], and right front [RF]).	.....57
FIGURE 3.12: Least square means (SE) for total milk yield when one rear quarter was dried-off within 120 DIM and more than 120 DIM.	.....58
FIGURE 3.13: Least square means (SE) for total milk yield when one front quarter was dried-off within 120 DIM and more than 120 DIM.	.....59
FIGURE 3.14: Least square means (SE) for total milk yield when one rear quarter was dried-off within 120 DIM and more than 120 DIM in primiparous cows.	.....60
FIGURE 3.15: Least square means (SE) for total milk yield when one rear quarter was dried-off within 120 DIM and more than 120 DIM in multiparous cows.	.....61
FIGURE 3.16: Least square means (SE) for total milk yield when one front quarter was dried-off with more than 120 DIM in primiparous cows.	.....62
FIGURE 3.17: Least square means (SE) for total milk yield when one front quarter was dried-off within 120 DIM and more than 120 DIM in multiparous cows.	.....63
FIGURE 3.18: Least square means (SE) for front quarters milk yield when one rear quarter was dried-off within 120 DIM and more than 120 DIM.	.....64
FIGURE 3.19: Least square means (SE) for rear quarters milk yield when one front quarter was dried-off within 120 DIM and more than 120 DIM.	.....65
FIGURE 3.20: Least square means (SE) for front quarters milk yield when one rear quarter was dried-off within 120 DIM and more than 120 DIM in primiparous cows.	.....66

FIGURE 3.21: Least square means (SE) for rear quarters milk yield when one front quarter was dried-off within 120 DIM and more than 120 DIM in primiparous cows.67

FIGURE 3.22: Least square means (SE) for front quarters milk yield when one rear quarter was dried-off within 120 DIM and more than 120 DIM in multiparous cows.68

FIGURE 3.23: Least square means (SE) for rear quarters milk yield when one front quarter was dried-off within 120 DIM and more than 120 DIM in multiparous cows.69

FIGURE 3.24: Least square means (SE) for total milk yield after one front or rear quarter was dried-off within 120 DIM after the procedure.....7

CHAPTER 1: LITERATURE REVIEW

Advancements in genetics, nutrition, and management have led to significant increases in milk yield among dairy cows. However, this has also led to new challenges, such as a decline in udder health and the increase in the incidence of mastitis, an inflammatory disease affecting the mammary gland (De Vliegher et al., 2012; Oltenacu et al., 2010; Davidson and Stabenfeldt, 2020). In this chapter the anatomy and physiology of the mammary gland are explored along with an overview of mastitis classification and key management practices to control the disease.

Anatomy and physiology of the mammary gland

The bovine udder consists of four individual mammary glands, which are separated by the median suspensory ligaments. These elastic structures are attached to the pelvic bone, the tendons of the external oblique abdominal muscles. Additionally, a connective tissue septum runs transversally to the ligament, giving as a result four segments of the udder. The median suspensory ligaments form the intermammary groove and provide key support for the udder, ensuring its functionality and health. Without these structural components, the udder's production capacity, udder health and overall well-being would be compromised, as pendulous udders are more susceptible to mastitis (Seykora and McDaniel, 1986; Nickerson, 2011). The lateral ligaments, which are a less elastic continuation of the median ligaments, surround the glandular tissue of each mammary gland. This glandular tissue includes the parenchyma, ducts, gland cistern, teat cistern, teat canal, and teat sphincter (Figure 1.1; Nickerson, 2011).

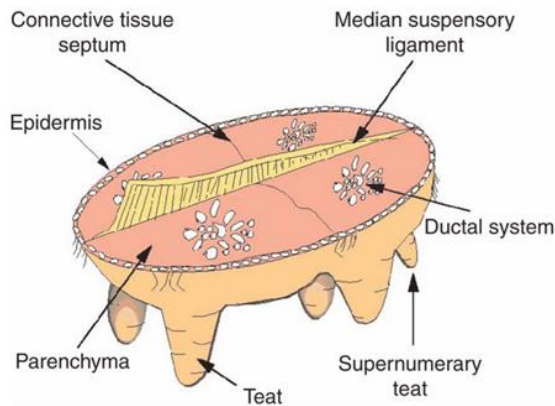


Figure 1.1: Extracted from Nickerson (2011). Diagrammatic cross section of the four quarters of the udder illustrating the gross anatomy.

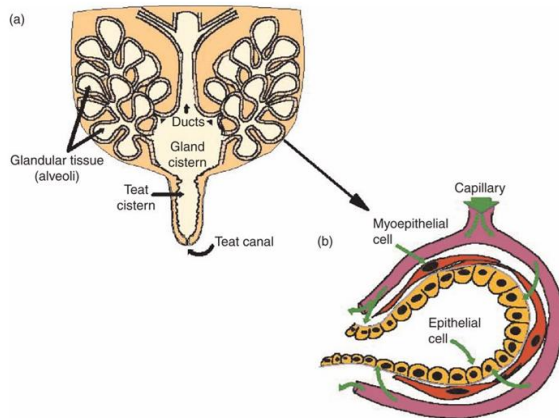


Figure 1.2: Extracted from Nickerson (2011). (a) Diagram of a mammary quarter illustrating the alveoli or glandular tissue (not drawn to scale), ducts, gland and teat cisterns, and teat canal. (b) Diagrammatic cross section of an alveolus illustrating mammary epithelial cells, myoepithelial cells, and capillary network.

Beyond structural support, the glandular tissue within the mammary gland plays a critical role in milk production and storage. The parenchyma of the mammary gland is composed of epithelial cells that form the alveoli, which serve as the secreting unit of the gland (Figure 1.2; Nickerson, 2011). Surrounding these alveoli are myoepithelial cells, which contract in response to oxytocin binding to oxytocin receptors after a stimuli, triggering the release of milk produced by the epithelial cells. The milk stored in the ducts flow into the gland cistern and teat cistern,

structures adapted for milk storage. Upon stimulation, the milk travels through the teat canal and is released via the teat sphincter (Davidson and Stabenfeldt, 2020).

The release of milk stored in the ducts and cisterns is closely regulated by the nervous system, ensuring efficient milk ejection during the milking process. The teat cistern, which acts as a continuation of the gland cistern, has a capacity to hold up to 50 ml of milk and connects directly to the teat canal. The teat canal measures between 5 and 13 mm in length, with an average of 8.5 mm. Its diameter varies along the canal, measuring 0.4 mm at the distal end, 1.63 mm at proximal end, and averaging 0.46 mm in the midsection. These dimensions also evolve with subsequent lactations, as older cows typically develop longer teat canals. The canal is covered by keratin, which serves as the first barrier against bacterial infection. Surrounding the teat canal are smooth muscle fibers, which ensure the sphincter to remain closed. When these muscle fibers are weak or relaxed, cows may experience milk leakage or *incontinentia lactis* (Nickerson, 2011). This condition can also result from an increased intramammary pressure, elevating the risk of environmental exposure to pathogens, potentially leading to intramammary infections and clinical mastitis (Peeler et al., 2000; Rovai et al., 2007; Blau et al., 2019).

Sensory nerves play a critical role in relaxing muscle fibers in response to physical stimuli, facilitating the opening of the teat sphincter and enhancing hormonal circulation during the milking process. The udder is innervated by two types of nerves. The first type consists of sympathetic nerves, composed of motor fibers that innervate smooth muscle fibers in the walls of the arteries, regulating blood flow, as well as the fibers from the teat sphincter. The second type is sensory nerves, which are activated by physical stimuli. All these nerve fibers converge through the inguinal nerve, connecting to the second, third and fourth sacral nerves, which transmit signals to the brain. Although the response to stimuli does not directly cause the milk ejection, it triggers the

relaxation of the smooth muscle fibers, opening the teat canal's sphincter and increasing the circulation of hormones in the bloodstream (Bruckmaier and Blum, 1998; Nickerson, 2011).

Hormones circulating in the bloodstream play a crucial role in regulating various structures within the mammary gland. One key feature is the semi-permeable blood-milk barrier, which is composed of endothelial cells, connective tissue, the basal membrane, and epithelial cells. This barrier is essential for preventing the transfer from certain components into the bloodstream, while allowing the selective movement of substances from the blood to the milk. These include water, electrolytes, immune cells, antibodies, and amino acids for the production of proteins like casein (Burton and Erskine, 2003; Stelwagen and Singh, 2014). The permeability of this barrier increases during colostrogenesis and involution but remains less permeable throughout most of lactation. This selective permeability is maintained by structures such as desmosomes, tight junctions, and adherent junctions, all of which are hormonally regulated (Wei and Huang, 2013).

Hormones such as estrogen and progesterone play a pivotal role in regulating junctions within the mammary gland. The presence and timing of these hormones can influence the cow's susceptibility to mastitis. The proliferations of the mammary ducts system begins at puberty, driven by estrogen, growth hormones, and adrenal steroids. During the heifer's first pregnancy, progesterone and prolactin finalize the development of the mammary gland, preparing it for milk production. At the time of dry-off, the mammary gland undergoes a process known as involution, during which the glandular system regresses and transitions into a state of readiness for the next lactation (Davidson and Stabenfeldt, 2020).

Among the hormones that regulate mammary gland function, oxytocin is particularly essential in facilitating milk ejection. Sensory stimuli are transmitted to the supraoptic and paraventricular nuclei of the hypothalamus, where they trigger the transport of oxytocin in vesicles

and its release from the posterior pituitary gland. Elevated concentrations of oxytocin in blood activate receptors on myoepithelial cells in the mammary gland. The alveoli, which store 60% of the milk produced in the mammary gland, respond contracting under the influence of the hormone releasing the milk. The remaining 40% of the milk is stored in the ducts and cisterns, representing milk accumulated during the inter-milking interval. If the gland is not milked after about 1 to 2 minutes since the cow receives the stimuli till the release of milk, the increase in intramammary pressure will decrease milk production from the alveoli (McKusick et al., 2002; Belo and Bruckmaier, 2010; Nickerson, 2011). Therefore, timely milking is essential to maintain uninterrupted milk flow and preventing issues such as bimodal milking (Bruckmaier and Blum, 1998).

Disruptions in the structures and function of the mammary gland, mentioned above, can turn into mastitis. Wrongly applied mechanical forces by the milking machine, like abnormal vacuum levels, or maximal alveolar contraction due to high levels of oxytocin can result in short-term impairments. These factors influence intramammary pressure, compromising the blood-milk barrier, increasing permeability, and increasing susceptibility to intramammary infections (Wellnitz and Bruckmaier, 2021). Mastitis alters the composition of the milk, as evidenced by the elevated concentrations of white blood cells, blood and electrolytes. The vacuum created by the milking machine also impacts on the teat tissue, causing short term effects like increased thickened due to intra and extravascular fluid accumulation (Vierbauch et al., 2021). Overtime, this can lead to congestion and hyperkeratosis. Typically, teat tissue thickness recovers within 35 minutes following a normal milking, but in cases of overmilking (leaving the milking machine attached to the udder after milk flow has significantly decreased or stopped) lasting five minutes, the recovery time can double (Odorcic et al., 2020). This delayed recovery highlights the critical role of post-

dipping, as it helps protect the mammary gland during its heightened vulnerability to intramammary infections and the increased risk of mastitis.

The alterations caused by mastitis not only affect the mammary gland's health but also result in significant changes to milk composition. Normal milk composition values for different breeds are as follows. Holstein cows typically produce higher quantities of milk, but it is less concentrated in solids. Their average cumulative milk production over a 305-day lactation period is 12,893 kg, with 4.11% fat and 3.22% protein. In contrast, Jersey cows have lower milk yields, averaging 9,504 kg over 305 days, but their milk is richer in solids, containing 4.91% fat and 3.72% protein (CDCB Council on Dairy Cattle Breeding, 2023). Beyond breed differences, factors such as days in milk, parity, seasonality, and udder health also influence milk composition. Mastitis, in particular, impacts milk yield and alters its composition, affecting the casein-to-total protein ratio, lactose levels, nonfat solids, and pH (Coulon et al., 2002; Ogola et al., 2007; Malek dos Reis et al., 2013; Bobbo et al., 2017).

Mastitis pathogenesis and classification

Mastitis can be classified in various ways, including its etiology or epidemiology of the pathogens that cause mastitis, its duration, and its clinical signs. When considering its duration, chronic mastitis is characterized by recurring clinical events that fail to cure, or cases which cows present two consecutive high somatic cell counts (Cardozo et al., 2015). In contrast, mastitis cases that can be resolved within a short period of time are classified as acute. A case is defined as new if two diagnoses are separated by 14 days; otherwise, it is categorized as chronic mastitis (Ruegg, 2003).

Mastitis can be classified based on its clinical expression as either clinical or subclinical. Clinical mastitis is characterized by abnormal milk secretion, which may appear watery, with blood

or clots. These can be accompanied by visible signs on the udder or not, such as swelling, redness, and fever, as well as systemic symptoms like anorexia, and/or apathy. In contrast, subclinical mastitis presents abnormalities in the milk that are not detectable to the naked eye and can only be detected through diagnostic techniques and laboratory tests. These include qualitative or quantitative somatic cell count and bacteriological analyses (Ruegg, 2011).

Subclinical mastitis poses a significant concern within the herds due to its impact on milk yield, the challenges it presents for diagnosis, and its role as a reservoir for pathogens, increasing the risk of further intramammary infections within the herd (Cobirka et al., 2020). Somatic cell count (SCC) is a key indicator of udder health and is used to diagnose mastitis both at the individual cow and herd levels. Bulk-tank somatic cell count (BTSCC) reflects the prevalence of intramammary infections within the herd (Wenz et al., 2007). It measures the concentration of white blood cells and secretory cells in one milliliter of raw milk, serving as an important indicator of milk quality at herd level and the limit in the US industry is of 750,000 cells/mL. SCC functions similarly to BTSCC but is measuring milk quality for individual animals (USDA, 2016).

All milk contains white blood cells called leukocytes, which make up the majority of somatic cells. In the presence of mastitis, the number of these cells increase. The normal value for SCC is 200,000 cells per milliliter or lower. Counts exceeding this threshold are considered abnormal and often indicate potential infection. Elevated counts can also be associated with decreased milk production, as the concentration of cells per milliliter increases (NMC, 2016).

Mastitis can be categorized based on the causative agent and mode of transmission as environmental or contagious (Ruegg, 2011). These two categories require distinct approaches for control, since they have different reservoir sources (Smith and Hogan, 1993). Environmental mastitis is caused by opportunistic pathogens that coexist with cows in their surroundings. The

most common pathogens are gram-negative bacteria, including *E. coli*, *Klebsiella pneumoniae*, and *Enterobacter aerogenes*, along with other from the general *Serratia*, *Pseudomonas*, and *Proteus*. Infections caused by gram-negative bacteria are typically clinical nature, accounting for 80-90% of the cases, with approximately 10% manifesting in peracute form (Smith et al., 1985). Although gram-negative infections have a low prevalence (1-2%), most of the clinical mastitis cases resolve spontaneously within a week. However, chronic mastitis caused by environmental pathogens is occasionally linked to infections caused by *Klebsiella spp.* or *Serratia* infections (Todhunter et al., 1990; Smith and Hogan, 1993). Other microorganisms, such as *Streptococcus uberis*, also contribute to the environmental mastitis, with clinical mastitis occurring in approximately 25% of the cases (USDA, 2016).

Environmental mastitis risk is influenced by factors such as stage of lactation, season, parity, and type of housing. The dry period is particularly sensitive, with most intramammary infections occurring within the first two weeks after dry-off, subsequently presenting as clinical mastitis in early lactation. Dry cow pens often serve as reservoir for environmental mastitis agents, leading to new intramammary infections within herds. While dry-off therapy with antibiotics offers protection during the initial weeks of the dry period, its efficacy in preventing infections during the periparturient period or against coliforms remains uncertain (Smith, 1985; Smith et al., 1985; Todhunter et al., 1990). Parity plays a role, as older cows have higher likelihood of developing mastitis, though heifers are not exempt and can also contract intramammary infections, which often manifest as clinical mastitis after calving (Cardozo et al., 2015; Hogan et al., 1989). Seasonal variations further contribute to mastitis risk; indoor housing farms in regions such as Florida, seasons with high temperature humidity index, like summer, are associated with higher rates of clinical mastitis due to increased microorganism activity in bedding (Dahl and

McFadden, 2022). Conversely, pasture based systems see elevated rates of environmental mastitis during rainy season (Olde Riekerink et al., 2007).

Unlike environmental mastitis, which arises from opportunistic pathogens in the cow's surroundings, contagious mastitis is transmitted between infected and healthy quarters, mainly during the milking process, requiring different management strategies (Smith and Hogan, 1993). Contagious mastitis is often linked to chronic subclinical mastitis. Common pathogens include *Staphylococcus aureus*, *Streptococcus agalactiae*, *Corynebacterium bovis*, *Streptococcus dysgalactiae*, and *Mycoplasma spp* (Fox and Gay, 1993). Subclinical infections caused by contagious pathogens are indicated by somatic cell counts exceeding 200,000 cells/mL (Ruegg, 2011). These pathogens possess virulent factors that enable them to establish intramammary infections. For example, *Staphylococcus aureus* can adhere to epithelial cells on the mucosal surface and internalize within these cells, allowing protection from the immune system as well as bactericidal products. Additionally, these pathogens are capable of interfering with neutrophil function by binding to immunoglobins, inhibiting opsonization, and producing microabscesses. Similarly, *Mycoplasma bovis* lacks a cell wall and adheres to the host's cell, relying on precursors for colonization and growth, while enhances resistance to antibiotics and evasion of the immune system as well (Fox and Gay, 1993). These attributes contribute to chronic and subclinical infections, making their control challenging and preventive measures essential.

Beyond their mode of transmission, mastitis pathogens are also categorized based on their prevalence and the severity of the infections they cause. (Cobirka et al., 2020). Major pathogens include *E. coli*, *S. aureus*, and *Streptococci spp.*, while minor pathogens comprise *S. chromogenes*, *S. haemolyticus*, *S. epidermis*, *S. simulans*, *S. sciuri*, *Corynebacterium bovis*, yeast, and fungi (Heikkilä et al., 2018a).

Mastitis management and control

The National Mastitis Council proposed a five-point plan for mastitis prevention, which includes identifying and treating clinical cases, post-dipping, dry cow therapy, culling chronic cases, and regular cleaning of the milking machine (Ruegg, 2017). However, the foundation of this approach was first described by Neave et al. (1969), who recommended pre-milking teat disinfection, use of gloves, sanitization of the teat cups, and post-dipping. The five point plan focus on maintaining hygiene of the milking machine, teat cups, and the milking parlor, in addition to implementing a clean and consistent milking routine to reduce the risk of transmitting contagious pathogens.

An essential aspect of implementing the five-point plan is establishing a proper milking routine, which not only reduces pathogen transmission but also ensures optimal udder health. A proper milking routine also ensures cows are adequately stimulated, preventing the occurrence of bimodal milking and its negative consequences, such as damage to the mammary gland structures (Ruegg, 2003). Key considerations for milking include a correct attachment of the teat cups and avoiding overmilking, which can be achieved by utilizing automatic removers. Research shows that automatic take-offs are associated with lower bulk tank somatic cell counts (BTSCC) (Wenz et al., 2007), reflecting improved udder health. Avoiding overmilking is crucial to prevent short-term damage to the mammary gland, which can develop into long term conditions, such as hyperkeratosis at the teat end, ultimately increasing risk of infection (Odorcic et al., 2020).

While milking practices are vital for preventing mastitis, identifying risk factors and tailoring control measures are equally important for effective management. Effective control measures for mastitis involve identifying the type of mastitis, the causative agent, and potential risk factors (Bramley and Dodd, 1984). Developing a control and prevention plan requires

distinguishing between subclinical or clinical and calculating their prevalence and incidence. BTSCC can be used to estimate the potential subclinical mastitis within the herd. However, this value can be misleading as it is influenced by factor such as seasonality, region, and herd size. It can also be misleading since the proportion of cows contributing somatic cell counts to the total count can vary. For this reason, individual somatic cell count (SCC) is a more reliable approach. Ideally, less than 15% of the cows in the herd should have SCC values exceeding 250,000 cells/mL, interpreting this value as the prevalence. Incidence values (percentage of new cases) should be <5% (Ruegg, 2011).

For clinical mastitis, detection depends heavily on the training and observational skills of farm employees. A target incidence rate of $\leq 25\%$ annually ($\leq 2\%$ monthly) is recommended. The rate can be calculate using the formula= number of quarters affected (monthly)/ (number of lactating cows) x 100, considering a new case after 14 days (Ruegg, 2011).

The use of scatter graphs is a useful visual tool for monitoring mastitis trends within a herd. The graph is divided into four squares (A, B, C, D; A= cured, B=chronic, C=healthy, D= new cases). The distribution of cows within these quadrants provides insights into the type of mastitis affecting the herd. For example, a high number of cows in quadrant B indicate chronic mastitis, possibly caused by contagious pathogens, while high numbers in quadrants A and D suggest clinical mastitis, possibly caused by environmental pathogens (Ruegg, 2003).

Once control measures are in place, the next step is employing diagnostic tools to accurately identify mastitis cases and adapt treatments accordingly. Diagnostic tools such as microbiology, SCC, California mastitis test (CMT), and electroconductivity can be used to define the case. Modern diagnostic approaches also include advanced techniques like metabolomics, ultrasonography, blood gas analysis, and infra-red thermography (Flöck and Winter, 2006; Mourya

et al., 2020; Machado et al., 2021; Feng et al., 2022; Tommasoni et al., 2023). Conducting microbiological tests is essential for adapting treatments to specific pathogens and assessing treatment effectiveness. Bacteriological culture and PCR are considered gold standard for mastitis diagnosis (Tommasoni et al., 2023).

The MALDI-TOF technique further enhances diagnostic precision by identifying specific genera and species, minimizing errors. Meanwhile, real time PCR is particularly useful for detecting microorganisms that are difficult to culture or when the sample preservation conditions are suboptimal (Loy et al., 2023). Diagnostic results can vary depending on factor such as different sampling methods, laboratory protocols, or whether composite or individual quarter samples are used. Similarly, samples used for SCC analysis can yield different results based on whether they were taking as composite or individual. Standard plate counts are another valuable diagnostic tool, particularly for identifying hygiene issues related to milking equipment (Ruegg, 2003). On-farm bacteriological culture offers a quick alternative for the diagnosing clinical and subclinical mastitis, enabling selective treatment for specific pathogens (Tommasoni et al., 2023).

Among the available diagnostic tools, California Mastitis Test is a practical, on-farm diagnostic method performed directly besides the cow. It provides an indirect estimate of leukocyte count in milk. Despite its practicality, only 20% of small farms and 9% of large farms, with an average of 15% of the farms in the US utilize this method to detect subclinical mastitis at dry-off (USDA, 2016). The test involves applying a reagent containing detergent and bromocresol to quarter samples. This reacts with the DNA of the cells present in the milk, giving a scale: negative (0-200,000 cells/mL), trace (150,000-500,000 cells/mL), 1(400,000-1,500,000 cells/mL), 2(800,000-5,000,000 cells/mL), 3(>5,000,000 cells/mL).

In addition to the California Mastitis Test, electroconductivity provides another method for diagnosing mastitis, though it requires careful interpretation due to various influencing factors including temperature, stage of lactation, fat percentage in milk, milking intervals, and breed (Hamann and Zeconi, 1998; Ruegg, 2003). These considerations must be accounted for to ensure a reliable interpretation of the electroconductivity results.

While diagnostic tools are essential for identifying mastitis cases, understanding risk factors at the cow, milking machine, and environmental levels is crucial for implementing effective prevention strategies (Ruegg, 2003). At the cow level, parity is an important factor, as older cows have a higher risk of mastitis events. However, heifers are not exempt from this disease, making preventive and control measures equally crucial. These include practices such as fly control, avoiding inter-suckling, and improving hygiene and comfort (Ruegg, 2011; De Vliegher et al., 2012). Moreover, heifers weaned from a different facility are often associated with higher BTSCC (Wenz et al., 2007). Consequently, developing a robust replacement program should be a priority for producers. Early lactation stages are particularly susceptible to environmental mastitis pathogens, often linked to a poor dry cow management. If SCC exceeds 200,000 cells/mL in over 20% of the early lactation cows, it suggest that dry cow management should be addressed (Ruegg, 2003).

Among the environmental factors that contribute to mastitis, udder hygiene and manure management are particularly critical, since these are strongly correlated with mastitis events. Ideally, fewer than 20% of cows in the herd should have dirty udders. Maintaining clean stalls, walkways, and milking parlor is crucial for reducing the risk of environmental mastitis (Schreiner and Ruegg, 2003; Reneau et al., 2005).

Another important environmental factor is the seasonal variation. Cows held in barns are more susceptible during summer, as elevated temperatures foster microorganism growth in bedding, increasing exposure to pathogens like *E. coli* and *Str. uberis* (Zhang et al., 2016). Additionally, heat stress exacerbates the issue by impairing the immune response, raising the risk of intramammary infections, increasing SCC, and reducing milk production (Lambertz et al., 2014; Ferreira and De Vries, 2015; Dahl and McFadden, 2022). On the contrary, pasture-based systems face heightened mastitis risk during rainy and humid seasons, where muddy udders become a primary concern (Smith et al., 1985). Prevention strategies tailored to the season and housing system include using bedding with lower organic matter content, which reduces bacterial growth, or composting bedding to reduce the bacterial count (Hogan and Smith, 2012). A study conducted by Wenz et al., (2007) found that the type of bedding like mattresses and sand are associated with low BTSCC. Reducing bedding moisture, cleaning stalls regularly, and avoiding overcrowding, minimize manure exposure, preventing intramammary infections (Barkema et al., 1998).

Alongside environmental and seasonal challenges, proper maintenance of milking equipment plays a pivotal role in minimizing mastitis risk. The periodical maintenance of the milking machine is a very important factor for udder health. Proper pulsation and vacuum levels are essential, as inadequate levels can damage the teat. High vacuum levels, while efficient at emptying the teat, increase measurements of the teat cistern and wall diameter, elevating risk of infection (Hamann et al., 1994; Besier and Bruckmaier, 2016).

While milking equipment maintenance helps prevent physical damage that increases mastitis risk, additional measures, such as antimicrobials and dry cow therapy, are critical for managing and treating infections. Antimicrobials, applied either intramammary or via injection, are common for treating clinical and subclinical mastitis during lactation or dry-off. These

therapies can be conducted selectively or as blanket treatments, where all cows receive the same therapy for all quarters (Tommasoni et al., 2023). According to a USDA (2014) study covering 80% of the U.S. dairy farms, nearly three-quarters of the operations used intramammary application of cephalosporins as their main antibiotic, with 12.6% of the operations using penicillin as their primary antibiotic against mastitis. Dry cow therapy, traditionally considered most effective when administered as blanket therapy, has been re-evaluated. Recent findings suggest significant differences between the outcomes of blanket therapy and selective therapy, making selective therapy an effective option, reducing antimicrobial resistance and less potential residues in milk (de Jong et al., 2023; Tommasoni et al., 2023). Dry cow therapy can be accompanied by the use of internal and external teat sealant, with criteria for drying off based on schedule (40 to 60 days before calving), low milk production, and/or chronic mastitis (NMC, 2006; USDA, 2016). Farms may implement abrupt or gradual cessation of milking; however, a study conducted by Wieland et al. (2023), concluded that both methods yield comparable results in terms of cow well-being, udder health, milk production, and survival. Feed restriction during dry-off can also help reduce the intramammary pressure at the time of dry-off (Blau et al., 2019).

In addition to dry cow therapy, vaccination during this period plays an essential role in preventing infections caused by mastitis pathogens. For gram negative pathogens like *E. coli*, immunization using vaccines such as J5, has proven effective in reducing the severity of the disease. Vaccines are recommended to be applied at dry-off and during early lactation for optimal protection (USDA, 2016; Hogan et al., 1992).

Finally, pain management during the course of the disease is a key point for animal welfare. Many clinical cases lack bacterial growth, and those with bacterial growth presence not always respond to antibiotic treatment. Non-steroidal anti-inflammatory drugs (NSAIDs), such as

meloxicam, flunixin meglumine, ketoprofen, and carprofen, are recommended to manage pain and inflammation. Flunixin meglumine is approved by the FDA for control of pain in mastitis and endotoxemia-related inflammation (Smith G. W., 2008).

While conventional farms have access to antimicrobials for treatment, organic dairy systems rely entirely on preventive management and alternative strategies due to restrictions on antibiotic use. Velez (2011) highlights the importance of developing and following protocols, as well as retaining thorough records. These records are important for training the workers, facilitating certification process, evaluating treatments effectiveness, and for protecting the producer against potential allegations of prohibited substance use. While prevention practices are largely similar between conventional and organic herds, organic farms depend entirely on management strategies due to their inability to use antimicrobials. Key components of organic herd management include strict milking protocols, the use of milking equipment with backflush system, proper maintenance of the milking equipment, intermittent milking during dry-off, culling chronically infected cows, vaccination against coliform bacteria, and maintaining clean stalls.

Given the restrictions on antibiotic use in organic systems, research into alternatives like herbal medicines and essential oils offers promising avenues for mastitis management (Li et al., 2023). Essential oils derived from phenolic compounds, such as eugenol, carvacrol, and thymol, exhibit antibacterial properties and can be found in various plants. Research indicates that these essential oils are particularly effective against gram-positive bacteria, by impacting on the bacterial cell membrane permeability (Tariq et al., 2019). For example, carvacrol showed to have an effective inhibitory effect on *S. aureus* and lesser on *K. pneumoniae* (Rani, 2022). Cinnamon has shown potential anti-inflammatory effects due to their phenolic and volatile compounds, potentially aiding in the reduction of inflammation and the healing of tissue damaged by mastitis

(Neculai-valeanu et al., 2021). Other essential oils, like tea tree oil extracted from the genus *Melaleuca* plant, has antibacterial effects against *E. coli* and *S. aureus* by inhibiting bacterial respiration, affecting membrane stability, and affecting potassium ion gradients (Sharifi-Rad et al., 2017). The *Lamiaceae* family includes the *Lavandula* genus, commonly known as lavender. These plants provide essential oils that mainly contain linalool and linalyl acetate, along with other terpenes in smaller quantities. Some *Lavandula* species have shown efficiency against *Staphylococcus aureus*, *Streptococcus agalactiae*, and *E. coli* (Noori et al., 2019). Similarly, sage (*Salvia* genus) and other plants, such as those from the *Mentha* genus, rosemary (*Rosmarinus officinalis*), and cedar (*Juniperus virginiana*), offer essential oils with potential antimicrobial activity. However, most studies on essential oils have been conducted in vitro, with few conclusive in vivo studies on dairy cows (Caneschi et al., 2023). In addition to alternative treatments, organic dairy farms often employ individual quarter dry-off (QDO) procedures as a key strategy for managing chronic mastitis.

Both conventional and organic systems commonly rely on individual quarter dry-off (QDO) procedures, though organic herds use this method primarily for managing chronic mastitis. Organic farms typically implement QDO by stopping milking the affected quarter, while other options include intramammary infusions of chlorhexidine or iodine (Middleton and Fox, 2001).

Although data on QDO procedures remain limited, some studies have analyzed their effects on udder health and production. Skarbye et al. (2018) conducted a randomized field trial on an organic herd, comparing QDO with continuous milking (CM). QDO was associated with pain, increased swelling, and firmness in the affected quarter, as well as a production loss of approximately 4.1 kg/day, with variation based on parity, DIM, and prior yield. However, compensatory production effects were observed when QDO was performed during early lactation.

A more recent study examined QDO's impact on udder health, milk production, and culling risk. All QDO groups experienced decreased production, lower SCC, and an elevated culling risk, particularly when the procedure was conducted following clinical mastitis events (Wieland and Skarbye, 2024).

Despite these findings, there remains a gap in research on QDO procedures. Further studies are needed to explore demographic factors influencing the procedure's success, as well as cow-level and quarter-level responses. While existing research emphasizes compensatory production effects, greater focus should be placed on understanding QDO's long-term feasibility and its impact on cow retention within herds.

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CHAPTER 2: DYNAMICS OF INDIVIDUAL QUARTER DRY-OFF IN CERTIFIED ORGANIC DAIRIES

Summary

Drying off individual quarters (QDO) represents an alternative for treating severe or chronic clinical mastitis in US certified organic dairies, where antibiotic use is prohibited. The objective of this study was to describe the dynamics of individual quarter dry-offs in organic-certified dairies. Data from cows calving from 2017 to 2023 in four organic dairies in CO, USA, were collected. The dataset included 2,881 cows with at least one quarter dried-off, 1,367 Primiparous (PP) (47.3%); 1,519 Multiparous (MP) (52.6%). Information included the date of the dry-off procedure and the quarter location (left-front [LF]; left-rear [LR]; right-front [RF]; and right-rear [RR]). The distribution of the first dry quarter (QDO) in primiparous was 28.0% (LF), 20.2% (LR), 31.0% (RF), and 20.8% (RR). In multiparous, the distribution was 29.8% (LF), 19.6% (LR), 31.7% (RF), and 18.9% (RR). Overall, QDO was more frequent in both groups in the RF quarter, and no association was identified between quarter location and parity category. The frequency of QDO in PP was greater in summer (30.4%), followed by winter (28.1%), spring (22.8%), and fall, (18.7%). In MP cows QDO frequency was greater in summer (34.9%), followed by spring (24.8%), winter, (23.8%), and fall, (16.5%). Mean \pm SE DIM at QDO was smaller in PP (92.4 ± 2.82 d) than in MP (159.0 ± 2.71 d) and the average time from QDO to a second dry quarter (QDO2) was 325 ± 21 d and 291.9 ± 19 d for PP and MP cows, respectively. No effect on the occurrence of QDO2 was identified for the parity category and the odds (95% CI) of QDO2 for MP vs. PP were 0.95 (0.80-1.12). Days to culling after the date of QDO were not different between PP (347.0 ± 84.6 d) and MP (364.9 ± 18.4 d). Actual and projected 305 milk yield were smaller in cows with QDO than in

healthy cows (597 kg [PP] and 436 kg [MP] less for actual 305 milk production; 628 kg [PP] and 495 kg [MP] less for projected 305 milk production). Milk yield was also smaller for cows with QDO when compared with overall herd mates. Days spent in the dry pen was not significant. These results contribute to the understanding of the dynamics of quarter dry-off, providing novel information for the control of mastitis, under the specific conditions of this study.

Introduction

Mastitis is the most common disease affecting dairy cows, with significant negative impacts on both animal welfare and farm profitability. The economic repercussions of mastitis include reductions in milk production, impaired milk quality, and premature culling. Additionally, animal welfare can be severely compromised, raising global concern within the dairy industry (Ruegg, 2003; Fogsgaard et al., 2015). Ruegg (2009) estimated the cost of medications for treating clinical mastitis events at \$28.48 per case for conventional farms and \$11.33 per case for organic farms, excluding losses from decreased milk production. Production losses are expected to range from 91 to 181 kg of milk per lactation, depending on factors such as parity, stage of lactation, milk production, and pathogen present (Gröhn et al., 2004; Ruegg, 2017), accounting for 70% of the cost of mastitis (Zhao and Lacasse, 2008).

Beyond its financial toll, mastitis significantly affects animal welfare, a critical concern for researchers, dairy producers, and consumers alike. Recent advancements have explored methods of measuring livestock well-being using technology. Lying time is a key parameter for assessing animal welfare, as cows unable to fulfill their lying needs suffer compromised well-being (EFSA, 2009). Mastitis events tend to reduce lying time, with cows compensating by standing up to alleviate mammary gland pain. This behavioral change leads to reduced time spent eating, drinking, and resting (Cyples et al., 2012), ultimately resulting in lower body condition scores and

decreased milk production. Visual signs of antalgic posture, indicating pain in cows affected by mastitis, further underscore the decline in welfare (Ginger et al., 2023).

Organic dairy production systems, while similarly affected by mastitis, adhere to strict practices aimed at recycling resources, maintaining ecological balance, and protecting biodiversity. Farms enrolled in the National Organic Program must meet several requirements, including the prohibition of antibiotic use (USDA, 2014). Common mastitis control and mil quality practices in organic herds include implementing strict milking routines, using milking equipment with a backflush system, maintaining milking equipment, managing dry cows effectively, vaccinating, employing good grazing practices, culturing and culling chronically infected cows (Velez, 2011), and adopting individual quarter dry-off (QDO) procedures for chronically infected quarters.

Given the reliance of organic farms on management-based solutions and individual quarter dry-off, it was hypothesized that the dynamics of QDO could be influenced by quarter location, season, parity number, and lactation stage. Consequently, the primary objective of this study was to analyze the individual quarter dry-off dynamics across four organic-certified dairy farms, with a focus on these factors. The secondary objective was to examine survival time after the first quarter was dried off and assess milk production performance.

Materials and Methods

Four dairies in northern Colorado were selected for this retrospective study. Cows were housed in free-stall barns with compost bedding and continuous access to a open lot. Cows were fed a total mixed ration twice daily to meet or exceed the nutritional requirements for lactating Holstein cows producing 30 kg/d of milk (3.8% fat and 3.1% true protein; NRC, 2001). The grazing season lasted 120 d/yr, from April to October, were at least 30% of the dry matter intake

came from pastures. High-producing pens were milked three times a day and low-producing pens and the hospital pen were milked twice daily. Data was collected from PCDart (©DRMS) for calvings from the years 2018 to 2023.

The decision to dry-off a cow or an individual quarter was based on the severity of clinical mastitis, or the presence of a chronic infection. This procedure was done by workers dedicated to health management on each farm. Once a quarter was designated for drying off, a color band was placed on one of the rear legs to indicate the quarters position, signaling to milkers to avoid milking that quarter. Information included the date of the dry-off procedure and the quarter location (left-front [LF]; left-rear [LR]; right-front [RF]; and right-rear [RR]). These management practices provided a consistent baseline for analyzing calving data collected over the study period. Out of 92,679 total calvings, 3,852 cows were identified as having at least one dry quarter. However, 23% of the total cows with QDO resumed milk production in subsequent lactation and were excluded from the study. Other animals were also eliminated from the study due to lack of information on the management software. After accounting for these exclusions, the study focused on a final sample size of 2,881 cows - 1,356 (47%) primiparous [PP] and 1,525 (53%) multiparous [MP]. During the study period, 16.9% of mastitis clinical cases resulted in QDO. 769 cows (26%) had a second individual dry quarter.

The variables considered in this study included quarter location, parity, days in milk (DIM), season, and survival after QDO. Additional analyses were conducted to compare healthy cows and cows with QDO in terms of their actual (305) milking yield, using the calving season as a covariate. Similar comparisons were made for projected (305) milk yield, herdmate deviation (analyzed by parity category), and the number of days in the dry pen for previous lactation. Statistical analyses

were performed using SAS (SAS Institute Inc.), employing chi-square goodness of fit, logistic regression, and ANOVA.

The objective of this study was to describe the dynamics of the individual quarter dry-off procedure and its association with the different variables mentioned above providing valuable insights into a topic with limited prior research.

Results

The location distribution of the QDO across quarters was as follows: 28.0% and 29.8% (LF), 20.2% and 19.6% (LR), 31.0% and 31.7% (RF), and 20.8% and 18.9% (RR) for PP and MP, respectively ($P < 0.01$; $P < 0.01$). Statistical analysis revealed no association between quarter location and parity category (Figure 2.1 and Figure 2.2).

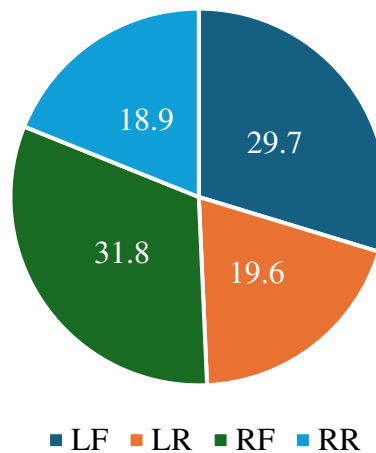


Figure 2.1: Frequency (%) of localization of individual quarter dry-off and parity group in multiparous (MP) cows (left rear [LR], right rear [RR], left front [LF], and right front [RF]).

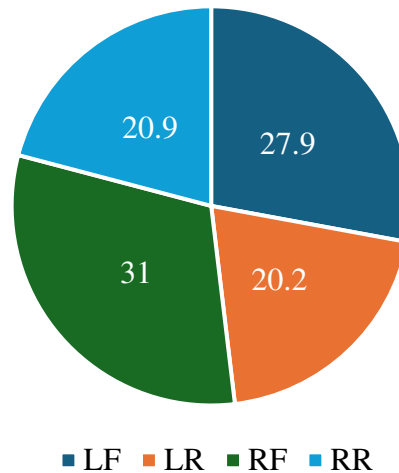


Figure 2.2: Frequency (%) of localization of individual quarter dry-off and parity group in primiparous (PP) cows (left rear [LR], right rear [RR], left front [LF], and right front [RF]).

Seasonal effects on QDO were more pronounced during winter, with frequencies of 26% for PP and 29.9% for MP cows. For primiparous cows, QDO frequencies was 25% (fall), 25% (spring), and 23% (summer). Similarly, for multiparous cows, frequencies were 24.9% (spring), 24.8% (fall), and 20.5% (summer) ($P < 0.01$, Figure 2.3 and Figure 2.4).

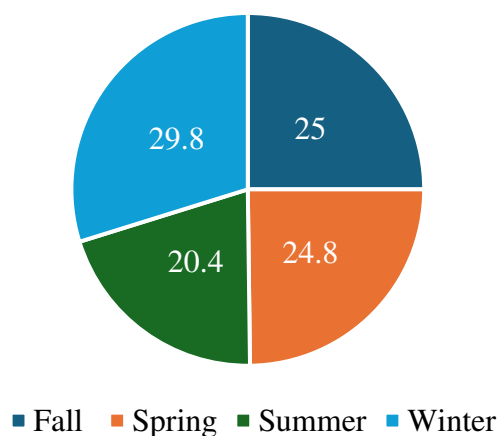


Figure 2.3: Frequency (%) of individual quarter dry-off by parity group in multiparous (MP) cows (left rear [LR], right rear [RR], left front [LF], and right front [RF]).

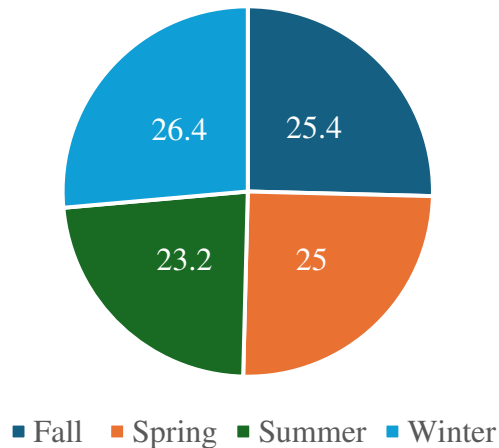


Figure 2.4: Frequency (%) of individual quarter dry-off by parity group in primiparous (PP) cows (left rear [LR], right rear [RR], left front [LF], and right front [RF]).

The mean days in milk (DIM) at the time of the first QDO were 92.4 ± 2.82 d SE for PP group, compared to 159.0 ± 2.71 d SE ($P < 0.01$) for the MP group. The average time from QDO to a second QDO (QDO2) was 325 ± 21 d and 291.9 ± 19 d for PP and MP cows, respectively ($P = 0.22$). No significant association was observed between parity category and the occurrence of a QDO2, with the odds ratio (95% CI) of QDO2 for MP versus PP calculated at 0.95 (0.80-1.12). This indicates no statistically significant difference between the two groups (Figure 2.3). The mean \pm SD of days to culling after the date of QDO was also not significantly different between groups, with PP cows averaging 347.0 ± 84.6 d, and MP 364.9 ± 18.4 d.

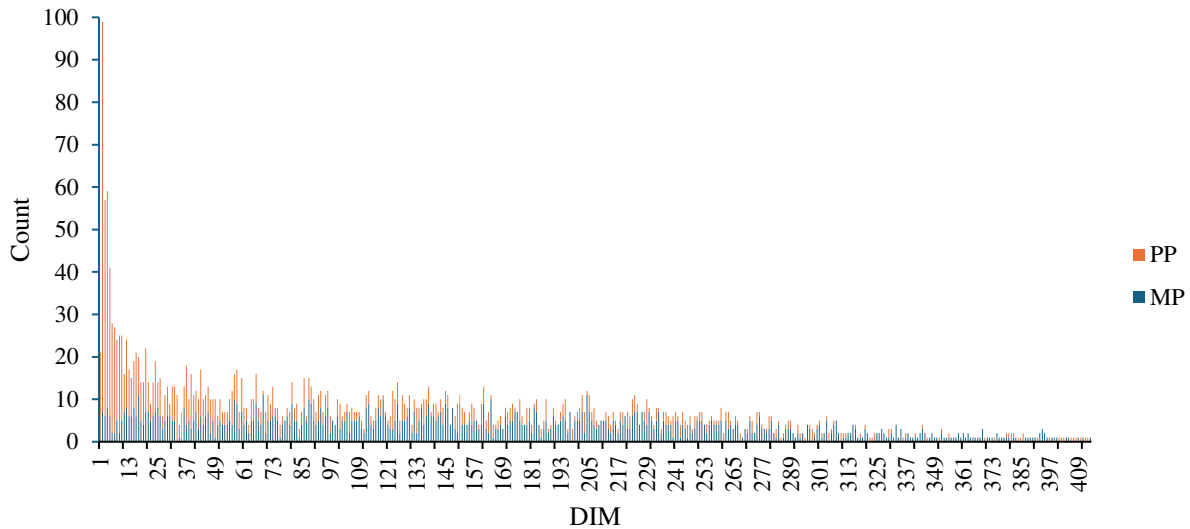


Figure 2.5: Frequency of individual quarter dry-off by DIM in primiparous (PP) and multiparous (MP) cows.

Mean \pm SE milk production for 24,735 healthy primiparous cows was $7,639 \pm 1,744$ kg, while affected cows with QDO produced $7,042.60 \pm 4,064$ kg ($P < 0.0001$). For multiparous cows, mean production was $9,864 \pm 6,181$ kg for healthy cows and $9,429 \pm 2,100$ kg for those with QDO ($P = 0.006$) (Table 2.1).

The projected milk production for healthy primiparous cows was $7,814 \pm 1,906$ kg, compared to $7,187 \pm 1,966$ kg for sick cows ($P < 0.0001$). For multiparous cows, the projected milk was $10,217 \pm 2,328$ kg for healthy cows and $9,722 \pm 2,386$ kg for sick cows ($P < 0.0001$) (Table 2.1).

Regarding herdmates deviation and dry days in the previous lactation, healthy primiparous cows had values of $-1,076 \pm 4,544$ kg, while sick cows had negative deviation of $-3,125$ kg ($P < 0.0001$). Multiparous cows showed a deviation of 733 kg for healthy cows and -510 kg for those with illnesses ($P = 0.006$). In terms of days spent in the dry pen during the previous lactation, the

mean was 65.2 days \pm 28 for healthy cows and 65.8 days \pm 24.5 for sick cows ($P = 0.38$) (Table 2.1).

Table 2.1: Mean, standard deviation, and p-values for actual milk 305, projected milk 305, herdmat deviation, and days dry in previous lactation by parity and level (0=healthy, 1=QDO).

	Parity	Level	N	Mean (kg)	Std Dev (kg)	P-Value
Actual Milk 305	Primiparous	0	24,735	7,639.90	1,744.20	<0.0001
		1	1,324	7,042.60	1,843.90	
	Multiparous	0	51,418	9,864.50	6,181.10	0.006
		1	1,507	9,428.90	2,099.90	
Projected Milk 305	Primiparous	0	24,317	7,814.40	1,906.70	<0.0001
		1	1,305	7,187.10	1,966.60	
	Multiparous	0	50,028	10,217.60	2,327.80	<0.0001
		1	1,488	9,722.50	2,386.10	
Herdmat Deviation	Primiparous	0	24,147	-488		<0.0001
		1	1,303	-1,417.50		
	Multiparous	0	49,890	332.5		
		1	1,487	-231.5		
Days Dry in Previous Lactation		0	51,256	65.2	28.03	0.38
		1	1,504	65.8	24.56	

Discussion

This study aimed to analyze the dynamics of individual quarter dry-off in certified organic dairy farms by evaluating factors like quarter location, parity, season, and days in milk. The objective was to assess how these variables influenced the incidence of QDO under various conditions, as well as to observe the survival time after the first QDO and its impact on milk production.

The analysis revealed key findings regarding the variables of interest, starting with quarter location. The findings showed that front quarter being most frequently affected. Previous research suggested that front quarters are more prone to overmilking (Tančin et al., 2006), which can lead to poorer teat condition scores in these front quarters since they typically produce less milk than rear quarters (Vierbauch et al., 2021). Although teat condition was not evaluated in this study, overmilking may be a contributing factor. Another possible explanation for the higher incidence of QDO in front quarters is inconsistent application of pre and post dip during the milking procedure. However, there was no analysis on the milking procedure, so this reason cannot be confirmed. No association was identified between the quarter location and parity category.

Seasonal effects also influenced QDO, with dry seasons linked to increased rates of clinical mastitis in indoor housing systems (Dahl and McFadden, 2022). Controversy, pasture-based systems, wet humid seasons, such as winter, led to higher rates of mastitis (Olde Riekerink et al., 2007). These seasonal trends are particularly relevant given the outdoor access provided to cows during winter in this study.

Older cows were found to have a higher mean DIM at the time of QDO than younger cows, consistent with previous studies reporting a herd-level average DIM of 133 at the onset of mastitis. The severity of mastitis has been shown to be greater in the early stages of lactation and to increase with additional lactations (Oliveira et al., 2013; Hallén Sandgren et al., 2021). The study's results also suggest that older cows are more predisposed to chronic mastitis, which may explain the observed differences in DIM between primiparous and multiparous cows (Stocco et al., 2023). However, it remains unclear why primiparous cows in this study tended to have QDO in the early stages of lactation, contrary to reports suggesting that primiparous cows are less susceptible to severe mastitis due to a stronger immune system (Fredebeul-Krein et al., 2022).

These production losses, coupled with the higher costs associated with organic dairy systems, further underscore the financial challenges posed by chronic mastitis in organic farms. It was reported 40.6 ± 28.5 days of survival after QDO in conventional systems (Wieland and Skarbye, 2024). The differences between organic and conventional systems may be influenced by higher costs associated with organic dairy production. According to the USDA (2024), organic cows auctioned at an average price of \$143.34 per hundredweight with an average weight of 1,240.1 pounds (\$1,777.50 per cow), compared to \$121.28 per hundredweight and an average weight of 1,345.0 pounds for conventional cows (\$1,631 per cow). Fluid milk prices also differ significantly, with half a gallon of organic milk priced at \$4.67 in July 2024, compared to \$2.39 for conventional milk. Additionally, the cost of replacement heifers is considerably higher for organic farms (\$3,000 per heifer) compared to conventional farms (\$1,825 per heifer) (Shrestha et al., 2025). These higher costs for animals, milk, and replacements may explain why organic producers may tend to keep cows longer than conventional farms. While udder health and reproduction are the primary reasons for culling in both systems (Ahlman et al., 2011), there is ongoing debate about culling rates. Some studies suggest no differences between systems, while others argue that organic systems have slightly higher rates. In cases where culling rates differ, retaining cows for longer periods in organic systems would be a logical strategy.

Milk production results demonstrated the impact of health status on yield in both parity categories. Healthy primiparous cows produced 596.5 kg more than cows that were under QDO, with a highly significant difference ($P < 0.0001$). The same trend was observed in multiparous cows, where healthy individuals produced 434.1 kg more than cows with QDO. Although the difference in multiparous cows was smaller, it was still significant, highlighting the long term impact of chronic mastitis on production. The higher standard deviation observed in multiparous

cows suggests that other factors, such as management or environmental conditions, can influence milk production. These findings align with previous studies that demonstrate how chronic infections lead to prolonged production losses (Heikkilä et al., 2018b).

Projected milk production data further supported the effect of health status on yield. Among primiparous cows, healthy individuals produced 624.3 kg more than sick cows, while the difference in multiparous cows was 494.4 kg ($P < 0.0001$). These results are consistent with studies showing reduced yield in cows affected by mastitis (Costa et al., 2025). The consistency of these results across parity groups suggests that prevention and early intervention are critical for maintaining milk yield and overall herd productivity.

In addition to direct milk yield impacts, differences in herdmate deviation further highlight the effect of health status on productivity. Analysis of herdmate deviation revealed that sick cows in both parity categories produced less milk than their herdmates. On average, sick primiparous cows produced -1,417.5 kg less, and multiparous cows produced -231.5 kg less than their herdmates. Interestingly, the negative deviation for healthy primiparous cows suggests that they were underperforming relative to their herdmates. These findings align with Dinsmore's research highlighting the significant effects of diseases such as mastitis, lameness, and metabolic disorders on milk yield (R. Page Dinsmore, 2024). The severity and timing of health care events, particularly during early lactation, can have significant effect. This could explain the stronger negative impact in primiparous cows after calving, since they are more vulnerable to metabolic stress and immune challenges at the beginning of the lactation.

In contrast, the number of days spent in the dry pen did not significantly differ between healthy and sick cows. While previous research has demonstrated that longer dry periods can influence milk production and mastitis risk (Jukna et al., 2024), the current study suggests that the

dry period alone is not a strong predictor for QDO occurrence in the following lactation. Factors such as management, nutrition, and immune status during the dry period may play a more influential role.

While these findings provide valuable insights, there are certain limitations to consider in this retrospective study. Since this is a retrospective study, researchers can only work with the information available in the cow herd management software. Furthermore, variations in farm management practices over the time from which the information was extracted may have led to fluctuations in the numbers from year to year.

Conclusion

Our results indicate that front quarters were the most affected by quarter dry-off. Seasonal variations indicating greater incidence during winter reveal the susceptibility of the cow to the conditions of the environment at that time of the year. The observed production losses associated with QDO underscore the economic implications of the procedure and the need for management practices and preventive measures.

This study provides novel information for the organic dairy farms in the state of Colorado, expanding our understanding of the individual quarter dry-off procedure and encouraging the search for new management practices to control mastitis in dairy cattle. Further research is necessary to comprehend furthermore the demographics of this procedure and its broader impact on cows, dairies, and the industry as a whole.

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CHAPTER 3: MILKING BEHAVIOUR AFTER INDIVIDUAL QUARTER DRY-OFF PROCEDURE IN AUTOMATIC MILKING SYSTEMS

Summary

This research aimed to describe the dynamics of milk yield following the individual dry-off of quarters in dairy cows (QDO). The study focused on cows with one QDO due to a chronic mastitis event, with milking records available for 30 days after the dry-off. A total of 144 cows were selected from an automatic milking system (AMS) dairy farm in Colorado, consisting of 79% multiparous cows and 21% primiparous. Data were extracted from DelPro and DairyComp on-farm software, and statistical analyses were performed in RStudio, utilizing linear mixed models with repeated measures and estimated marginal means (emmeans).

The results indicate a trend of increase in milk production following QDO, especially after a rear quarter was dried-off and in cows with ≤ 120 days in milk (DIM). However, the absence of control group in the study limited the ability to assess milk production compensation fully. The sample size for primiparous cows was limited, but the overall trend indicated a slight decline in milk production following the procedure. In contrast, multiparous cows exhibited an increase trend in production observed over the 30 days after the procedure, greater in cows with ≤ 120 DIM compared to those with > 120 DIM, and the production was notably greater when the dry-off procedure was performed on the rear quarters rather than the front quarters.

Among the variables analyzed, the number of days in milk after the procedure showed the strongest statistical significance in relation to milk production. In contrast, the presence or not of other diseases did not have a significant impact.

Introduction

Individual quarter dry-off (QDO) is a procedure performed to control subclinical and chronic mastitis (Skarbye et al., 2018). Subclinical mastitis is characterized by abnormalities in milk that are only detectable through diagnostic techniques and laboratory tests, indicating a somatic cell count (SCC) greater than 200,000 cells/mL and/or a positive bacteriological culture (Ruegg, 2011). Chronic mastitis refers to the persistence of the case over time and its inability to cure, these include recurring events with no response to treatment over time or cows that present 2 consecutive high somatic cell counts (Cardozo et al., 2015).

In these scenarios, producers might choose to individually dry-off the infected quarter to prevent the bacteria's spread out and reduce the SCC. The contribution of milk from cows with subclinical mastitis to the bulk tank can result in high numbers in bulk tank somatic cell counts and can cost producers monetary penalties as well as suspension for commercializing the product (USDA, 2018). The QDO, whether performed without chemicals, by ceasing milking the affected quarter, or with the application of chlorhexidine or povidone-iodine, offers a safer alternative to antibiotic treatment for control of the disease. This is important given the concern over bacteria resistance to antibiotics. Therefore, QDO is an alternative solution strategy for managing mastitis in dairy cows (Virto et al., 2022).

Given the need for more research on the QDO procedure to better understand its broader implication, this retrospective study was conducted on a commercial dairy farm in Colorado. The objective was to describe the dynamics of milk production for each quarter, opposite quarters, and total milk production after an event of mastitis followed by individual quarter dry-off of the infected quarter.

Materials and Methods

Study population

This retrospective study was conducted on a commercial dairy farm in Colorado. The dairy consisted of 62 DeLaval automatic milking system (AMS) units that milked 3,700 Holstein cows in total, where all the milking information was recorded from DelPro software. Mastitis detection at the farm followed a standardized protocol, where DelPro health checklist was used to identify the cows requiring evaluation. Milk samples were collected from these cows, and those with positive culture were moved to the hospital pen, where the milking was done on a conventional parlor without milking recording. If the cow failed respond to the antibiotic treatment, the decision was made to dry-off the affected quarter and return to the AMS to the regular milking. Since the time spent at the hospital varied according to the treatment protocol, only the cows that had milking records within 30 days after QDO were included in the study.

A total of 144 cows were selected for this study (79% multiparous; Table 2.2). The average DIM at the peak of lactation in the study cows was 120 (DIM). This value was used as a threshold to categorize the data in two groups (pre-peak: ≤ 120 DIM; post-peak: > 120 DIM). Some analyses were conducted separately for primiparous and multiparous cows, while others included the two parity groups.

The quarter dried-off procedure was considered for the front and rear quarters due to the limited number of animals analyzed. Nevertheless, the analysis for each quarter was made and the nomenclature is as follows: left rear [LR], right rear [RR], left front [LF], and right front [RF].

Table 3.1: Number of animals per parity category, quarter position, and period of lactation.

Front quarters	Rear quarters
----------------	---------------

Parity	n	≤120	>120	≤120	>120
Primiparous	30	3	6	6	15
Multiparous	114	18	40	19	37
Total	144		67		77

Statistical Analysis

Due to the low number of QDO cases, the affected quarters were grouped into front or rear categories for analysis (Rear=RR+LR; Front=RF+LF). The outcome variables assessed in this study included total milk yield of each quarter per milking, total milk yield by the opposite two quarters per day, and total milk yield per day by the remaining three quarters. Opposite quarters mean that milk production of the front quarters together, when a rear quarter is dried off, and vice versa. Predictor variables included number of days (d) after the quarter was dried off, concurrent diseases within the 30 days after QDO, parity category (primiparous; multiparous), and identification number (ID) as a random variable.

The data were analyzed using linear mixed models with repeated measures in RStudio version 4.2.3, employing the lme4 package. Statistical testing was further conducted using anova with car package and estimated marginal means with emmeans package.

Results

Figure 3.1 illustrates milk production per quarter for the overall study population with QDO done pre-peak of lactation. During the first week following the dry-off procedure, the RR quarter had the highest milk yield, followed by LF and RF quarters. After the first week, milk

production of the three remaining quarters showed a trend of increase, with LF being the most productive quarter, followed by RF, while RR produced the least.

When QDO was done on RR quarter, the LR milk production demonstrated the lowest milk yield per day, compared to RF and LF. Overall milk production showed a slight tendency of increased over the days. No significant associations were found between the outcome and parity, days in milk, or the presence of other diseases. However, significant associations were identified between days in milk after the quarter was dried off and milk production of all four quarters ($P = 0.01$; $P = 0.01$; $P = 0.004$; $P < 0.001$, respectively).

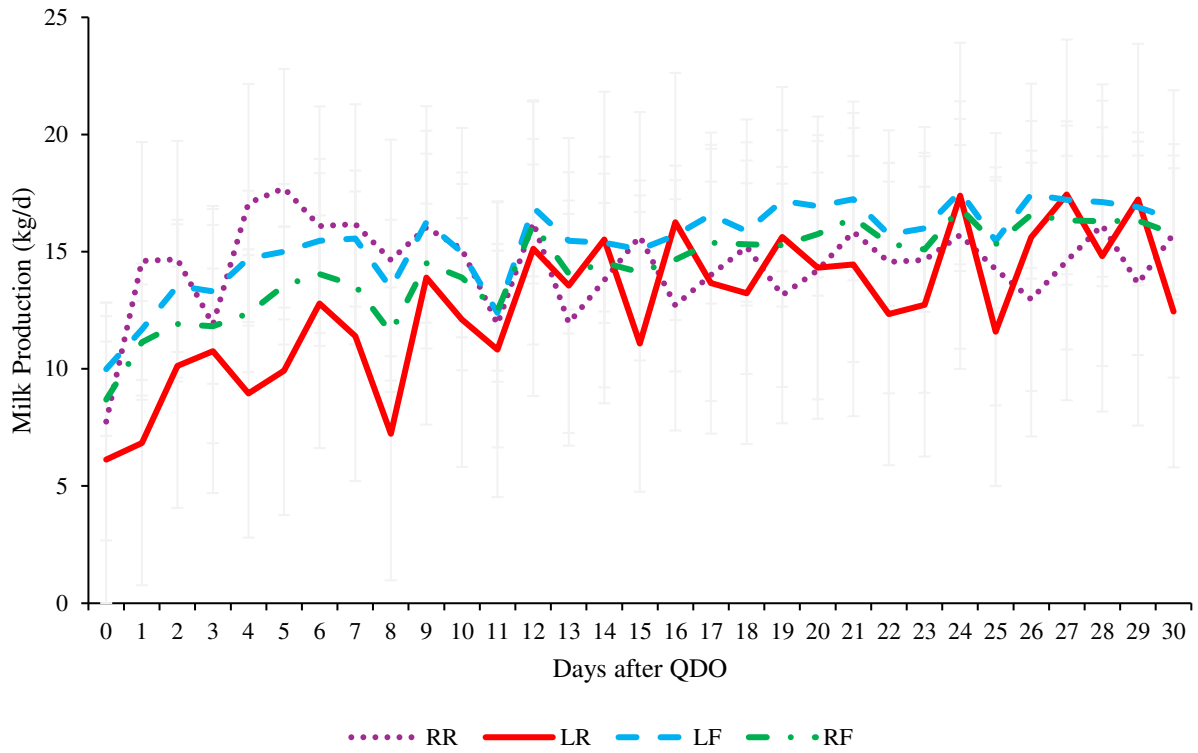


Figure 3.1: Least square means (SE) for quarter milk yield when one rear quarter was dried-off within 120 DIM (left rear [LR], right rear [RR], left front [LF], and right front [RF]). (Note that the information for each rear quarter is presented when the other rear quarter was dried off).

When the QDO was done on a rear quarter post-peak of lactation, specifically on the LR, the RR quarter showed a significantly lower milk production compared to the two front quarters. Moreover, RR production steadily decreased from day 0 to day 30 post-QDO. In contrast, the remaining quarters produced more milk, with no significant differences in milk yield between them and no change in overall milk production. Conversely, when QDO was applied to RR quarter, the.

LR quarter demonstrates a tendency in increase milk production in comparison to both front quarters throughout the 30 days following QDO (Figure 3.2).

Daily milk production for RR, LR and EF quarters showed no associations with days in milk after QDO, parity, presence of other diseases, or days in milk. LF daily milk production only had an association with days in milk ($P=0.01$).

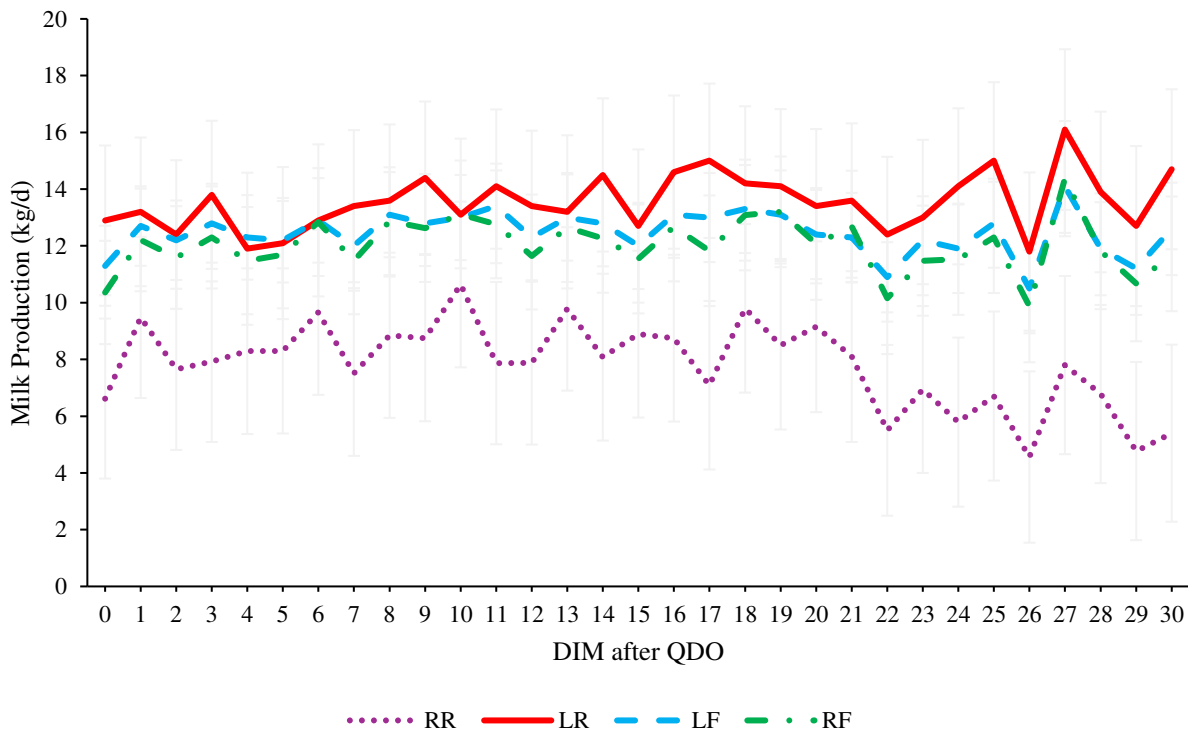


Figure 3.2: Least square means (SE) for quarter milk yield when one rear quarter was dried-off with more than 120 DIM (left rear [LR], right rear [RR], left front [LF], and right front [RF]). (Note that the information for each rear quarter is presented when the other rear quarter was dried off).

For primiparous cows pre-peak of lactation, the milk production of RR, LF, and RF remained consistent along the 30 days after QDO of a rear quarter, specifically the LR. The milk production tended to decrease over the 30 day period. However, since the number of animals used for this model was too small, there were no sufficient records to analyze the milk production when

the quarter died off was the RR, reason why there is no line showing LR milk production (Figure 3.3). At 120 DIM following a rear QDO, the highest yielding quarter was the RF, followed by LF and LR, when the quarter being dried off was RR. In contrast, RR quarter exhibited the lowest milk production after a QDO on LR. Overall, there was a steady milk production from the day they return to the robot to day 30 after QDO (Figure 3.4). There was no association found between milk production and DIM after QDO and DIM.

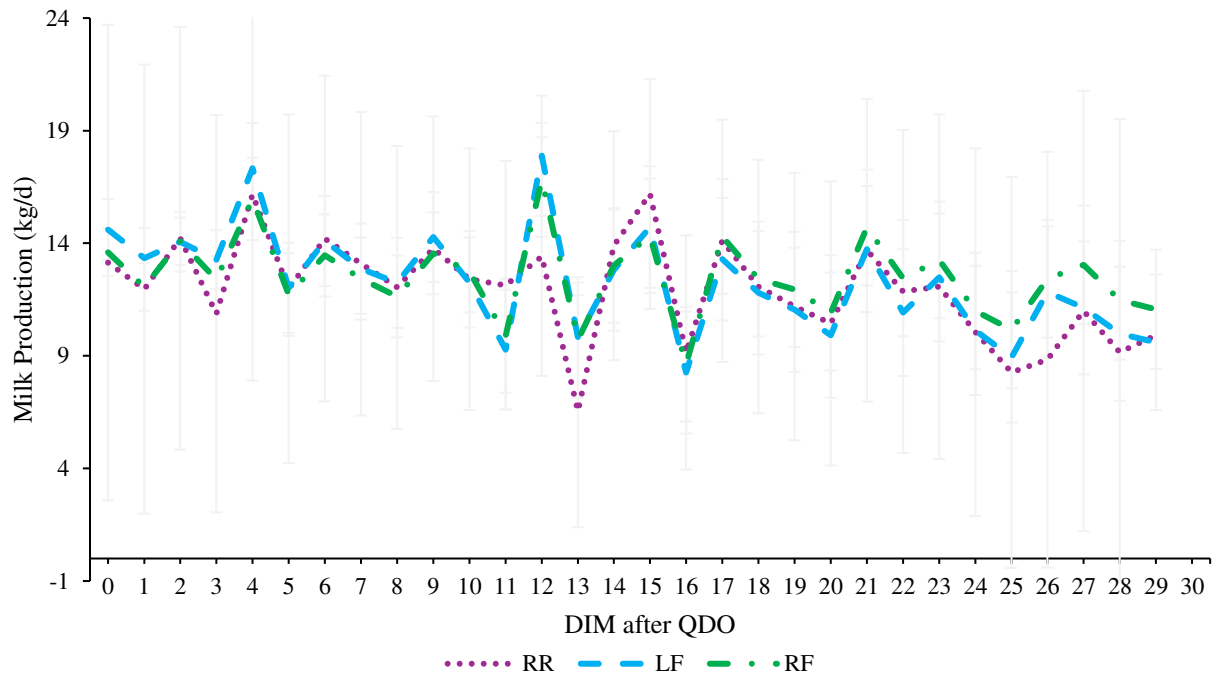


Figure 3.3: Least square means (SE) for quarter milk yield when one rear quarter was dried-off within 120 DIM in primiparous cows (left rear [LR], right rear [RR], left front [LF], and right front [RF]). (Note that the information for each rear quarter is presented when the other rear quarter was dried off).

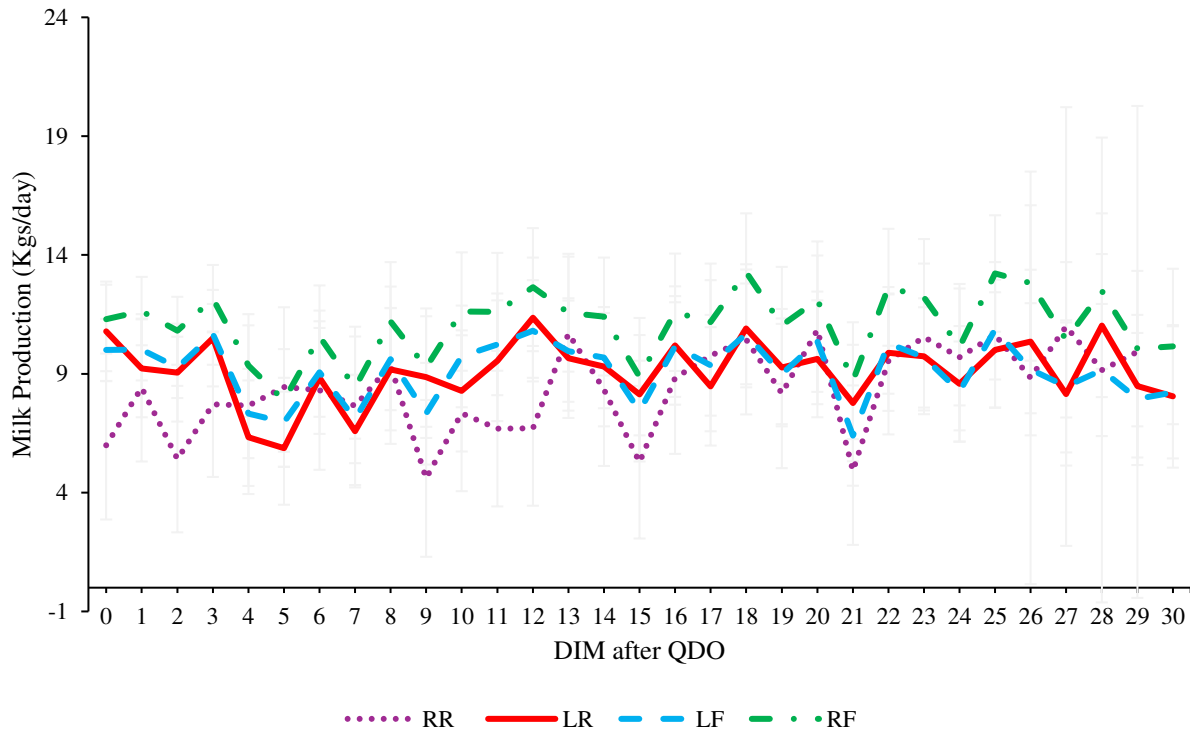


Figure 3.4: Least square means (SE) for quarter milk yield when one rear quarter was dried-off with more than 120 DIM in primiparous cows (left rear [LR], right rear [RR], left front [LF], and right front [RF]). (Note that the information for each rear quarter is presented when the other rear quarter was dried off).

For multiparous cows on pre-peak of lactation, the first week after QDO, RR was the quarter producing the most followed by LF, persisting throughout the 30 days. As for RF and LR, these were the least productive quarters, being LR the least productive. The overall trend was of an increase in production over the 30 days (Figure 3.5). RR, LR, LF, and RF milk production were associated with DIM after QDO ($P=0.004$, $P=0.01$, $P=0.001$, $P<0.001$, respectively). With more than 120 DIM, RR was the least productive when LR was the quarter died off. LR, LF, and RF, all exhibited similar milk yields throughout the 30 days, while RR decreased its production from day

0 to day 30 after QDO (Figure 3.6). There was no association between quarter production and DIM after QDO, other diseases, and DIM.

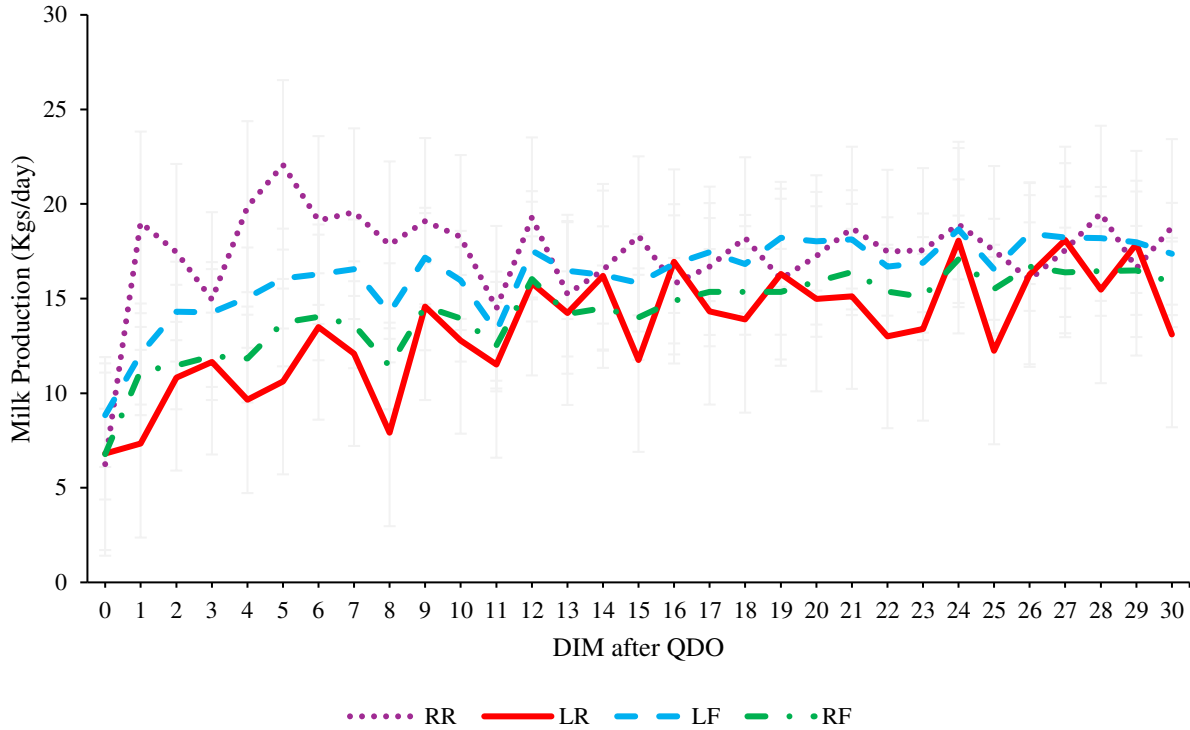


Figure 3.5: Least square means (SE) for quarter milk yield when one rear quarter was dried-off within 120 DIM in multiparous cows (left rear [LR], right rear [RR], left front [LF], and right front [RF]). (Note that the information for each rear quarter is presented when the other rear quarter was dried off).

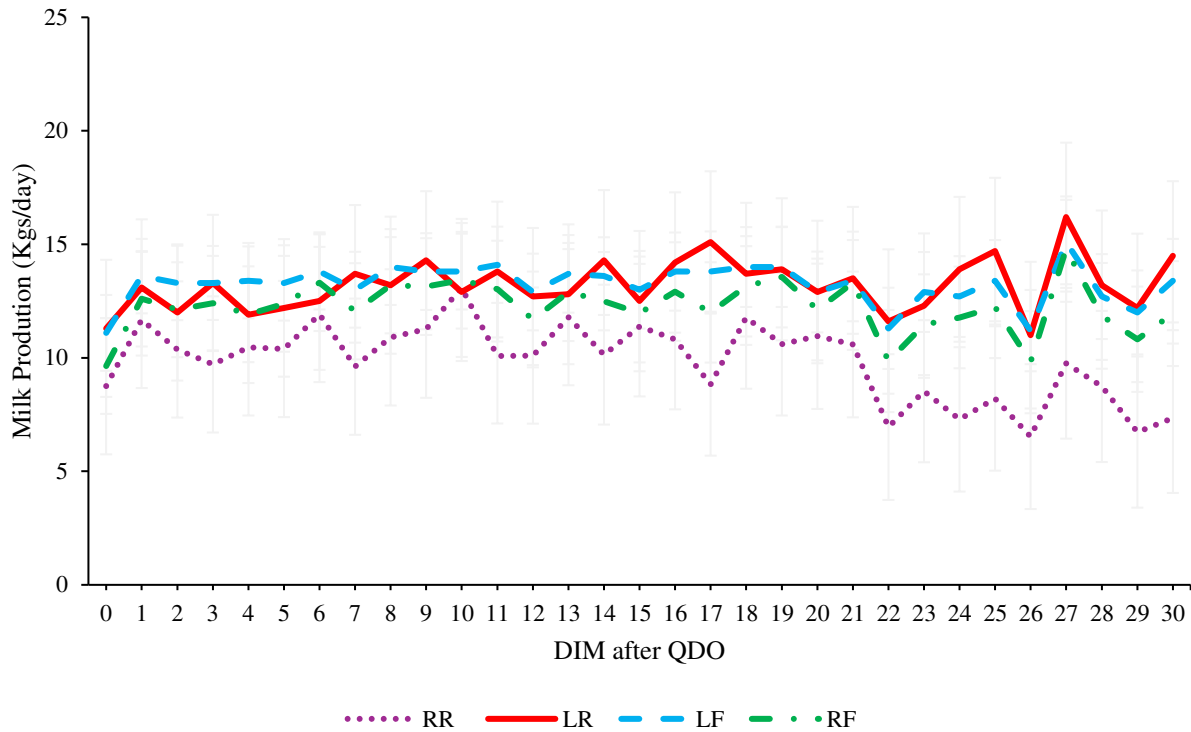


Figure 3.6: Least square means (SE) for quarter milk yield when one rear quarter was dried-off with more than 120 DIM in multiparous cows (left rear [LR], right rear [RR], left front [LF], and right front [RF]). (Note that the information for each rear quarter is presented when the other rear quarter was dried off).

For cows pre-peak of lactation who had a front quarter dried-off had the milk production of both rear quarters producing more than the two front quarters throughout the 30 days. For the first fifteen days, RF produced more milk when the QDO was done on LF, but in the last 15 days, they both made the same. Across all quarters there was a slight trend of increase in production for throughout the 30 days post-QDO (Figure 3.7). There was an association between DIM after

quarter dry-off and milk production for RR and LR ($P=0.02$ and $P=0.04$, respectively). DIM had an association with RR milk production ($P=0.03$).

For those with front QDO and passed their peak of lactation, RR was the highest in production, followed by LF and RF, and lastly LR with the least producing quarter after the event, where production was stable during the 30 days (Figure 3.8). There was an association between daily milk production from RR, LR, and RF quarters with DIM at QDO and DIM ($P=0.03$, $P<0.001$; $P=0.02$, $P=0.01$; $P=0.003$, and $P<0.001$, respectively). No association was found between responsive variables and LF milk production.

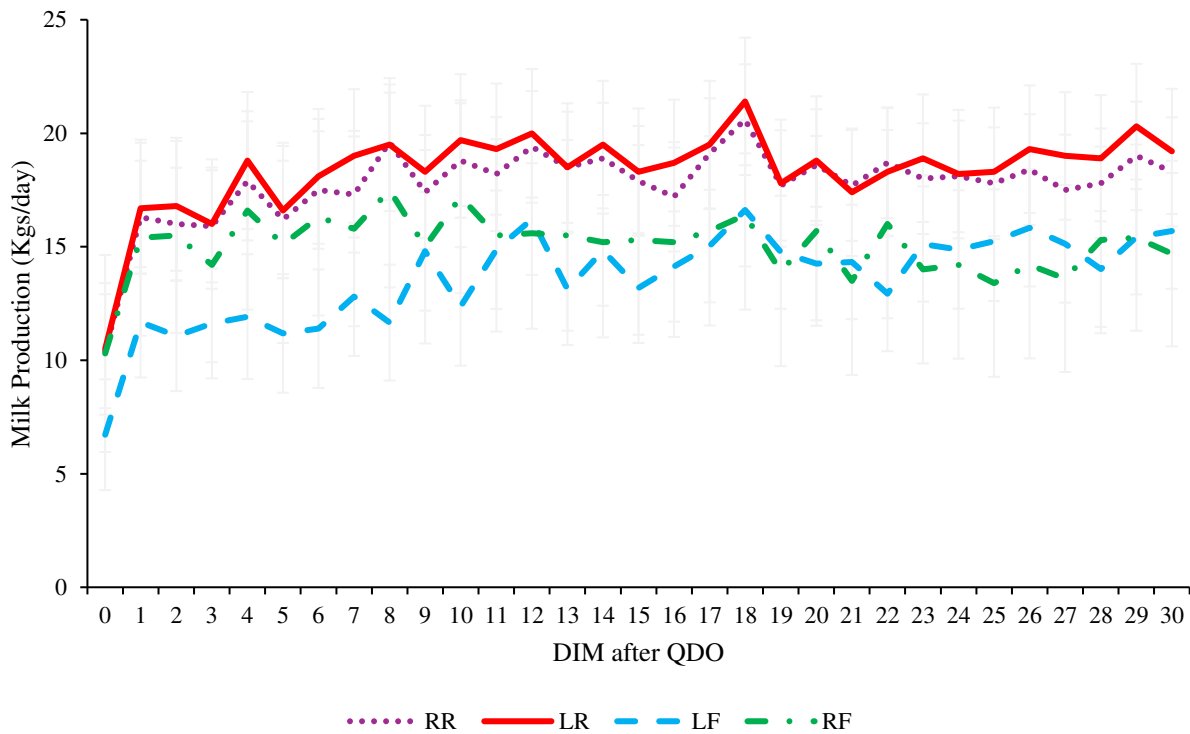


Figure 3.7: Least square means (SE) for quarter milk yield when one front quarter was dried-off within 120 DIM (left rear [LR], right rear [RR], left front [LF], and right front [RF]). (Note that the information for each front quarter is presented when the other front quarter was dried off).

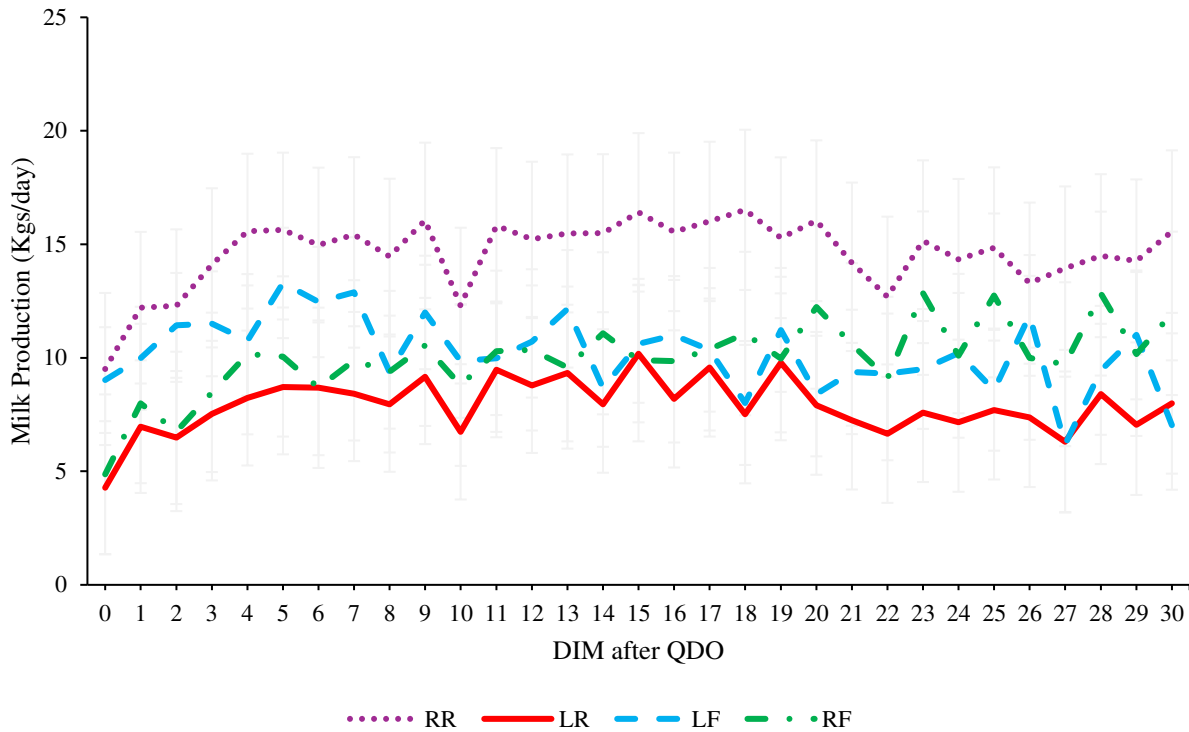


Figure 3.8: Least square means (SE) for quarter milk yield when one front quarter was dried-off with more than 120 DIM (left rear [LR], right rear [RR], left front [LF], and right front [RF]). (Note that the information for each front quarter is presented when the other front quarter was dried off).

Due to the low number of animals in the primiparous analysis, there were no first lactation animals to analyze with equal or less than 120 DIM with a front QDO. No associations were found between milk production and DIM after QDO, other diseases, or DIM.

For those primiparous cows that were post-peak, milk production tended to increase in the first five days following QDO. After day five, RR, LR, and LF showed a similar trend, with all quarters showing a steady decrease in milk production (Figure 3.9). However, since the number of animals used for this model was too small, there were no sufficient records to analyze the milk

production when the quarter died off was the LF, reason why there is no line showing LR milk production. No associations were found with DIM after QDO and DIM with milk production.

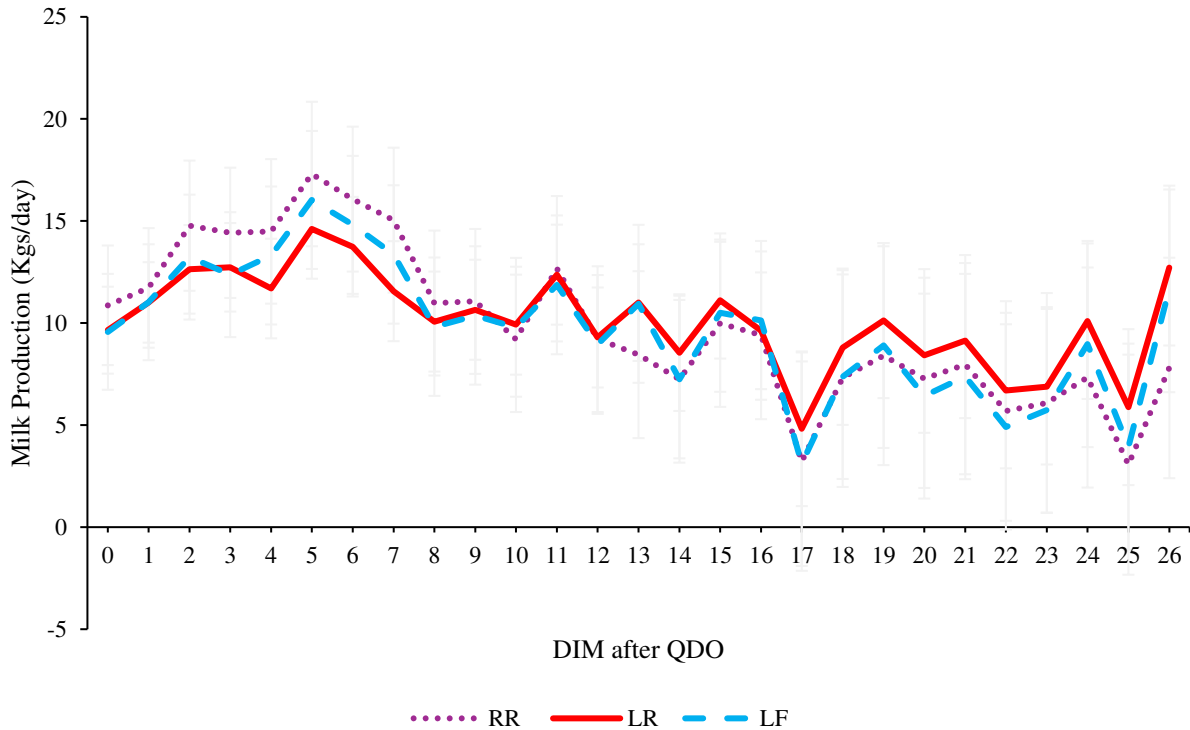


Figure 3.9: Least square means (SE) for quarter milk yield when one front quarter was dried-off with more than 120 DIM in primiparous cows (left rear [LR], right rear [RR], and left front [LF]). (Note that the information for each quarter is presented when the other front quarter was dried off).

For multiparous cows with ≤ 120 DIM following a front QDO, the overall production had a trend across all quarters, with the two rear quarters being the most productive. Specifically, RF ranked next in production after LF was dried off, while LF was the least productive (Figure 3.10).

significant association was found between RR milk production and DIM after QDO, and DIM ($P=0.02$ and $P=0.03$, respectively).

For those on post-peak of lactation period, RR was the highest yielding quarter, with a trend of increase in production over the 30-day period. RF followed a similar trend, showing an increase in production as well. In contrast, LF and LR showed an overall stable production along the 30 days (Figure 3.11). An association was found between DIM after QDO and daily milk production of RR ($P=0.04$), LR ($P=0.01$), and RF ($P=0.001$). There was also an association between milk production and DIM for those same quarters, being $P<0.001$, $P=0.02$, and $P<0.001$, respectively.

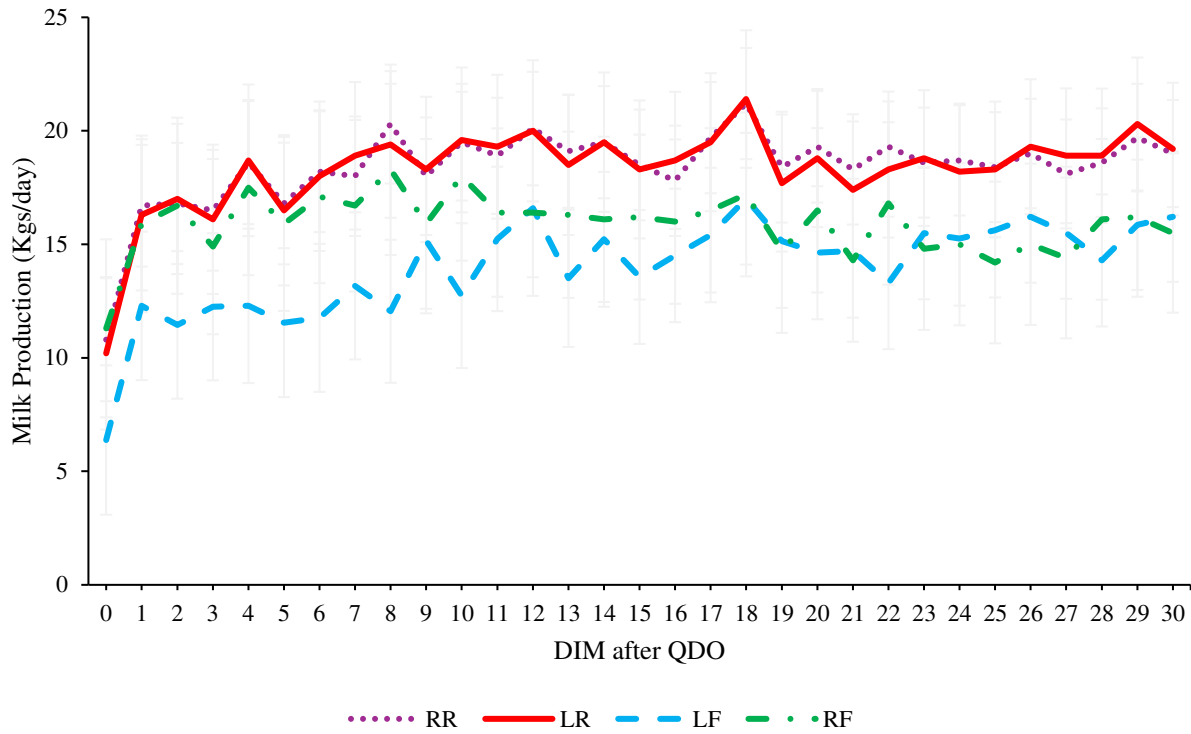


Figure 3.10: Least square means (SE) for quarter milk yield when one front quarter was dried-off within 120 DIM in multiparous cows (left rear [LR], right rear [RR], left front [LF], and right front [RF]). (Note that the information for each quarter is presented when the other front quarter was dried off).

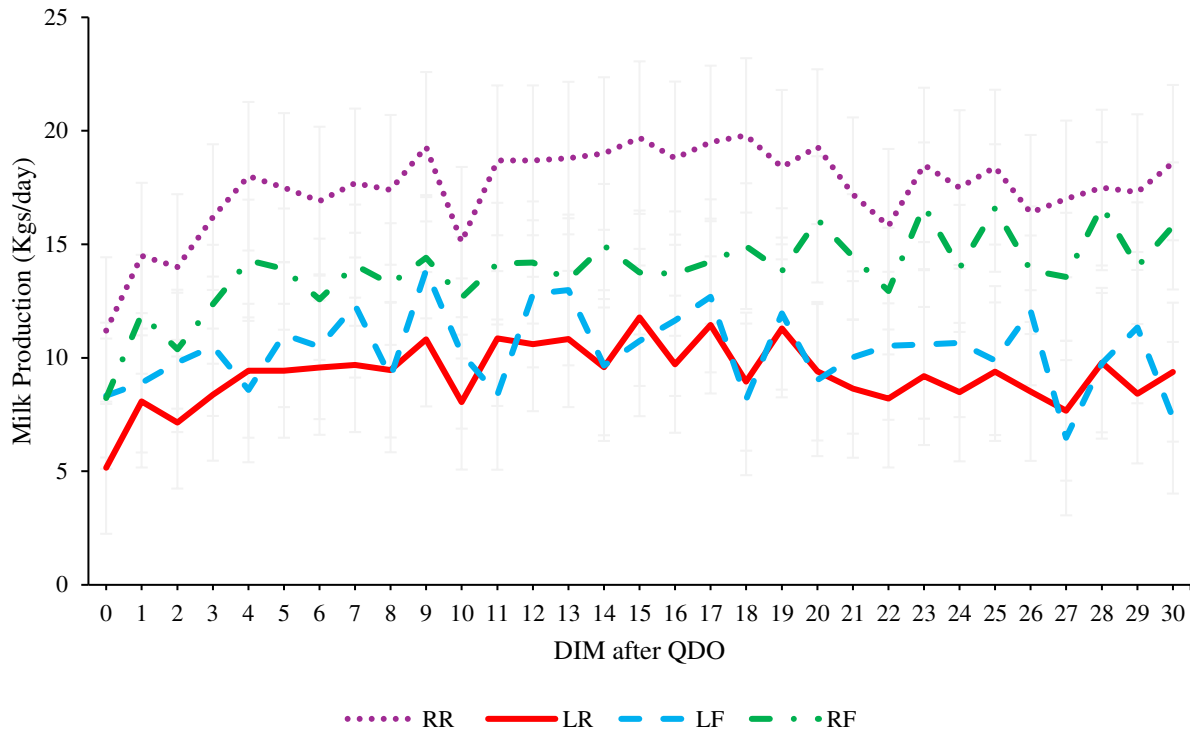


Figure 3.11: Least square means (SE) for quarter milk yield when one front quarter was dried-off with more than 120 DIM in multiparous cows (left rear [LR], right rear [RR], left front [LF], and right front [RF]). (Note that the information for each quarter is presented when the other front quarter was dried off).

When analyzing the total milk production of the cow, representing the three remaining quarters following QDO on a rear or front quarter, the results demonstrated consistent trends. Cows with ≤ 120 DIM had higher total milk production compared to those past their lactation peak. An increase in production was observed for cows in their pre-peak after a rear quarter dried-off, as well as during the initial days post QDO for pre-peak of lactation cows after a front QDO. For all other cases, the milk production was stable over the 30 days after QDO. The total average milk production (kgs) after a rear QDO was 46.7 ± 8.6 and 36.8 ± 5.01 , for ≤ 120 DIM and >120 DIM, respectively. The total average milk production (kgs) after a front QDO were 50.9 ± 6.04 and 34.7 ± 7.5 , for ≤ 120 DIM and >120 DIM, respectively (Figure 3.12 and Figure 3.13). An association

was found between total milk production and DIM after a rear individual quarter dry-off in cows equal to or less than 120 DIM ($P=0.001$). Moreover, DIM after QDO ($P=0.008$) and DIM ($P=0.05$) for those with ≤ 120 DIM. For those cows with more than a 120 DIM, association between total milk production and DIM after QDO ($P=0.03$) and DIM ($P<0.001$) was found.

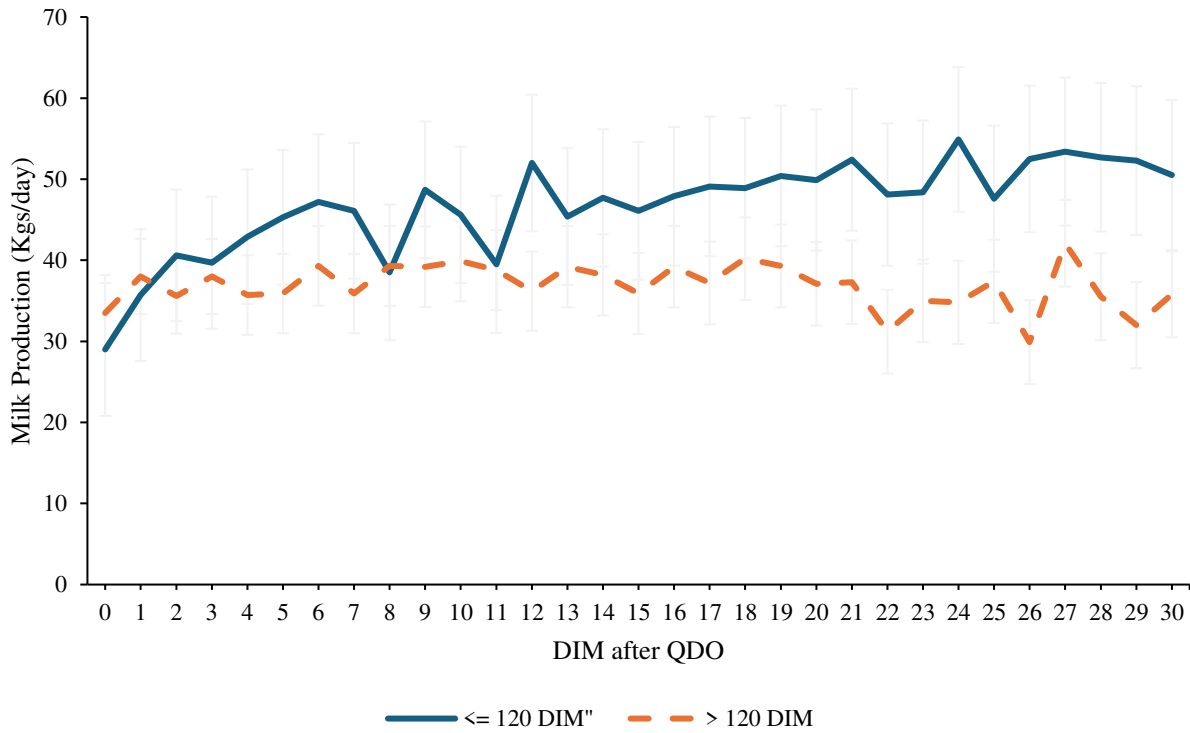


Figure 3.12: Least square means (SE) for total milk yield when one rear quarter was dried-off within 120 DIM and more than 120 DIM.

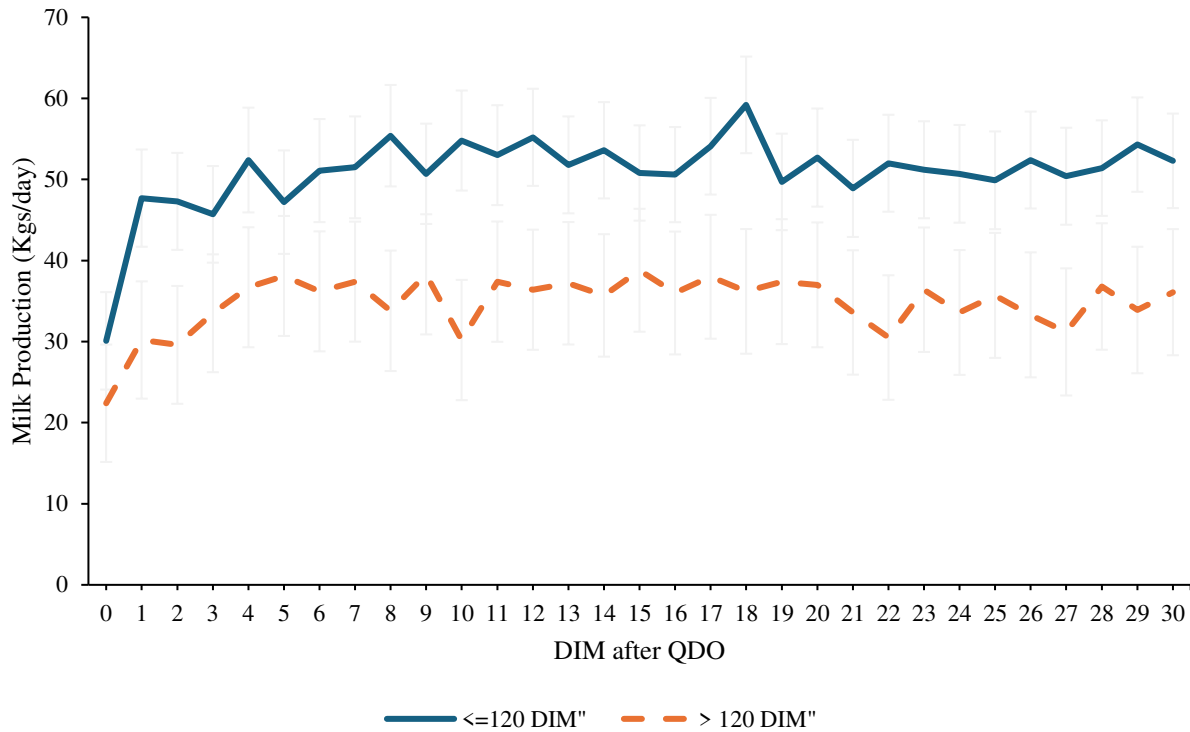


Figure 3.13: Least square means (SE) for total milk yield when one front quarter was dried-off within 120 DIM and more than 120 DIM.

Primiparous cows had a total milk production slightly higher in cows with less than 120 DIM after a rear QDO (total mean 36.81 ± 7 kgs), in comparison to those with more than 120 DIM (total mean 31.4 ± 6.64 kgs). Nevertheless, milk production remained stable during the 30 days after individual QDO (Figure 3.14). No significant associations were found.

When the QDO was done on multiparous cows, the total milk production was higher for those with ≤ 120 DIM and with a tendency to increase from day 0 to day 30, and with an association found between milk production and DIM after QDO ($P < 0.001$). For those multiparous cows on

their post-peak, the production stayed the same in all 30 days. The total mean for milk production was 50.2 ± 7.6 and 37.7 ± 5.6 , for pre and post-peak respectively (Figure 3.15).

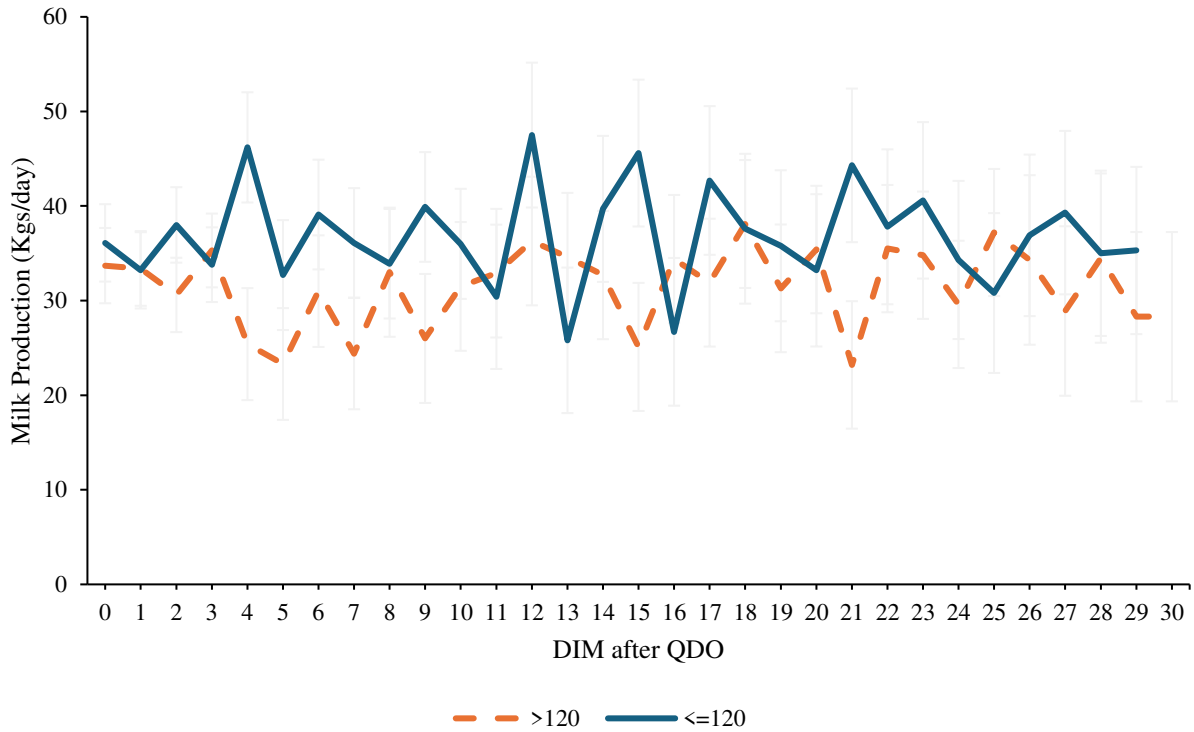


Figure 3.14: Least square means (SE) for total milk yield when one rear quarter was dried-off within 120 DIM and more than 120 DIM in primiparous cows.

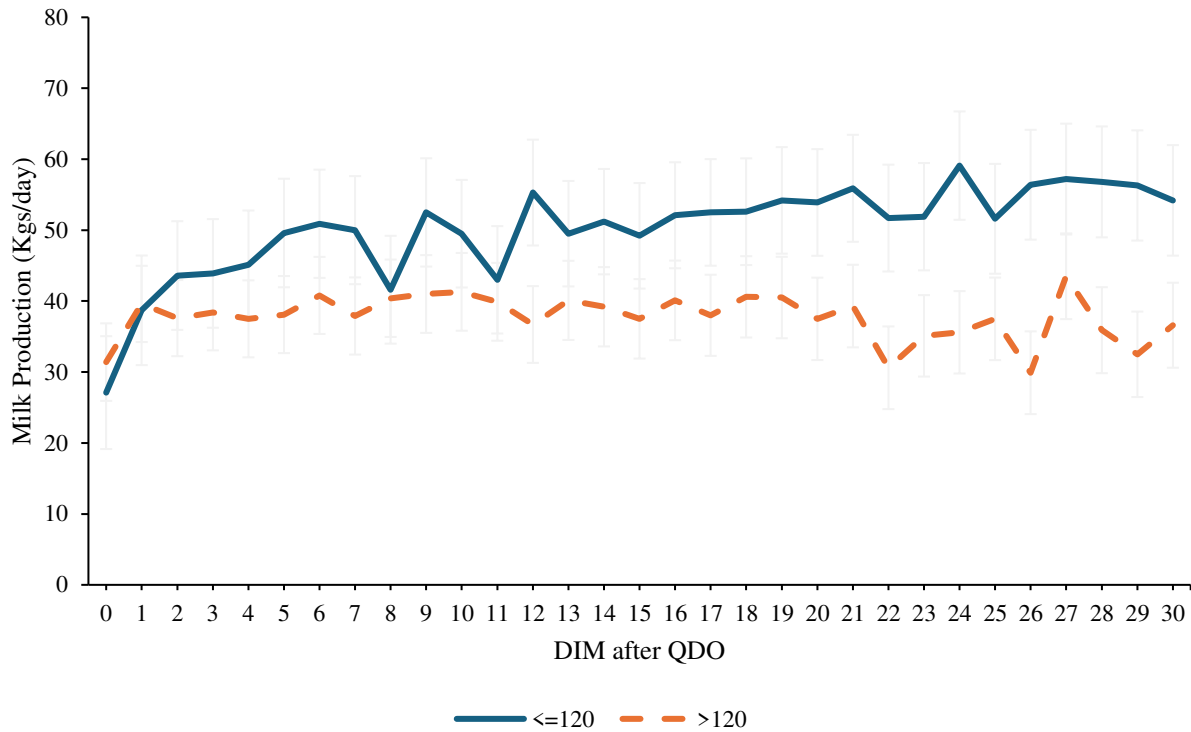


Figure 3.15: Least square means (SE) for total milk yield when one rear quarter was dried-off within 120 DIM and more than 120 DIM in multiparous cows.

When analyzing the effect of the individual quarter dry-off on milk production for front quarters, primiparous cows showed a decreased tendency for those that passed their peak of lactation with a total average milk production of $28.7 \text{ kgs} \pm 13$. Due to a small sample size in the analysis, there were no animals included in the pre-peak of lactation (Figure 3.16).

Multiparous cows had higher total milk production than those with equal or less than 120 days in milk (mean $53.6 \pm 0.6 \text{ kgs}$ and $39.8 \pm 7.1 \text{ kgs}$, respectively). For both, the tendency was of a slight increase from day 0 to day 30 after QDO (Figure 3.17). The only associations found were on multiparous cows, between milk production and DIM after QDO ($P=0.01$) and DIM ($P=0.04$)

on those cows with equal to or less than 120 DIM, and between milk production and DIM after QDO ($P<0.001$) and DIM ($P<0.001$) on those cows with more than 120 DIM.

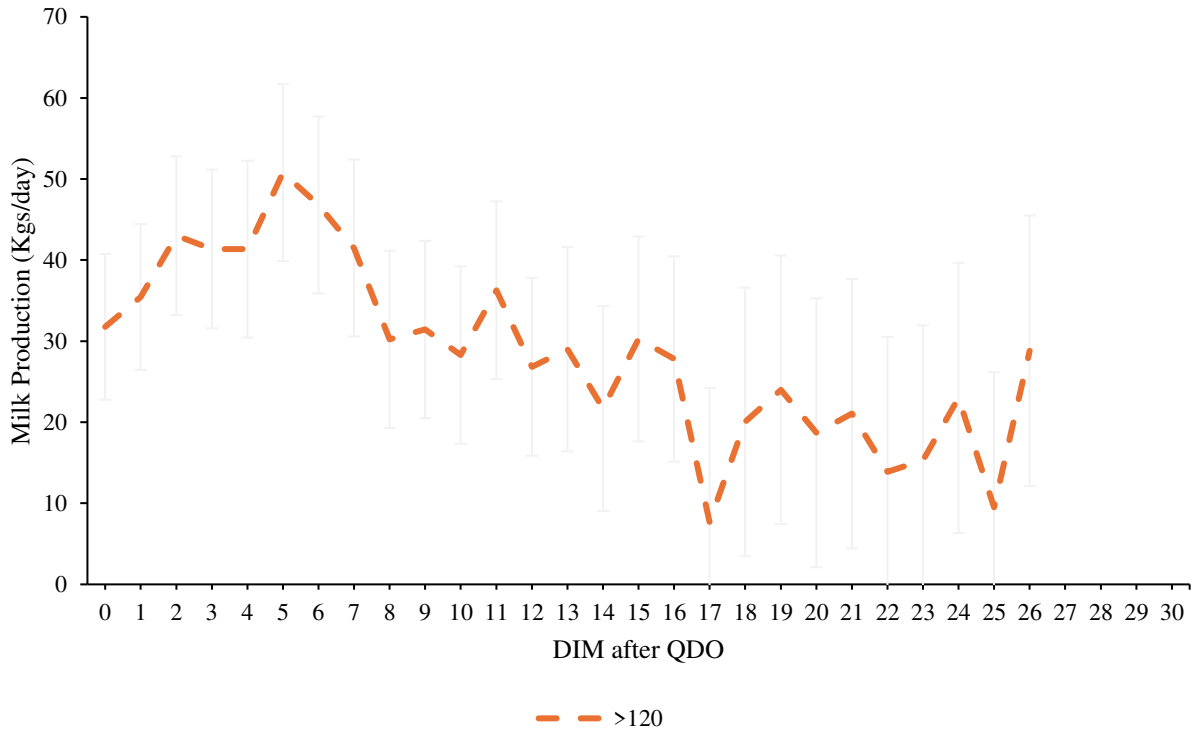


Figure 3.16: Least square means (SE) for total milk yield when one front quarter was dried-off with more than 120 DIM in primiparous cows.

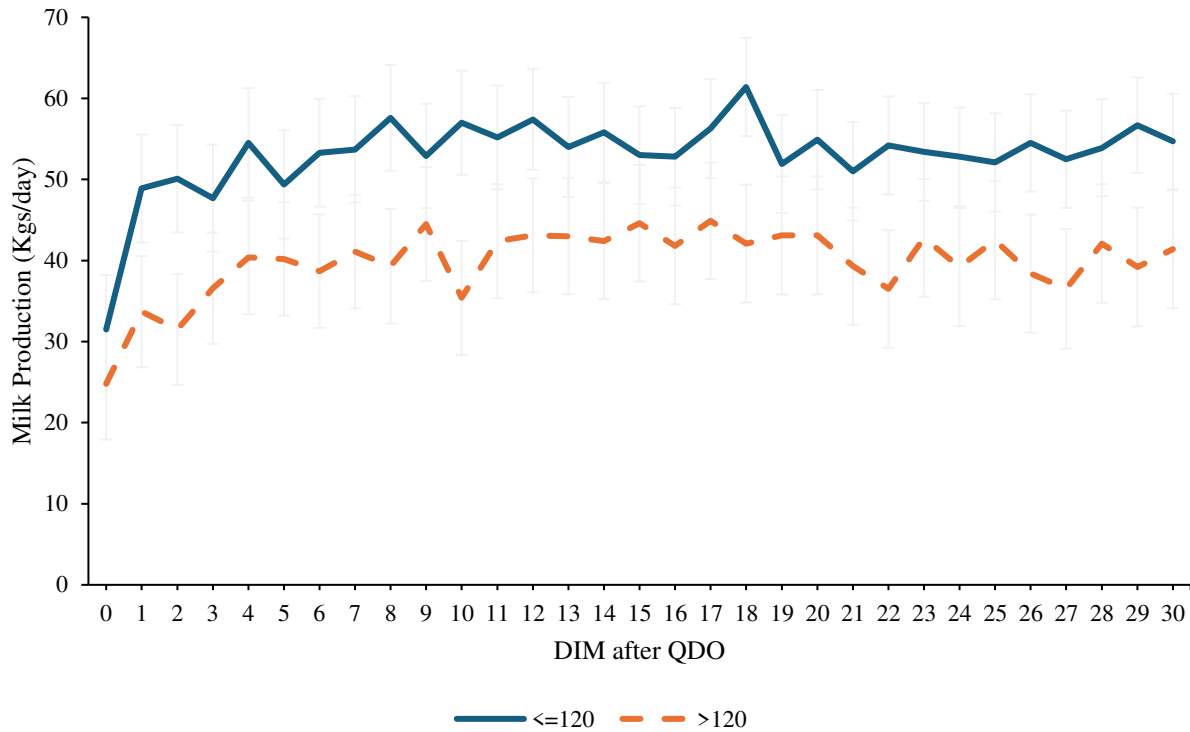


Figure 3.17: Least square means (SE) for total milk yield when one front quarter was dried-off within 120 DIM and more than 120 DIM in multiparous cows.

The results in the analysis made for figure 3.19 was done for the two opposite remaining quarters, interpreted as milk production combined of the two opposite to the QDO. The milk production of front quarters when the QDO was done on a rear quarter increased for those cows that have not reached their peak of lactation and its production was higher than those on their post-peak, with total averages of $29.7 \text{ kgs} \pm 5.3$ and $23.3 \text{ kgs} \pm 3.3$, respectively (Figure 3.18). Rear quarter production after a front QDO was much higher for those with equal or less than 120 DIM (avg. $36 \text{ kgs} \pm 4.6$) and the tendency was to increase. For those cows past their peak of lactation, the production was stable during the 30-day period after QDO, with a total average of 22.3 ± 5.1 kgs (Figure 3.19). DIM after QDO and milk production had an association with front quarters milk production ($P < 0.001$) on cows pre-peak. No associations found for those with >120 DIM. As for

rear milk production after a front QDO, for both lactation periods, an association was found with DIM after QDO and milk production ($P=0.006$, and $P=0.01$, respectively). DIM and milk production only had an association on those cows who passed their peak of lactation ($P<0.001$).

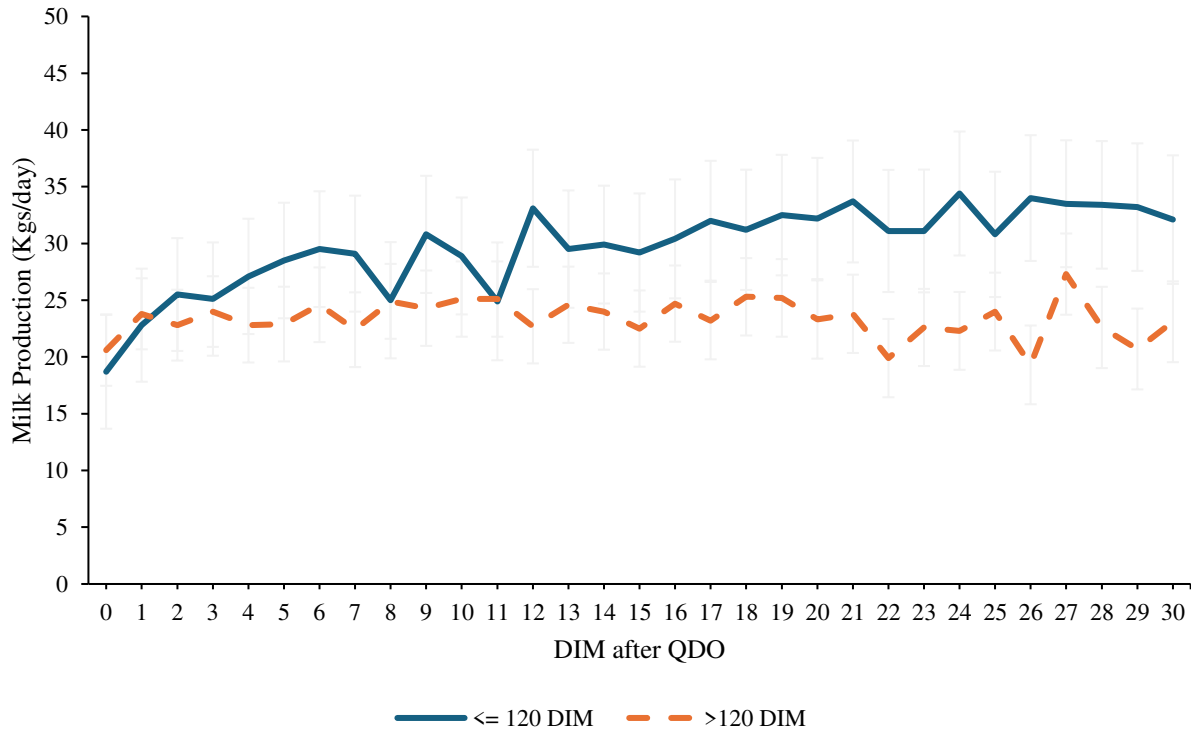


Figure 3.18: Least square means (SE) for front quarters milk yield when one rear quarter was dried-off within 120 DIM and more than 120 DIM.

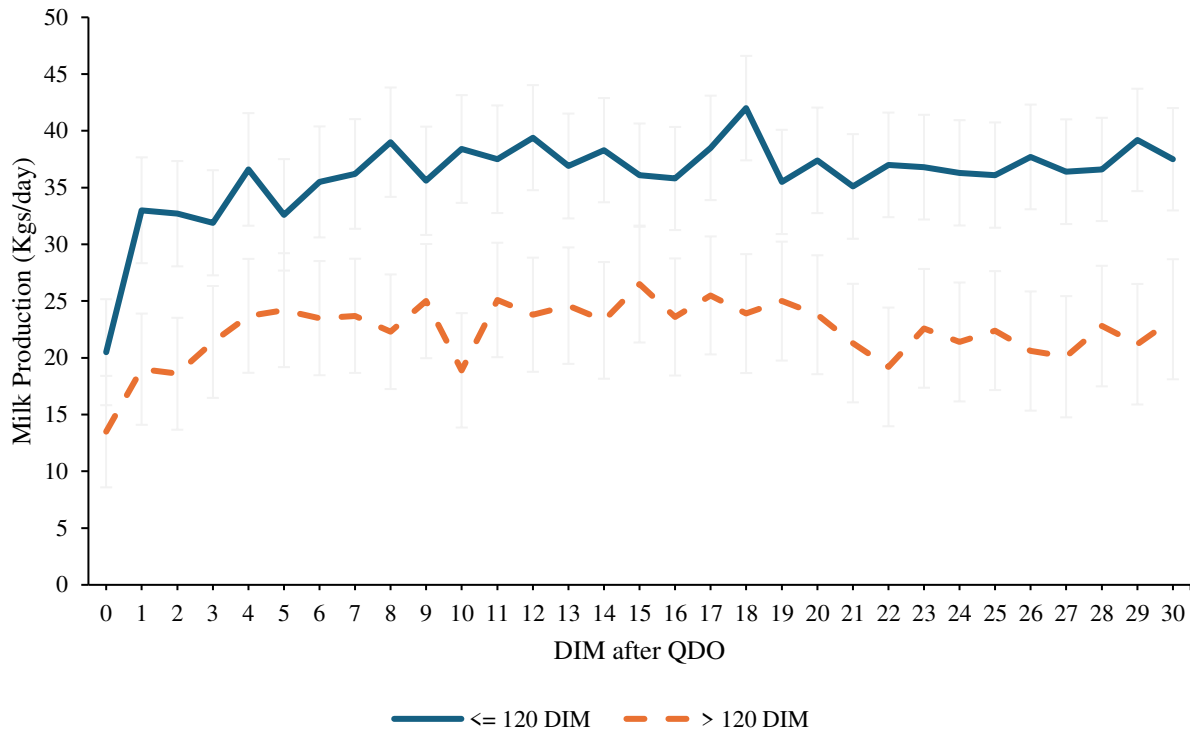


Figure 3.19: Least square means (SE) for rear quarters milk yield when one front quarter was dried-off within 120 DIM and more than 120 DIM.

Results of opposite quarter milk production on primiparous cows go as follows. Front quarters milk production were higher on those cows before their peak of lactation with an average of 24.8 ± 4.3 kg. Nevertheless, the tendency was of decreased milk production. For those cows that passed their peak of lactation, the milk production was stable during the 30 days after QDO (20.2 ± 4.4 kg) (Figure 3.20). Since the number of primiparous for the study was low, there were no results for rear front milk production after a front quarter was dried off within the first 120 days

of lactation. For those with more than 120 days in milk, the production in the rear quarters was reduced after QDO on the front quarter (average milk production was 20 ± 7.1 kg) (Figure 3.21).

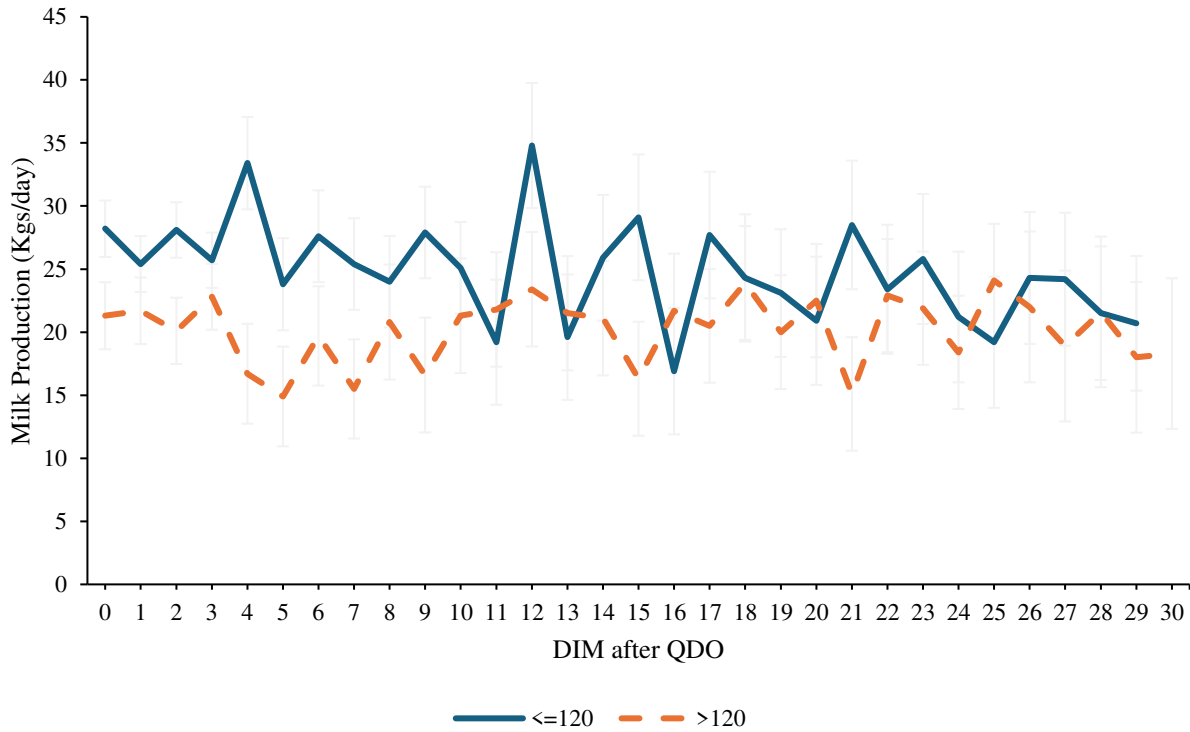


Figure 3.20: Least square means (SE) for front quarters milk yield when one rear quarter was dried-off within 120 DIM and more than 120 DIM in primiparous cows.



Figure 3.21: Least square means (SE) for rear quarters milk yield when one front quarter was dried-off within 120 DIM and more than 120 DIM in primiparous cows.

Multiparous cows transitioning the first 120 days of lactation showed more milk production in the rear quarters (average 36.6 ± 3.8 kg) compared to the front quarters (average 30.6 ± 4.6 kg) when individual quarter dry-off procedure was done in a front quarter and rear quarters, respectively. Milk production in front quarters showed an association to DIM after QDO ($fP < 0.001$ and $P = 0.008$, for front and rear milk production respectively). There was a slight tendency of increase in milk production but for those >120 DIM after rear quarter dry-off, which stayed the

same (Figure 3.22 and Figure 3.23). DIM associated with milk production on rear quarter milk production ($P<0.001$) was found on those cows with more than 120 DIM.

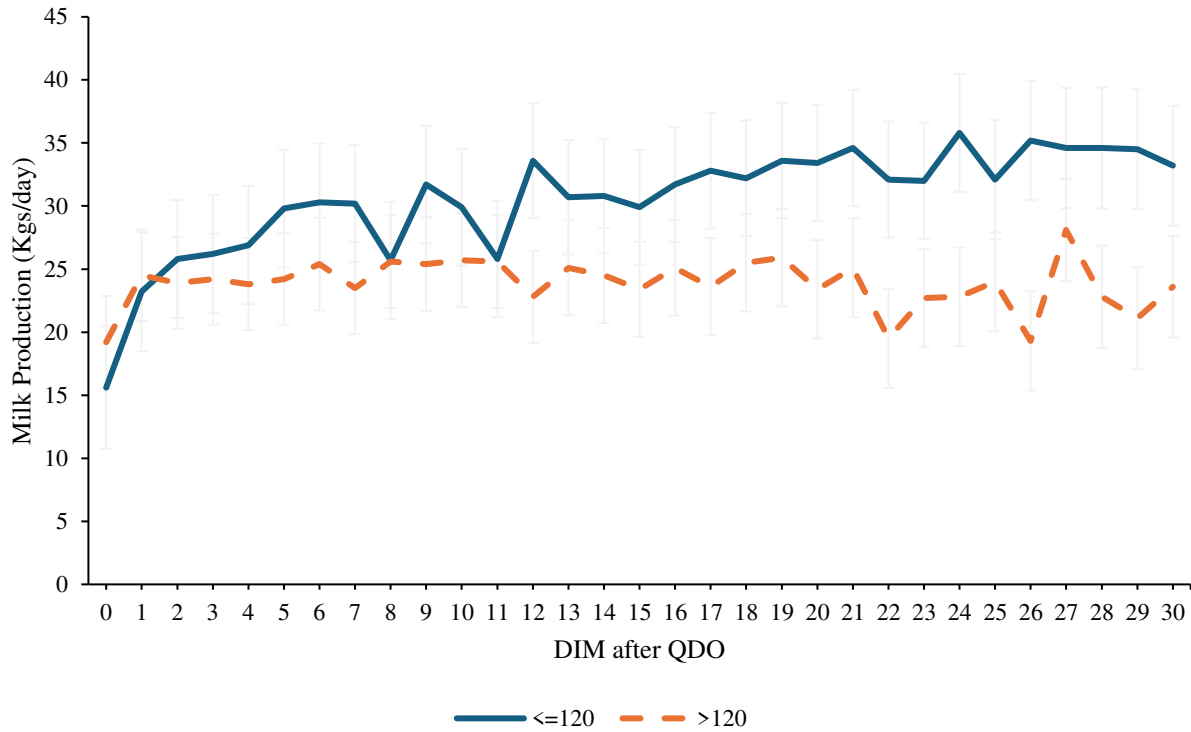


Figure 3.22: Least square means (SE) for front quarters milk yield when one rear quarter was dried-off within 120 DIM and more than 120 DIM in multiparous cows.

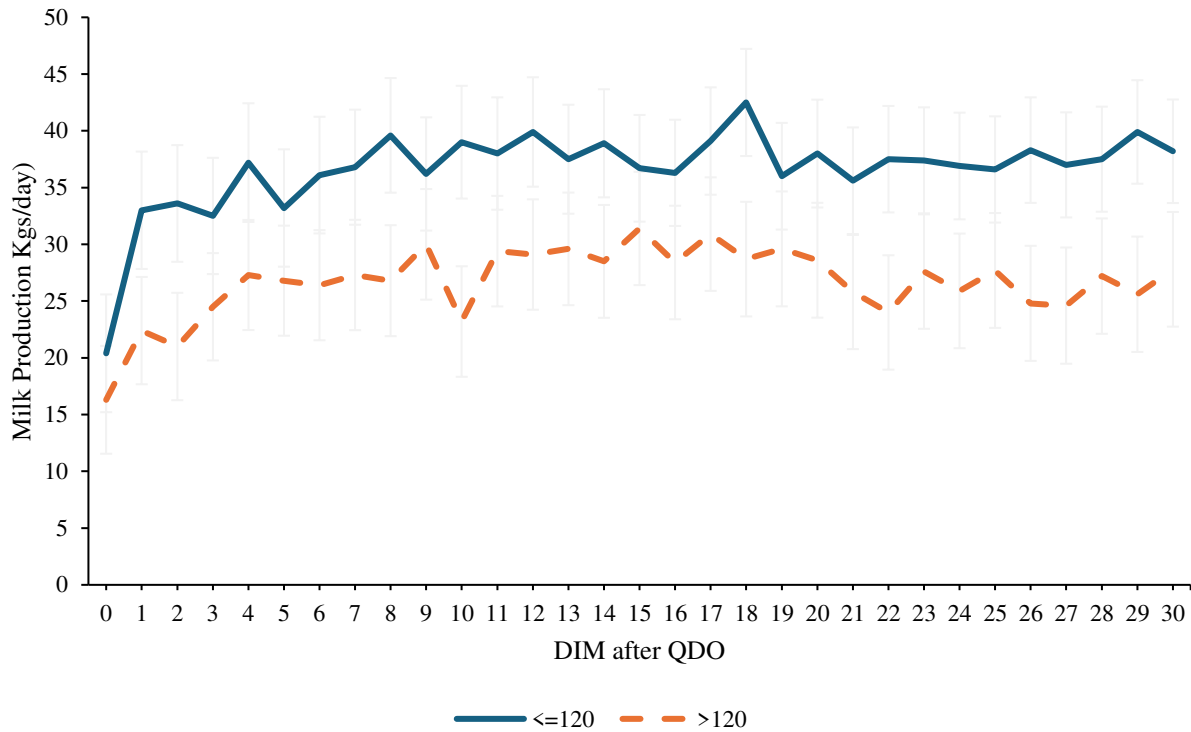


Figure 3.23: Least square means (SE) for rear quarters milk yield when one front quarter was dried-off within 120 DIM and more than 120 DIM in multiparous cows.

Lastly, the result for total milk production in cows with milking records of 120 days after individual quarter dry-off on front or rear quarters is presented below. When the procedure was done on a rear quarter the average was of 39.6 kg/day, while the total milk production when a front

quarter was dried off was of 29 kg/day. In both cases the tendency was to decrease in milk production (Figure 3.24).

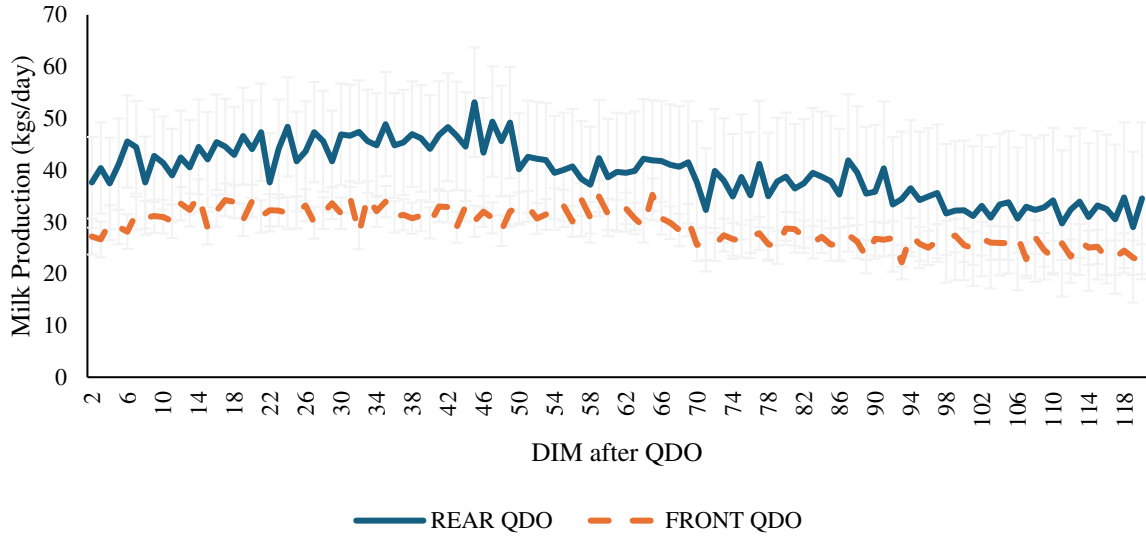


Figure 3.24: Least square means (SE) for total milk yield after one front or rear quarter was dried-off within 120 DIM after the procedure.

Discussion

This study provided novel information on dynamics of milk yield following QDO. Even though the compensation was not directly calculated, the milk curve's behavior gives insight into how total milk production could behave. Moreover, differences in milk yield following QDO were observed depending on quarter positions, parity, and days in milk.

Regardless of parity, cows in early lactation exhibited an increase in milk production ranging between 10 and 15 kg per day. Notably, rear quarters consistently tended to produce more milk than front quarters, as expected. In contrast, cows in mid-to-late lactation produced lower amounts of milk (5-15 kg/day) and generally maintained production levels rather than showing an

increase in trend. This suggests that early lactation cows may exhibit better milk production compensation due to enhanced mammary gland adaptability (Wieland and Skarbye, 2024).

Even though parity was not a variable statistically significant in all of the cases, multiparous cows tended to have more average of milk production than primiparous cows, in cases up to 13 kg of difference. Previous research on milk compensation after stopping milking a quarter indicated an overall increase of approximately 4%, with the compensatory effect being significantly lower in primiparous cows than in multiparous cows (Hamann and Reichmuth, 1990). Multiparous cows with equal to or less than 120 DIM exhibited greater milk production following the drying-off of a front quarter, reaching up to 20 kg/day. In contrast, primiparous cows had stable or decreased trend in milk production after a front quarter being dried off. Additionally, rear quarters were found to be the most productive, aligning with findings from other studies that have highlighted higher milk production in rear quarters compared to front quarters (Tančin et al., 2006).

For multiparous cows, milk production increased regardless of which quarter was being dried off, likely due to a greater amount of mammary gland tissue and an inherently higher milk production capacity. In contrast, primiparous cows showed a relatively stable total milk production across different lactation stages, but sample size limitations hindered a more detailed analysis of this group (Knight and Wilde, 1993; Cattaneo et al., 2023).

Cows with equal to or less than 120 days in milk demonstrated greater milk production capacity following QDO compared to those in mid-to-late lactation. Primiparous cows, when a front quarter was dried off, milk production tended to increase from day 0 to day 30. In other cases, production remained stable with no observable increases, suggesting that milk compensation is unlikely once a cow passed its lactation peak. Additionally, total daily milk production after QDO was higher when one front quarter was dried off, and the impact of lactation stage was more

pronounced over the 30-day observation period of these cows. Cows past their peak of lactation produce less milk than those pre-peak of lactation (Skarbye et al., 2018).

For the total milk production in 120 days after QDO, the results were not as expected, since the rear quarters tend to produce more than the front quarters, therefore, the expectation would be to have more milk production after one front quarter being dried off. Nevertheless, these results may be affected by the small sample size.

One of the limitations of this research was the moderate number of animals enrolled in the study, especially primiparous cows. Moreover, information from previous lactations or specific days at the robot was missing from some cows. Health status, meaning the presence of other diseases, did not have a significant association and research has proven that it will impact milk production. Previous research demonstrated changes in the behavior of the animal, such as rumination time, and milk production after diseases such as mastitis, metabolic, digestive, and reproductive disorders (Stangaferro et al., 2016a; b; c). It has been reported that sick cows can produce 15 kg/day less than healthy cows (Edwards and Tozer, 2004). Therefore, more research needs to be done in that area to see the long-term effects of QDO on health and milk composition.

Conclusion

Early lactation cows, particularly multiparous cows, continued increasing milk production after the QDO procedure, with the rear quarters being the most productive. However, further research with larger sample sizes is necessary to better understand the long-term effects of QDO on health and milk compensation in dairy cows.

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