Effects of Herd Management Practices and a Feed Supplement on Milk Yield, Milk Components, and Automatic Milking System Metrics

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Chapter 1

Literature Review

AUTOMATIC MILKING SYSTEMS

Conventional milking is the process of having workers fetch and bring groups of cows for milking at specified intervals, commonly done twice or thrice a day. The Automatic Milking System (AMS) development in 1992 began the revolution of transforming laborious milking into automatic milking. Most AMS used in North America are single milking boxes and motivation for the cow to enter the box is voluntary, supported by concentrate feeding, in turn, reducing the need for human labor (de Koning and Rodenburg, 2004). Cows voluntary enter the AMS and as part of the system, cows are electronically identified, teats are sanitized, milk is harvested, post-treatment is applied, and abnormalities in the milk are detected, reducing the need for manual labor.

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AMS Considerations

Producers can choose between a conventional milking system (CMS) or an AMS when considering milking systems; motivations for adopting either milking system vary. Hogeveen et al. (2004) reported that the motives for adopting AMS included less (heavy) labor (21% of respondents), labor flexibility (13% of respondents), milking more than twice per day, and labor availability (11% each). Less (heavy) labor and labor flexibility were also found and classified as social reasons (Mathijs, 2004). The CMS purchasing motives were that the cost of the AMS was too high (29%), did not want a dependency on AMS (15% of respondents), and uncertainty about AMS (9%).

AMS Changes to Quality of Life

Implementation of AMS was evaluated in relation to how it improves the producers' quality of life (**QOL**) and meets producers’ expectations (Tse et al., 2018). The QOL was better for dairy producers using AMS compared to CMS (Hansen and Stræte, 2021). As mentioned by Hogeveen et al. (2004) and Mathijs (2004), the most improved QOL from transitioning included increased time flexibility (97%) as some producers reported spending more time with family, attending meetings, and having more time for other farm chores (Tse et al., 2018). In addition, milking-related activities decreased by 2.5 hours/day for DeLaval owners and 3.4 hours/day for Lely owners (Tse et al., 2018b).

There was less physical demand and stress on the body, which ranked second in terms of improving QOL according to Tse et al. (2018). In addition, producers reported reduced neck and back pain, which supports the claim that people's health concerns reduce their job satisfaction (Hansen and Stræte, 2021).

The third factor improving QOL was easier employee management (14%), as producers could decrease their employees by 20% (Tse et al., 2018b). However, feeling lonely is associated with decreased job satisfaction, so fewer employees may harm QOL when transitioning.

Hansen and Stræte (2021) reported that job satisfaction decreased with increasing milk quota (milk demand) and Tse et al. (2018) reported too much milk production as a challenge after converting to AMS. Also, producers feeling that technical competence was critical to farming had decreased job satisfaction (Hansen and Stræte, 2021); and that was also the main challenge found by Tse et al. (2018). Other factors improving job satisfaction included increased income, new cowshed, and continued farming (Hansen and Stræte, 2021), but it should be noted that income did not mean profit. Mentioned by Hogeveen et al. (2004) and Mathijs (2004) and demonstrated by Tse et al. (2018), the main motive and outcome of transitioning to an AMS was an improvement to QOL.

AMS Changes to Milk Yield

In addition to QOL, Hogeveen et al. (2004) found that producers wanted more milkings per day as they believed there would be an improvement in milk yield. In a comparative study, rather than a transitioning observation, AMS systems yielded greater milk than CMS systems (Hansen et al., 2019); however, Matei et al. (2020) did not find a difference in milk yield per cow per year in AMS vs. CMS. Data from 1990 to 2002 indicated that milk yield increased by 2% one year after the installation of AMS; however, genetic and management improvement was given credit for this increase (Wade et al., 2004). Tse et al. (2018b) reported that within 2 years of transitioning to AMS, 79% of producers reported an increase in milk yield, 6% reported a decrease in milk yield, and 15% reported no difference. Meanwhile, 83% of producers having AMS for greater than 2 years reported an increase in milk yield, 3% reported a decrease in milk yield, and 14% reported no difference, and for both date ranges, no difference between brand of AMS was detected. Hansen et al. (2019) also found that farms that installed AMS more than 4 years before and had 45 to 50 or more cows had higher gross farm income than those with CMS. It is important to note that herd management factors may influence the reported productivity, but management factors could be improved as more experience with the AMS occurs.

AMS Changes to Milk Component Yield and Milk Quality

In a comparison study between AMS and CMS, no difference in fat yield was observed, protein yield on AMS was decreased (Matei et al., 2020). Wade et al. (2004) found 2.0% and 1.9% increases in fat yield and protein yield, respectively, 1 year after the implementation of AMS. Tse et al. (2018b) reported that within 2 years of transitioning to AMS, 22% of producers reported an increase in fat yield, 13% reported a decrease in fat yield, and 65% reported no difference. In addition, 36% of producers having AMS for over 2 years reported an increase in fat yield, 14% reported a decrease in fat yield, and 50% reported no difference. For protein yield within 2 years of transitioning to AMS, 4% of producers reported an increase, 9% reported a decrease, and 87% reported no difference. Meanwhile, 15% of producers having AMS for more than 2 years reported an increase in protein yield, 7% reported a decrease, and

78% reported no difference. In addition to fat and protein yield, another characteristic in milk quality is somatic cell count **(SCC)**. Farms that transitioned to AMS were followed for a year and SCC was elevated for several months post transition (van den Borne et al., 2021). Bulk-tank SCC, proportion of cows having a composite SCC >200,000 cells/mL, and the proportion of cows having a new elevated SCC were all increased post transition, but all decreased as time with the AMS passes. Important to mention from the same study, the negative impact on udder health decreased in recent years as technology improved, but still remains an issue to pay attention to. Using the insight from Hansen et al. (2019) and van den Borne et al. (2021), we can suggest that more experience with the AMS improves milk component yield and quality.

AMS Changes in Income and Expenses

The potential increases in milk and component yield would increase income for producers in countries not using a quota system and the increase would improve job satisfaction (Hansen & Stræte, 2021), assuming expenses do not substantially increase.

Expected capital expenditures were higher for AMS than CMS as there are increased costs of constructing buildings for AMS installation and AMS maintenance (Matei et al., 2020; Steeneveld et al., 2012). Nevertheless, there were similar staff expenses (Matei et al., 2020) and total number of full-time equivalent (FTE) employees (Steeneveld et al., 2012). The same FTE indicates that labor flexibility might be improved and is being spent on other farm chores, resulting in greater job satisfaction (Hogeveen et al., 2004; Mathijs, 2004). Economic efficiency between AMS and CMS is undetermined as many factors influence economic efficiency. Bijl et al. (2007) concluded that economic efficiency is similar between AMS and CMS operations. Hansen et al. (2019) concluded that small AMS farms were less economically efficient, but larger AMS farms with more experience were more profitable than CMS. No profitability difference was detected in the assumption that the producer decreases labor costs in exchange for increased fixed costs of the AMS. Important to note, that labor flexibility increases as time spent milking can be exchanged for other farm chores.

Free Flow vs. Guided Flow AMS

There are two leading brands of AMS in the U.S.: DeLaval (Bannockburn, IL, United States) and Lely (Pella, IA, United States). DeLaval AMS are mainly guided flow systems. Guided flow AMS require cows to visit barn areas in a sequence (Salfer et al., 2018). They work by using a combination of pre-selection and one-way gates to guide cows to visit areas of a barn in a sequence. An example of this flow would be cows traveling from their bedding area to the AMS to be milked and then into the feeding area. As opposed to guided flow, Lely AMS are free flow meaning that the cows are not restricted from any area. Munksgaard et al. (2011) did not find any significant evidence that milk yield was affected by the type of traffic flow. However, newer studies have found that free flow systems yield greater milk than guided flow (Siewert et al., 2019; Tremblay et al., 2016). However, guided flow was associated with decreased fetching and reduced labor (Rodenburg, 2017).

TRANSITION PERIOD

The transition period of a dairy cow is traditionally known as three weeks prior to calving through three weeks post-calving (Drackley, 1999); however, some companies consider the range of time for this period to be 60 days before calving (the entire dry period) to 30 days in milk (DIM) coining the term The Vital 90™ (Mcclary et al., 2014). Many are now considering there are two transition periods (lactation to dry off and dry off to lactation). During this time frame, numerous metabolic and physiological changes occur including: drying off lactating cows (end of milk production), change in environment and ration composition, rapid fetal growth, a decline in dry matter intake (DMI), initiation of colostrum production, hormonal changes, parturition, and an increase in the production of milk.

The dry period aims to improve the odds of optimal milk production in the subsequent lactation by allowing udder tissue regeneration (Hurley, 1987; Wisnieski et al., 2019). The length of the dry period may vary by operation, but the current gold standard is 40 to 60 days. Improvements in lactating rations have allowed cows to approach the genetic potential of milk yield (Odensten et al., 2007) and, combined with improvements in genetic selection, have drastically increased milk yield making the cessation of lactation increasingly difficult (Stefanon et al., 2002). Before the stopping of milking, the ration changes from a high energy lactation ration to a lower energy dry-off ration, consisting of more fiber (Rajala-Schultz et al., 2005; Zobel et al., 2015), to decrease milk yield to have decreased painful inframammary pressure (Oliver and Sordillo, 1988). After the cessation of milking, cows are typically housed with other dry cows.

Dry Period

Udder tissue regeneration occurs during the dry period (Hurley, 1987; Wisnieski et al., 2019) for previous lactating cows, and udder tissue grows for heifers (Swanson and Poffenbarger, 1979). The mammary gland prepares for colostrogenesis, transfer of immunoglobulins from the maternal circulation to mammary secretions, and lactogenesis. Weeks before parturition, colostrogenesis occurs and abruptly stops immediately before parturition (Brandon et al., 1971)**.** Simultaneously these animals are supporting a growing fetus, and it is estimated that the daily fetal and placental growth demands in the last three weeks of gestation are 360g of metabolizable protein and 3 to 5 Mcal of Net Energy (Bell, 1995), resulting in an energy requirement increase.

Additional energy requirements are met by increasing energy intake; however, 2-3 weeks before parturition DMI begins to decrease (Grummer et al., 2004). It is estimated that DMI decreases are 25% for first/second parity and 52% for third parity or greater (Marquardt et al., 1977), respectively 2 weeks prior, and DMI decreases 30% in the week prior (Bertics et al., 1992). The cause of the decrease in DMI is unknown, but many theories are suggested. Grant and Albright (1995) and Robinson (1997) note that the fetus begins growing rapidly 3 weeks before calving and begins crowding the abdominal space, in turn displacing the total rumen volume and causing a decrease in DMI; however, the prepartum DMI curves are not consistent with the growth of the fetus (Grummer et al., 2004). Others suggest that systemic inflammation results in DMI reduction (Bertoni et al., 2016), but there is confusion on whether systemic inflammation is responsible for decreased DMI or if the decreased DMI is responsible for systemic inflammation (Pascottini et al., 2020). With the decrease in DMI and the increase in energy expenditure, the animal enters a negative energy balance (NEB). Grummer et al. (2004) states that the NEB is not mainly resulting from the increase in energy required but from the decrease in DMI.

Lactation Period

After parturition, the dry period transitions into the early lactation period. Genetic selection for increased milk yield results in an intensified NEB as DMI is not sufficient to meet the energy requirements. The NEB results in mobilizing body nutrient reserves to meet these energy requirements and can contribute to either milk yield not being maximized or transition disorders occurring (Bauman and Currie., 1980; Baumgard et al., 2017). Baumgard et al. (2017) estimated that 30 to 50% of all dairy cows cannot adapt to the stress around the time of calving and experience a type of transition disorder. Transition disorders are classified as metabolic disorders such as hypocalcemia, hypomagnesemia, and ketosis; or immunological disorders such as retained placenta, metritis, and laminitis (Mulligan and Doherty, 2008).

Post-calving, DMI begins to recover at a rate of 1.5 to 2.5 kg per week (Grant and Albright., 1995), and it has been shown that multiparous cows recover DMI sooner than primiparous cows (Kertz et al., 1991; Robinson and Garrett, 1999). Thirty days after calving, the cow has successfully adapted to transition, although the NEB may be present until milk yield decreases to less than 80% of the peak milk yield (Bauman and Currie, 1980).

The optimal outcome for dairy producers during the transition period is to have cows adapt to the metabolic, physiological, and management changes, with minimal to no transition disorders occurring.

Management Practices for Transition Period

A current topic in dairy research is looking at interactions between AMS management practices and their effects on milk yield, along with minimizing the harmful effects of the transition period.

Feed Push-Up

Feed push-up serves a vital role in the availability of feed throughout the day as cows naturally sort through their ration (DeVries, 2019). Sorting introduces two issues; the first is that cows push feed away from the feed bunk, which prevents continuous access, and the second is that sorting allows the cow to select which parts of the ration they desire, resulting in variation among diets within pens. Feed push-up attempts to reduce sorting by pushing the feed closer to the cows. Therefore, the frequency of feed push-up is essential. Deming et al. (2013) and King et al. (2016) noted an association between greater lying time and greater frequency of feed push-ups. Also, herds not performing feed push-ups yielded less milk per cow. The literature previously mentioned illustrates that feed push-up is essential, but in AMS operations, there is an often more significant push for automation by using automatic feed-push-up methods. This method allows feed to be pushed up on a set schedule without the need of a laborer, compared to manual-feed push-up methods where feed is only pushed up when a laborer performs the act. The average number of feed pushes per day was found to be greater with an automatic feed push-up than a manual feed push-up (Matson et al., 2021) and with an automatic feed pushup method, feed is able to be pushed up routinely throughout the night while a laborer may not be pushing up feed. In addition, automatic feed push-up was associated with an increase in milk yield per AMS and milk yield per cow compared to manual feed push-up (Siewert et al., 2018). Important to consider is that feed-push-up frequency is associated with greater milk yield (DeVries, 2019) and may be the factor important to investigate rather than the feed push-up method type. However, Bach et al. (2008) and DeVries et al. (2003) did not find an association between feed push-up frequency and milk yield. However, an automatic feed push-up method would reduce the time spent on feeding activities.

AMS per Pen

The AMS is installed within the pen, and the number of AMS per pen is a conflicting topic as various management decisions play a role (Rodenburg, 2010). A study showed that 2 AMS per 120 cows was associated with greater milk yield than 1 AMS per 60 cows (Tremblay et al., 2016). However, Siewert et al. (2018) found no significant difference between farms with 1 AMS/pen and those with more than 1 AMS/pen. The number of cows/AMS, or AMS stocking density, was positively associated with daily milk yield/AMS and daily milk yield/cow (Siewert et al., 2018; Tremblay et al., 2016). Siewert et al. (2018) had an average of 55.8 cows/AMS, approaching the 60 cows/AMS recommendation (Rodenburg. 2017); however, Tremblay et al. (2016) had an average of 47.5 cows/AMS. Castro et al. (2012) suggest that the maximum number of cows per AMS box could be increased to 68. AMS stocking density should also depend on cows average milking time, milking speed, box time, and other factors serving a role in AMS utilization time.

Number of Concentrates Offered

Prescott et al. (1998) found that cows are more motivated to consume feed rather than being milked, thus driving them to enter the AMS. Cows assumed to have the greatest udder fill tend to be driven to milk, but investigational evidence indicates that feed is the main incentive for entering the AMS (Bach et al., 2007; Prescott et al., 1998; Scott et al., 2014). The AMS offers milking incentives, typically in the form of concentrates (de Koning and Rodenburg, 2004). The amount of concentrate intake in the AMS had a positive correlation with milk yield (Kliś et al., 2021; Siewert et al., 2018), and the magnitude of the relationship increased over subsequent weeks (Kliś et al., 2021). Menajovsky et al. (2018) found that milk yield and protein yield tended to be greater when cows were fed a higher amount of concentrate but found that higher concentrate intake was associated with decreased fat concentration. However, the varying quantity of concentrate in the AMS did not affect milk yield (Paddick et al., 2019) or component yield (Schwanke et al., 2022). Incentives are also helpful in training cows and heifers to familiarize them with the AMS.

AMS Training

The main goal of training heifers and cows is to familiarize them with the AMS and have them be trained to reduce the need for fetching them. Companies providing AMS distribute various training programs to help with the transition, but there is no standard program yet. A program recommendation is to bring the cows to the AMS 1 to 4 times daily for 3 to 14 days before starting the herd on AMS (Tse et al., 2018b). The median days for cows to adapt to the AMS was 30 days, and the average time it took producers to train cows or heifers was 7 days (Tse et al., 2018b). However, producers who trained cows (Jacobs and Siegford, 2012) and those who did not (Spolders et al., 2016) reported a similar average of seven to eight days for cows to adapt to AMS. Even with the successful transition at the herd level, Jacobs et al. (2012) found that only 80-90% of the cows use the system voluntarily.

Cow/Heifer Fetching

Fetching is the chore of finding cows that have not met the producers' defined maximum milking interval and bringing them into the AMS. The milking interval itself has high variability on AMS farms. Shorter milking intervals resulted in higher milk yield per cow per hour, dependent on the total milk yield of the cow (Hogeveen et al., 2001). The voluntary milking interval varying between farms could have an impact on the number of fetchings per day. In addition to the milking interval, the total AMS utilization serves a role in the number of fetchings per day. If the AMS is being utilized for durations where the number of cows is overstocked in the pen, then an increase in fetching would occur.

Producers were found to fetch a median of 2 times/day with a median of 3 fetch cows (Tse et al., 2018b). Another study found that 78% of AMS producers fetched 2 times/day with an average of 4.7 cows/AMS per day on free flow farms and 3.3 cows/AMS per day for guided flow traffic (Salfer et al., 2018).

Fetching occurs more frequently during the first 14 DIM, and there was no association between cows fetched and reluctance to enter the AMS (Rousing et al., 2006). Training programs have been found to reduce the proportion of animals that had to be fetched compared to those not trained (von Kuhlberg et al., 2021).

Fresh Pen

Dairy producers commonly group dairy cows to improve feed efficiency and management. Grouping strategies vary among farms; one study found that fresh cow grouping was performed by 21.6% of commercial farms (Heuwieser et al., 2010). The fresh pen assists in monitoring cows during the post-calving transition period (Cabrera and Kalantari, 2016). The average time cows spend in a fresh pen varies from 3 to over 30 days (Espadamala et al., 2016) and up to 73 days (Rossow and Aly, 2013). Hoseyni et al. (2020) found that cows that spent 10 days in the fresh pen yielded more milk and reached peak lactation sooner than cows spending 21 days in a fresh pen. However, both had similar peak milk yields. It may be possible that the extended stay results in a hierarchy within the fresh pen influencing newly introduced cows. Though these studies were performed in CMS, implementation of this practice may prove beneficial in AMS.

First Lactation Pen

In addition to a fresh pen for improving feed efficiency and management, AMS producers may implement a first lactation pen. In this pen, the first lactation cows are housed together. Like the fresh pen, a first lactation pen would allow more efficient management of those cows, and diets would be formulated for this specific lactation group. Two reasons exist for this practice, one being more careful monitoring of lactating primiparous cows and the second being that they require lower Net energy of lactation compared to second and greater lactation ("Nutrient Requirements of Dairy Cattle," 2021). Also, it is believed that the primiparous cows will rank lower in a social hierarchy due to their smaller frame (Wierenga and Hopster, 1990), recommending that the primiparous cows should be housed separately from the multiparous cows (Grant and Albright, 1995). However, Bach et al. (2006) found that primiparous cows had a longer eating time when grouped with multiparous cows compared to the primiparous only pen, but the primiparous only pen did consume one additional meal per day. Numerically, Bach et al. (2006) saw an increase in the number of daily milkings and an increase in fat yield but no difference in milk yield or protein yield.

Liquid Feed

Early lactation cows have an increase in energy requirement and a decrease in DMI, meaning that more energy-dense feeds are required to meet energy requirements for rapidly increasing milk yield. Early lactation rations are commonly higher in energy and starch and lower in forage and fiber (McCarthy et al., 2015). Numerous studies have investigated liquid feed usage in CMS (DeVries and Gill, 2012; Leonardi and Armentano, 2003; McCarthy et al., 2015), but few investigated liquid feed fed in an AMS. Moore et al. (2020) found that supplementing molasses in the AMS resulted in lower β-hydroxy-butyrate concentrations at 15 days in milk, body condition score loss through 60 days in milk but no differences in milk yield, energy corrected milk, or fat corrected milk.

Use of Body Weight

Utilization of cow body weight (BW) may assist in management decisions. Producers can equip the AMS with a scale that will record the cow's weight every time she enters the box, and the AMS software will generate the average of the observations to create a daily BW. Body weight has been noted to respond to physiological and pathological changes in dairy cattle (Maltz et al., 1997). A decline in BW has been associated with disease detection and response to estrus. It has been shown that 68% of cows dropped BW when showing standing heat, and others have dropped weight the day before standing heat (Berry et al., 2007). Decreased cow BW recorded by AMS has been associated with primiparous cows' metritis (Gáspárdy et al., 2014; King et al., 2017), lameness, pneumonia, subclinical ketosis, hoof disorders, and metritis (King et al., 2017).

Use of Activity

Monitoring the activity of dairy cattle may be helpful in the management of a dairy farm operation. Activity is monitored and recorded by a neck collar that measures head and neck motion. Daily reductions in activity were observed in the comparison between sick and healthy cows. Reductions in activity have been associated with lameness (Steensels et al., 2017; van Hertem et al., 2013; Weigele et al., 2018), clinical ketosis (Stangaferro et al., 2016b, 2016a, 2016c), subclinical ketosis (Liboreiro et al., 2015), retained placenta (Liboreiro et al., 2015), displaced abomasum (Liboreiro et al., 2015), and mastitis (Fogsgaard et al., 2015). In contrast, Siivonen et al. (2011) observed that activity increased after the diagnosis of mastitis. Increases in activity have been associated with the time of estrus (Dolecheck et al., 2015; Firk et al., 2002; Mayo et al., 2019).

Use of Rumination Time

Similar to activity, rumination time (RT) in AMS is recorded by neck collars. Rumination time was positively associated with milk yield (Kaufman et al., 2018) and peak milk yield (Peiter et al., 2021). In addition, RT was negatively associated with milk fat content and milk fat to protein ratios (Kaufman et al., 2018), and increasing FP ratios have been linked to subclinical ketosis (Duffield et al., 1997; Jenkins et al., 2015). Decreases in RT have been correlated to cows experiencing subclinical ketosis, displaced abomasum, indigestion, ruminal acidosis (Devries et al., 2009; Kaufman et al., 2018; Stangaferro et al., 2016c), estrus (Reith and Hoy, 2012), and 48 hours before calving (Schirmann et al., 2013).

Bedding Frequency

Cows in tie-stall and free-stall barns lie down on stalls. Stalls are typically covered with bedding, with the main two types being organic and inorganic bedding materials (Kumar Singh et al., 2020). Organic bedding materials consist of straw (hay and grass), wood shavings, crop residues, sawdust (Bradley et al., 2018), composted manure, and wood chips (Chamberlain, 2018). Meanwhile, inorganic bedding materials consist of sand, limestone, and gypsum (Bradley et al., 2018).

Bedding has a variety of purposes, with the primary purpose of providing comfort to the animal by providing cushioning and reducing friction between the cow and the bed surface**.** In addition to cow comfort, health and performance are affected by bedding materials. Maintaining dry bedding is vital as wet bedding may provide a breeding ground for microbes. The pathogenic microbes growing on wet bedding are typically the cause of environmental mastitis (Fávero et al., 2015). Manure solids used as bedding have been associated with higher bedding bacteria counts, dirtier udders, and poor udder health measures compared to other organic non-manure materials, reclaimed sand, or new sand bedding materials (Murphy et al., 2019; Patel et al., 2019).

To reduce the transmission of environmental mastitis pathogens, producers may increase the frequency of adding new bedding to stalls and scraping manure off the stalls (Murphy et al., 2019). However, the frequency of scraping stalls had a weak correlation in some studies (Robles et al., 2020). However, more frequent adding of clean bedding resulted in decreased somatic cell, in the bulk tank (Robles et al., 2020; Rowbotham and Ruegg, 2015). Studies do not show a direct relationship between milk yield and bedding type, but mastitis decreases milk yield by 180 to 1100 kg per 305-day lactation (Sharma et al., 2011).

Automatic Manure Scraper

Operations with stalls and alleyways that accumulate manure need frequent cleaning. Cleaning is performed by scraping manure from the stalls into the alleyways and scraping it out of the alleyway. Scraping off the alleyways can be performed by a laborer, with water-assisted flushes, or with an automatic manure scraper. As technology becomes cheaper, the prevalence of automatic manure scrapers may increase, with the most recent upper Midwest prevalence being 52% of farms using some form of an automatic manure scraper on AMS operations (Siewert et al., 2018). Siewert et al. (2018) did not see an association between use of an automatic manure scraper and milk yield. Automatic manure scrapers, like other automated processes, can reduce the need for a laborer to perform tasks. Also, these scrapers have been seen to clean alleys an average of 12.1 times per day (Matson et al., 2021). No study has directly examined the automatic manure scraper and its effect on milk yield. However, a variety of studies saw increased locomotion scores (Barker et al., 2007), increased severe hock injuries (Barrientos et al., 2013), and an increase in lameness (Barker et al., 2010) with the use of automatic manure scrapers. These may be due to the use of headlocks and the fact that the auto scraper does not stop moving if it senses a cow. Lameness has been noted to lead to a loss of milk yield ranging from 270 to 574 kg/ lactation when lameness has been diagnosed (Huxley, 2013). Additionally, pre- and post-lameness diagnosis has been associated with milk loss (Amory et al., 2008; Charfeddine and Pérez-Cabal, 2017; Green et al., 2002).

Ventilation

Dairy barns come in all sorts of designs, and ventilation is a characteristic that varies between farms. The goal of ventilation on dairy farms is to provide fresh air. Ventilation is necessary to prevent a dangerous buildup of temperature, humidity, and harmful gases beyond safe levels and to remove still air (Callan and Garry, 2002). The types of ventilation are natural and mechanical (Mondaca, 2019).

SORBITOL

Sorbitol is a carbohydrate categorized as a polyol, a category of sugar alcohols (Panoff, 2020). This water-soluble polyol also goes by the names of d-sorbitol and d-glucitol. The use of sorbitol in human food is widespread and includes preserving moisture, adding sweetness, providing texture, and potentially supporting digestive and oral health.

A sorbitol-containing feed supplement (Rally, Purina-LOL, Arden Hills, MN) was developed as a transition feed technology (Porter et al., 2004). This supplement resulted in higher true milk protein and total solids for 1 to 28 DIM, higher fat, lactose, and solids percentages for 29 to 56 DIM, and tended to have higher fat-corrected milk (FCM). It also had lower NEFA and BHB concentrations at days -21, -7 before calving and 10 DIM. Commercial records show that before and after supplementation of Rally 1-60 DIM, there was an increase in milk yield, FCM, percent fat, and percent protein in multiparous cows, with the same findings for primiparous cows, except for milk yield.

McFadden et al. (2008) found that multiparous cows receiving prepartum sugar alcohol supplementation (sorbitol and mannitol) had increased milk yield and decreased protein content, but no difference in protein yield, milk fat content and yield, somatic cell count, and milk urea nitrogen. A proposed explanation was that either DMI increased or sorbitol impacted rumen papillae growth. An increase in papillae size and number could allow cows to absorb propionate better during early lactation (Goff and Horst, 1997), thus increasing the net energy supply for milk yield.

Supplementation with sorbitol and another feed component showed an increase in milk yield over 4 weeks while decreasing DMI (Luhman, 2002). This decrease in DMI yet increase in milk yield suggests that sorbitol may improve papillae growth. Miller et al. (2014) also found that feeding ruminants sugar alcohol during heat stress resulted in lower DMI but a higher milk-to-feed ratio. Todd et al. (2006) observed a numerical higher daily milk yield in sorbitol supplemented cows and the highest FCM/DMI. It is plausible that sorbitol is improving nutrient absorption.

Sorbitol Fed to Beef bulls

Sorbitol fed to beef bulls resulted in increased live weight gain, feed efficiency, pre-prandial (before a meal) insulin levels, and a drop in plasma glucose and amino acid concentrations (Geay et al., 1992). In addition, sorbitol increased pre-prandial insulin levels, associated with a drop in plasma glucose and amino acid concentrations. Also, Fontenot and Huchettet (1993) fed sorbitol to finishing steers and observed a 9% total BW increase and a 10% feed efficiency increase. Additionally, when sorbitol was fed in combination with monensin, it increased shrunk BW and full BW by 18% and 24%, respectively. In two additional studies, neither sorbitol nor monensin had the highest daily gain, but both tended to improve feed efficiency.

In vitro fermentation

Lister and Smithard (1984) performed in-vitro incubations using sheep ruminal fluid to study the effect of intrarumminal administration of a mixture of polyhydric alcohols, arabinitol, xylitol, galactitol, mannitol, and sorbitol, on fermentation pattern and the fate of polyhydric alcohols. There was a difference in propionate yield of 18.4 vs. 21.3 mmol/L in pre-polyol fluid and fluid with a polyol, respectively. After 3 weeks, there was a decrease in propionate yield and an increase in acetate yield, indicating a shift in fermentation from propionate to acetate. The half-life for xylitol, arabinitol, mannitol, and sorbitol all decreased as adaptation increased in weeks. Notably, sorbitol's half-life significantly decreased from week 0 to week 2, 4.5 to 2.0 h, respectively, but did not change from week 2 to week 3, 2.0 and 1.3, respectively.

THESIS OBJECTIVES

Study 1 (Chapter 2) will investigate the association between management factors and milk production on AMS farms. The increasing adoption of AMS technology in the Upper Midwest U.S. warrants research on AMS farms. In addition, factors influencing dairy production efficiency need to be identified and used for developing AMS facilities and management.

Study 2 (Chapter 3) will investigate the use of a sorbitol-containing feed additive dispensed in an AMS and its effect on milk production and AMS metrics on multiparous and primiparous cows during the early postpartum period. Previous work with sorbitol has shown improved milk-to-feed efficiency (McFadden et al., 2008; Miller et al., 2014) and gain-to-feed efficiency (Fontenot & Huchettet, 1993; Geay et al., 1992). Therefore, in a time with decreased DMI resulting in a NEB, an improved feed efficiency may improve the production during this period.

There is a need for more research investigating facility design characteristics and management practices on AMS dairy farms in the Upper Midwest U.S and their associations with milk yield, and how a sorbitol-containing pellet affects milk production and AMS metrics in early lactation.

Chapter 2

Association between facility design and management practices and milk yield on farms in the Upper Midwest United States using Automatic Milking Systems

SUMMARY

The objective of this observational study was to investigate the association among facility design characteristics and management practices with milk yield on farms using automatic milking systems (**AMS**). Farms (n=38) were given a questionnaire to gather information on various farm facility design characteristics and herd management practices. All farms enrolled in the study used free flow cow traffic located in Minnesota and Wisconsin, USA. Linear mixed models built by backward elimination showed farm facility design characteristics and management practices associated with milk yield per cow and milk yield per AMS. Characteristics and practices positively associated with milk yield included installing AMS in a newly built barn, using three or one AMS per pen compared to two, installing the AMS at the end or middle of the pen compared to the side, fetching primiparous cows 2 times per day compared to 3 times per day, and using body weight in management decisions. The number of cows per AMS box was negatively associated with milk yield per cow but positively associated with milk yield per AMS. The only herd characteristic negatively associated with milk yield per cow and milk yield per AMS was average DIM. Average lactation age, bedding frequency, breeding protocol category, installation of an automatic manure scraper, barn ventilation type, use of rumination time, use of a pen for fresh cows, and a protocol to train primiparous cows were not associated with milk yield per cow or milk yield per AMS. These findings indicate that various facility design characteristics and herd management practices are used across dairies; we found associations between these and farm milk yield which can point out areas that farmers could focus on to improve AMS success.

Key Words. Automatic milking, milk yield, robotic milking

INTRODUCTION

The adoption of the automatic milking system (AMS) has been on the rise, and in 2015 it was reported that over 25,000 farms had adopted AMS technology (Barkema et al., 2015). Research regarding optimal management strategies for AMS is a topic quickly gaining interest. With this technology constantly improving, various facility design characteristics and management practices formerly associated with the cow and AMS productivity may have been missed or outdated. Milk yield per cow and milk yield per AMS are two measurements that can assess productivity. Research solely investigating facility design characteristics, management practices, and productivity of AMS in the region of the Upper Midwest United States (upper central region of the country including the states of Iowa, Minnesota, Michigan, and Wisconsin) is limited and may be out of date. The upper Midwest has seen an increase in the adoption of this technology, with its first AMS being installed in 2001, and it is estimated that more than 300 farms in this region now use AMS (industry estimates by the authors).

The facility design characteristics in the 2-state region of Minnesota and Wisconsin vary greatly (Salfer et al., 2018). Dairy producers can retrofit the AMS into an existing barn or build new facilities to install AMS. Although retrofitting or building a new facility had no association with milk yield (Siewert et al., 2018; Tremblay et al., 2016), the knowledge base on AMS may have improved since the publication of the previous studies. Potentially, improvements to barn design have been implemented and may increase AMS productivity. However, justifying a facility with no increase in milk yield might be challenging to rationalize, as the initial cost of AMS is the primary concern for producers interested in this system (Hogeveen et al., 2004).

Whether or not AMS will be retrofitted or installed in a new barn, other facility design aspects may be synergistic on AMS farms. Ventilation on dairy farms is essential as the temperature, humidity, and harmful gasses can build up (Callan and Garry, 2002) and cause stress resulting in decreased milk yield. Pens and alleyways accumulate manure and need to be cleaned frequently. Methods to clean these areas are scraping performed by a laborer or an automated manure scraper. Siewert et al. (2018) found that 52% of farms installed automatic scrapers, and Matson et al. (2021) found that the average number of scrapes per day was 12.1 times when using an automatic scraper. No studies have looked directly into the effect of automatic manure scrapers on milk yield, but automatic manure scrapers have been associated with increased locomotion scores (Barker et al., 2007), increased severe hock injuries (Barrientos et al., 2013), and an increase in lameness (Barker et al., 2010) which could decrease milk yield.

Research has been performed on conventional milking system (**CMS**) management practices, but AMS farms require different approaches in management and labor (Steeneveld et al., 2012). The CMS milking process involves an employee retrieving a pen of cows and moving them to a milking parlor, while the AMS relies on voluntary milking by the cow. Training programs have been implemented to familiarize cows, especially primiparous cows, with the AMS, to train them to enter the AMS box and potentially reducing the need for laborious fetching of cows that have surpassed the producer's scheduled milking interval. However, it has been observed that cows take an average of 7 days to adapt to the AMS (Tse et al., 2018), regardless of receiving training (Jacobs and Siegford, 2012; Spolders et al., 2016).

In addition to training programs, management practices in response to changes in cow's activity, body weight (**BW**), and rumination time could assist in achieving optimal milk yield in AMS. Health disorders were associated with decreases in activity (Liboreiro et al., 2015; van Hertem et al., 2013; Weigele et al., 2018), BW (Gáspárdy et al., 2014; King et al., 2017), and rumination time (Devries et al., 2009; Kaufman et al., 2018; Stangaferro et al., 2016). It is important to manage diseases as they were associated with decreased milk yield (Edwards & Tozer, 2004). This study aimed to investigate the association between facility design characteristics and management practices of AMS farms with milk yield per cow and per AMS.

MATERIALS AND METHODS

Farms and Data Collection

Thirty-eight dairy farms in Minnesota and Wisconsin using AMS as the only milking system were enrolled in the current observational study. Potential farms were identified with the help of extension educators, consultants, equipment dealers, and producers. After the identification of farms, producers were contacted, and participation in this study was voluntary. Farms used Lely Astronaut (Lely

Industries NV, Maassluis, the Netherlands) AMS to milk their cows. Herds enrolled in this study were comprised of Holsteins, and all cows were housed in freestall barns with no access to pasture.

Each farm was visited once for data collection during the summer of 2018. Farm managers answered a standardized questionnaire that included questions about the farm's facility design and management practices, including new or retrofitted barn, number of AMS boxes per pen, location of AMS box within pen, installation of an automated manure scraper, barn ventilation type and management practices, including the use of a protocol to train primiparous cows, number of times fetching primiparous cows per day, utilization of activity, BW, and rumination time in management decisions, housing fresh cows in a separate pen, the frequency of bedding stalls and breeding protocols. Retrospective daily farm data was collected from the AMS software (T4C, Lely Industries), including animal identification, date, lactation number, days in milk, and milk yield (kg), for 30 days prior to the farm visit.

Data Processing and Statistical Analysis

All post-collection data management procedures and statistical analyses were performed in RStudio (R Core Team, 2020). Three farms were removed from data analysis due to incomplete questionnaires.

Responses to the questionnaire were categorized with the following levels: ventilation type (natural, cross-ventilated, or tunnel-ventilated), new or retrofitted facility (new or retrofit), location of the AMS (end of the pen, side of the pen, middle of the pen, combination of locations), installation of an automated manure scraper (yes or no), and the number of AMS per pen (1, 2, or 3), use of a training protocol for primiparous cows (yes or no), number of times fetching primiparous cows (2 or 3), utilizing activity in management decisions (yes or no), utilizing BW in management decisions (yes or no), utilizing rumination time in management decisions (yes or no), housing fresh cows in a separate pen (yes or no), frequency of bedding stalls (1, 2, or 3), and breeding protocol intensity (low, medium, or high). Breeding protocol intensity was categorized using the percent of first service cows submitted to a synchronization protocol. Low was considered using a synchronization protocol for 0 to <10% of the cows; medium was considered >= 10% to <=50%; and high was considered >50%. Use of activity was removed from the development of models as all farms used activity.

Daily milk yield per AMS and daily milk yield per cow was obtained from AMS software which summarized data on a daily basis. The AMS software calculated milk yield per AMS by summing the total milk per farm per day and dividing it by the number of AMS on the farm per day. Daily Milk yield per cow was calculated by summing the total milk per farm per day and dividing it by the number of cows on the farm on that day.

Two linear mixed models were built by backward elimination (R, lmerTest package) for milk yield per AMS and milk yield per cow. The initial exploratory model included all explanatory variables and covariates at once with farm as a random effect.

Explanatory variables in the initial exploratory model were: ventilation type, new or retrofitted facility, location of the AMS, installation of automated manure scraper, the number of AMS per pen, use of a training protocol for primiparous cows, number of times fetching primiparous cows, utilizing activity in management decisions , utilizing BW in management decisions, utilizing rumination time in management decisions, housing fresh cows in a separate pen, frequency of bedding stalls, and breeding protocol intensity. As part of a larger project, the current study investigated farm facility design and non-feeding management practices and their associations with milk yield on AMS farms in the Upper Midwest United States. Covariates in the initial exploratory model included average lactation number, average DIM, and the average number of cows per AMS.

The codebook package (R Core Team, 2020) was used to calculate the frequency of ventilation types, new or retrofitted facility, location of the AMS, installation of an automated manure scraper, the number of AMS per pen, use of a training protocol for primiparous cows, number of times fetching primiparous cows, utilizing BW in management decisions, utilizing rumination time in management decisions, housing fresh cows in a separate pen, frequency of bedding stalls, and breeding protocol intensity and compute descriptive statistics. Visually normally distributed data were reported with means ± standard deviation, and nonnormally distributed data were reported with median and interquartile range (**IQR**). The Tukey P-value adjustment was used for pairwise comparisons for categorical variables in the model, and least squares means reported and assigned groups if significant. Statistically significant differences were declared at $P \leq 0.05$.

RESULTS AND DISCUSSION

Descriptive Statistics

Herd characteristics. The average lactation age of the herd was 46.9 ± 4.1 months, average DIM was 170.7 ± 26.4, the median number of cows per farm was 136 (IQR:102), and the average cows per AMS was 60 ± 5.5.

Facility design characteristics. Of the 36 farms used in the analysis, 29% had 1 AMS per pen, 54% had 2 AMS per pen, and 17% had 3 AMS per pen. Fifty-seven percent of the farms had their AMS located at the end of the pen, 20% had their AMS located at the side of the pen, 9% located at the middle of the pen, and 14% had their AMS located at a mix of locations. Forty six percent of the farms retrofitted the AMS, and 54% designed new barns for their AMS. Eighty percent of the farms used automated manure scrapers, whereas only 23% had an area for the fresh cow group. Forty-six percent of the farms used natural ventilation, 26% had cross-ventilation, and 29% had tunnel ventilation.

Management practices. Only 9% of the farms trained their primiparous cows, 69% fetched their primiparous cows 2 times per day, and 31% fetched them 3 times per day. Sixty-nine percent utilized BW, and 80% utilized rumination. Twenty nine percent of farms did not bed their freestalls, 66% bedded their stalls 1 time per week, and 6% bedded 2 times per week. Low, medium and high breeding categories were 54%, 29%, and 17% of the farms, respectively.

Model Results

Final Models. The linear mixed model selected for milk yield per cow and milk yield per AMS both consisted of average DIM, average cows per AMS, using BW in management decisions, number of times fetching primiparous cows, location of AMS Box within pen, the number or AMS per pen, and new or retrofitted facility.

New barns were associated with greater milk yield per cow and milk yield per AMS. New barns produced 40.5 + 1.1 kg/d milk yield per cow and 2,432 + 65.3 kg/d milk yield per AMS, whereas retrofitted barns produced 35.6 + 0.8 kg/d milk yield per cow and 2,141 + 50.5 kg/d milk yield per AMS. Constructing a new barn before installing an AMS compared to fitting an old barn creates the idea that a new barn would be optimally designed for production with AMS. However, previous studies show conflicting results on building new facilities versus retrofitting (Siewert et al., 2018; Tremblay et al., 2016). There may be an advancement lag from the publication of these studies to the current study, suggesting that the knowledge design behind constructing barns with AMS may have found ways to improve yield. With various factors influencing building a new facility or retrofitting existing facilities, it is recommended that the farm evaluates the costs and benefits of retrofitting compared to those of building a new facility before making their decision (Rodenburg, 2010). Whether deciding to install an AMS in an existing facility or constructing a new barn, there are other factors in a barn that need attention. The AMS box takes up space and can interrupt air flow resulting in a decrease of heat abatement or an increase of gaseous build up. Though ventilation type was not significant in the current study, airflow should be monitored post installation of AMS as the retrofitted facilities may not be adjusting current ventilation. An additional aspect that could be resulting in a difference seen in retrofitted and new facilities would be the flooring type and type of manure scraping. The prevalence of automatic manure scrapers in the upper Midwest US has increased compared to Siewert et al. (2018). Automated manure scrapers are recommended in AMS as it might minimize disruption in the pen. On AMS farms, cows are constantly in the pen, so an improvement in pen cleanliness could also reduce cow slippage and encourage more movement and thus improving feed bunk visits and AMS visits. Retrofitted barns would have less flexibility with space, so new barns would have the ability to install separations pens. Separation pens are able to redirect the flow of cows exiting the AMS into a different pen for reasons chosen by the producers. Redirection into a different pen can allow and improvement in cow level management and possibly results in improved production for the cow.

The milk yield per cow for 1 AMS per pen, 2 AMS per pen, and 3 AMS per pen was 38.8 + 1.3 kg/d, 35.7 + 0.8 kg/d, and 39.6 + 1.3 kg/d, respectively. Milk yield per AMS was 2,324 + 76.1 kg/d, 2,149 + 50.6 kg/d, and 2,385 + 76.4 kg/d for 1 AMS per pen, 2 AMS per pen, and 3 AMS per pen, respectively. Having 3 AMS per pen was positively associated with greater milk yield per cow and milk yield per AMS compared to 2 AMS per pen. However, no associations were detected between 1 AMS per pen with 2 AMS per pen. These results differ from Tremblay et al. (2016) showing that 2 AMS and 3 AMS per pen were associated with higher milk yield than just 1 AMS per pen. They noted in their study that as box time and the number of milkings decreased per cow per day, there was a negative association with milk yield. The effect of AMS per pen may depend on number of cows per AMS and box time as there would be less use of the AMS. Siewert et al. (2018) found no associations between 1 AMS per pen and more than 1 AMS per pen. It has been shown that 2 AMS per pen had less milk yield loss when a single AMS unit is out of service for more than a couple of hours compared to 1 AMS per pen (Rodenburg and House, 2007). The milk yield per AMS may depend on the total AMS utilization as more cows or increased visits to the AMS could increase utilization and increase milk yield. Total utilization of the AMS is an important factor to pay attention to. An increase in utilization of the AMS would not necessarily reflect an increase in production, unless it is beneficial use. Producers should not be experiencing a high number of failures, refusals or increased box times due to failure to connect or cows entering the AMS within their given permission. It is also important to account for down time of the AMS when thinking about total utilization. If the pen is set up for the AMS to have no down time, then this would be negatively impacted when routine maintenance or an unpredicted malfunction occurs. The pressure on an individual AMS decreases as an additional AMS is added, but if an AMS would not be functioning, the other AMS in the pen would have increased pressure and the pen would be less productive.

The milk yield per cow for AMS located at the end of the pen, side of the pen, middle of the pen, and mixed was 38.4 + 0.7 kg/d, 34.4 + 1.1 kg/d, 40.6 + 1.9 kg/d, and 38.8 + 1.4 kg/d, respectively. Milk yield per AMS was 2,299 + 44.0 kg/d, 2,067 + 66.6 kg/d, 2,444 + 115.2 kg/d, and 2,335 +82.7 kg/d for AMS located at the end of the pen, side of the pen, middle of the pen, or mixed, respectively. AMS located at the side of the pen yielded less milk per cow and milk per AMS than AMS located at the end of the pen and middle of the pen. No difference was detected between AMS located at the side of the pen and a mix of locations. AMS located at the side of the pen are attached to the pen rather than being within the pen. AMS being attached to the side of the pen may be easier to install in instances of retrofitting, however, in the current study only 29% of AMS installed at the side of the pen were installed in retrofitted barn. With the AMS being on the side of the pen, it may not influence the flow of cows from the free stall, feeding bunk, and the AMS. The AMS being on the side of the pen may result in blockage in alleyways preventing smooth traffic flow or the AMS is not seen by the cows and attracting them. Prevention of cows developing a cyclic routine or interfering with access to the feed bunk, stalls, or AMS may decrease milk yield. Interestingly, all farms with AMS in the middle of the pen are from barns that retrofitted the AMS. This may indicate that retrofitting the AMS does not harm production but it is more of where the AMS is placed within the pen. As mentioned earlier, flooring type may influence mobility within the pen but if cows have a shorter travel distance to access the AMS then this may result in more frequent AMS visits However, AMS installed in the middle of the pen could interfere with airflow within the pen and precautions or adjustments to current ventilation should be taken.

Farms fetching primiparous cows 2 times per day produced 40.0 + 0.9 kg/d milk yield per cow and 2,412 + 51.3 kg/d milk yield per AMS compared to 36.1 + 1.0 kg/d milk yield per cow and 2,160 + 61.1 kg/d milk yield per AMS for farms fetching 3 times per day. Three times per day fetching may be a need rather than a want. Three times per day producers may be experiencing a lack of voluntary milking which is reducing the productivity of the AMS and the cow, meanwhile producers fetching 2 times per day may have cows entering the AMS more voluntarily removing the need to fetch 1 extra time per day. A consideration of the number of voluntary milkings per cow would be the individual’s milk production. If cows are yielding less milk, then they may not desire to be milked compared to their higher producing counterparts. However, a reduction in voluntary milkings would also reduce the number of milkings, which is associated with a decrease in milk yield (Hogeveen et al., 2001). Fetching 3 times per day may also be an attempt to stimulate an increase in the number of milkings which increases milk yield. However, fetching requires a laborer to enter the pen and frequent movements in the pen caused by fetching may disrupt cow behavior, resulting in decreased milk yield. In addition, fetching 2 times per day requires less cow disruption potentially increasing milk yield. It is important for producers to diagnose why there is a low number of voluntary milkings and how to improve this number.

Utilizing BW in management decisions was positively associated with greater milk yield per cow and milk yield per AMS compared to not using BW. Farms using BW produced 39.8 + 1.1 kg/d milk yield per cow and 2,387 + 63.0 kg/d milk yield per AMS compared to 36.3 + 0.7 kg/d milk yield per cow and 2,185 + 43.9 kg/d milk yield per AMS for farms not using BW. Cow’s BW can change as a response to physiological and pathological changes (Maltz et al., 1997), and reductions in BW have been associated with a decrease in milk yield, and a deviation from daily fluctuations appears to be an indicator of health problems (Maltz, 1997). The BW decreases recorded by AMS have been associated with primiparous cows with metritis (Gáspárdy et al., 2014; King et al., 2017), lameness, pneumonia, subclinical ketosis, hoof disorder, and metritis (King et al., 2017).

Besides health problems, decreases in BW are associated with animals entering estrus (Maltz, 1997). Utilizing BW as a tool has various implementations in management.

The average DIM was negatively associated with milk yield per cow (P<0.0001) (Table 1) and milk yield per AMS (P<0.0001) (Table 2). Similar studies did not include average DIM in their models investigating milk yield (Castro et al., 2022; Siewert et al., 2018). However, Siewert et al. (2018) removed average DIM from their milk yield per AMS final model but found a negative association in the milk yield per cow model. Lactation curves of dairy cows indicate that cows reach peak milk yield four to eight weeks after calving and decrease afterward (García and Holmes, 2001; Macciotta et al., 2005; Silvestre et al., 2009). The average DIM in the current study was 171, which is well after peak milk yield and this may explain the negative association as milk yield decreases after the milk yield peak. Herds can decrease average herd DIM by improving their reproduction management, resulting in their cows getting pregnant sooner. Improving reproduction would decrease average DIM, keeping cows in the ideal DIM range of 175-180 days (Ishler, 2019) by decreasing calving interval, which is negatively associated with a productive life, cash flow, and lifetime profit (Do et al., 2013; Gonzá Lez-Recio et al., 2004; Graves et al., 2017). Striving for the average DIM of the herd to be below 175-180 DIM can keep the herd in the profitability zone.

The number of cows per AMS was negatively associated with milk yield per cow (Table 1) but positively associated with milk yield per AMS (Table 2). Previous literature shows a positive association between the number of cows per

AMS and milk yield per cow (Siewert et al., 2018; Tremblay et al., 2016). However, the average number of cows per AMS was 55.8 cows (Siewert et al., 2018) and 47.5 cows (Tremblay et al., 2016) in the comparing studies compared to 60 cows in the current study. On the other hand, the positive association between the number of cows and milk yield per AMS could be expected; as with more cows, higher amounts of milk would be distributed across fewer AMS as similar results were shown in other studies (Siewert et al., 2018; Tremblay et al., 2016). Siewert et al. (2018) approached the recommendation of 60 cows per AMS Rodenburg. (2017). However, Castro et al. (2012) suggested 68 cows per AMS as the maximum number. The current study averaged at the 60 cow per AMS recommendation and showed that the number of cows was negatively associated with milk yield per cow but positively associated with milk yield per AMS. The stocking density seen in the current study may imply that it is not optimal for the cow but is still productive for the AMS. Other factors could be playing a role in the AMS stocking density, such as average DIM and time since transition. Pens with higher DIM may have more cows with reduced udder pressure, reducing their voluntary milking frequency. In addition, herds that recently transitioned to AMS from CMS that were milking 2 times per day may have cows familiar with milking 2 times per day (Wagner-Storch and Palmer, 2003). All of these factors need to be considered in evaluating total utilization of the AMS. Proper utilization of the AMS and planned AMS down time is an important factor determining the number of cows per AMS effect on milk yield.

CONCLUSIONS

Facility design characteristics and management strategies were found to be associated with milk yield on AMS dairy farms in the current study, all of which could be considered before the installation of an AMS. Designing a new barn before the installation of AMS using new recommendations appears to increase milk yield along with installing 1 or 3 AMS per pen either at the end or middle of the pen. Fetching cows fewer times and monitoring body weight are all management practices that appeared to improve milk yield.

Chapter 3

Effects of feeding a sorbitol-containing additive to dairy cows for 30 days postpartum

SUMMARY

The objective of this study was to determine the effects of early postpartum supplementation of a sorbitol-containing feed additive (**RAL**) on lactation performance and automatic milking system (**AMS**) metrics on a commercial dairy farm. Multiparous (**MP**) and primiparous (**PP**) Holstein cows were randomly assigned to either RAL supplementation (**RAL-MP**, n = 75, **RAL-PP**, n = 34) or control (**CTL-MP**, n = 72, **CTL-PP**, n = 38). The RAL cows were supplemented from 1 – 30 days in milk (**DIM**) via an automated feed dispenser in the AMS and their milk production and other metrics were recorded for 1 – 90 DIM along with CTL cows not receiving supplementation. The analysis was conducted separately for the 2 periods of supplementation (1-30 DIM) or post-supplementation (31 to 90 DIM). Supplementation period daily milk yield was 2.29 kg higher overall for RAL and 3.00 kg higher for RAL-MP compared to CTL-MP. Supplementation period daily energy-corrected milk (**ECM**) yield was 2.33 kg higher overall for RAL and 3.52 kg higher for RAL-MP compared to CTL-MP. Supplementation period daily protein yield was 0.08 kg higher overall for RAL and 0.10 kg higher for RAL-MP than CTL-MP. Supplementation period daily fat yield was 0.08 kg higher overall for RAL and 0.14 kg higher for RAL-MP than CTL-MP. The number of refusal visits/day during the supplementation period was 0.35 refusal visits less for RAL, and RAL-MP had 0.66 fewer refusal visits than CTL-MP. Daily milk yield, ECM yield, fat and protein yield, number of refusal visits/ day were similar for RAL-PP cows and CTL-PP cows during the supplementation period. During the supplementation period, milking time, milking speed, milking interval, box time, rumination time, and the number of milkings per day were similar between RAL and CTL. During the post supplementation period, daily milk yield was 1.89 kg higher overall for RAL, 1.99 kg higher for RAL-MP compared to CTL-MP. Post supplementation daily ECM yield was 2.17 kg higher for RAL-MP compared to CTL-MP, but similar between RAL and CTL. Post supplementation daily protein yield was 0.07 kg higher for RAL compared to CTL, 0.07 kg higher for RAL-MP compared to CTL-MP. Post supplementation fat yield was 0.08 kg higher for RAL-MP compared to CTL-MP. Rumination time during the post supplementation period was 12.5 minutes less for RAL-MP than CTL-MP, but similar for RAL and CTL. The number of refusal visits/day during the post supplementation was 0.59 fewer visits for RAL-MP compared to CTL-MP, but similar for RAL and CTL. Daily milk yield, ECM yield, fat and protein yield, rumination time, number of refusal visits per day during the post supplementation period were similar between RAL-PP cows and CTL-PP cows. During the post supplementation period, milking time, milking speed, milking interval, box time, and the number of milkings were similar between RAL and CTL. The results from this study indicate that RAL supplementation during the first 30 DIM would increase milk yield when fed to multiparous cows.

INTRODUCTION

The window ranging from three weeks before until three weeks after calving is referred to as the transition period (Drackley, 1999). During this time, the cow undergoes massive physiologic stress caused by the growing fetus, the process of parturition including immunologic suppression, to meeting demands of genetically selected high milk yield. It has been estimated that 50% of dairy cows experience a metabolic or infectious disease (classified as transition disease) around the time of calving (Baumgard et al., 2017). Dry matter intake (**DMI)** is depressed prior to calving (Bertics et al., 1992) and starts to recover at a rate of 1.5 to 2.5 kg per week after calving (Grant and Albright, 1995). With this decrease in DMI, the cow enters a negative energy balance where she begins mobilizing body nutrient reserves to meet the net energy requirement (Bauman and Currie, 1980). A zero net energy balance is achieved when her milk yield is 80% of her peak milk production.

With the conventional milking process being labor intensive, producers are transitioning to Automatic Milking Systems (**AMS**) (de Koning & Rodenburg, 2004). AMS technology is constantly improving and provides daily information at a cow level, allowing the individual cow management of the herd. Literature has shown that more frequent milking in AMS is associated with increased milk production (Tremblay et al., 2016). It is speculative that this increase in milk yield could result from higher concentrate consumption in the AMS or from more visits to the feed bunk to consume the partial mixed ration. Therefore, the combination of transition management practices and AMS technology may reduce the transition period's negative impact and improve milk yield.

A feed additive containing sorbitol (sugar alcohol) (Rally©, Purina Animal Nutrition, Arden Hills, MN; **RAL**) has been investigated in transitioning multiparous cows fed via TMR and resulted in higher percentages of milk protein, total solids, lactose, fat and higher fat-corrected milk (Porter et al., 2004). Another study showed that multiparous cows receiving sorbitol and mannitol three weeks prior to calving had increased milk yield but less protein content, yet total milk protein yield was not affected (McFadden et al., 2008). These results overlap with a patent showing that DMI was lower, yet milk yield was greater, for sorbitol-fed cows compared to a control group (Luhman, 2002). Production records from CMS commercial herds showed an improved milk yield, fat percentage, and protein percentage for 1-60 DIM after introducing RAL (Porter et al., 2004). The objective of the current study was to investigate the effects of a sorbitol-containing feed additive fed in an AMS for 30 days after calving on milk yield, ECM yield, fat yield, protein yield, and metrics recorded by the AMS.

MATERIALS AND METHODS

Animals and Treatments

This study was conducted on a commercial dairy farm in Minnesota between December 2021 and August 2022. The study protocol was approved by the University of Minnesota Institutional Animal Care and Use Committee (protocol number 2111-39583A).

A total of 219 Holstein dairy cows consisting of 72 primiparous (PP) cows and 147 multiparous (MP) cows were used in the study. Cows were randomly assigned to either a base diet/control group (CTL) or a group that had the inclusion of Rally (RAL) from 1 to 30 DIM with 34 PP cows assigned to RAL (RAL-PP), 38 PP cows assigned to CTL (CTL-PP), 75 MP cows assigned to RAL (RAL-MP) and 72 MP cows assigned to CTL (CTL-MP). The proportion of PP to MP animals was chosen based on the proportion maintained on the farm. The initial number of cows enrolled in the study was 248, but 29 cows were culled prior to 90 DIM for reasons not related to the study and were removed from the final dataset as they had incomplete data. There was no difference on the number of cows removed according to treatment (RAL or CTL).

Management and supplementation

Animals in the study were housed in 4 pens of equal size, and animals within each pen had access to two Lely A4 Astronaut (Lely Industries, Maassluis, The Netherlands) AMS. Animals were randomly assigned to pens based on the producer’s management. PP cows were placed into one pen, while bigger PP and 2nd lactation cows were placed in another pen and pens 3 and 4 were filled with 2nd lactation and greater based on space availability. Researchers were blind to the treatments until the end of the study after all the data were collected by the AMS software (T4C; Lely, Maassluis, The Netherlands). The free flow traffic system allowed all the cows constant access to the AMS in each pen. On calving day, PP and MP were in a calving pen and then allocated to the other pens based on the producer's discretion.

After calving, all animals were offered the same partial mixed ration (PMR) delivered between 07:00 and 08:00 AM. The PMR was reviewed and adjusted by the farm’s nutritionist to ensure similar nutrient composition over the study. In addition, all cows were supplemented with a commercial fatty acid pellet (Propel, Purina-LOL, Arden Hills, MN) dispensed in the AMS during the first 30 DIM adjusted for milk yield. The RAL cows were supplemented with 570 g of Rally/day for the first 30 DIM using an additional automatic feed dispenser in the AMS.

Data collection

Milk yield was recorded by the AMS software for each milking visit. Milk fat and protein percentages were estimated at each milking by the AMS in-line measurement system (MQC2: Milk Quality Control, type 2; Lely, Maassluis, The Netherlands) and then recorded as daily percentages. Milk fat and protein calibration was performed on a routine basis by the dairy producer using bulk tank records. The AMS software also recorded the daily number of milkings and number of refusal visits and each visit's milking time, box time, milking interval, milking speed, and daily rumination time.

Health records were obtained at the end of the study period. Health protocols and health records were managed and maintained by the farm staff. Cow diagnosis was carried out at the discretion of the veterinarian and producer, and the producers administered treatments and culled cows as needed.

Blood was collected from each cow's coccygeal (tail) vein at 4-10 and 24-30 DIM using a 20G × 1 1/2 " aluminum hub needle. Immediately after collection, a drop of blood was used to measure the β-hydroxybutyrate (BHB) concentration using a BHBCheck Bovine Blood Ketone Test Monitor (PortaCheck Inc, Mooristown, NJ).

Individual cow body condition scores (BCS) were collected at 4-10 DIM and 24-30 DIM on a scale of 1 – 5 (1= thin, 5= obese) on a 0.25 increment level (Ferguson et al., 1994) by one single trained observer throughout the study.

Statistical Analysis

Sample size was calculated using a detectable difference of 2.0 kg/d, a standard deviation of 5.30 kg/d, an alpha level of 0.05 and a beta level of 0.2 based on previous research utilizing sorbitol (LOL-Purina)**.** A minimum of 110 cows per group was calculated as the number needed to detect the difference and the sample size was inflated by 13% to account for culling.

Multiple statistical analyses were performed for production and AMS metrics data. Two models were constructed investigating the effects of RAL supplementation: Supplementation period (1 DIM to 30 DIM) and post-supplementation period (31 DIM to 90 DIM), similarly to the methodology of Chandler et al. (2017). Visit data were aggregated into daily values. Daily milk yield, fat percentage, protein percentage, number of milkings, number of refusals, milking time, milking speed, box time, and milking interval were then calculated into weekly averages of daily values beginning on 1 DIM through 90 DIM. Weekly averages of fat yield and protein yield were calculated by multiplying weekly average milk yield and weekly average fat percentage to obtain weekly average fat yield, and weekly average milk yield was multiplied by weekly average protein percentage to obtain weekly protein yield. Energy corrected milk (ECM) was calculated by the formula (0.327 *milk lbs + 12.95*Fat lbs + 7.2*Protein lbs) (Michael, 2014). Post conversions, all measurements recorded in lbs were converted to kg. Weekly box time, milking interval, milking time, and milking speed were searched for outliers, and any weekly observation that was 1.5*IQR ± the median was removed from the dataset.

BHB concentrations and BCS were split into CTL cows and RAL cows and compared using a 2-sample T-Test (R, stats package). BHB and BCS are reported as average and standard deviation. Weekly milk yield, ECM yield, fat yield, protein yield, rumination time, milking time, box time, milking interval, number of milkings, milking speed, and number of refusals were analyzed using the LMER function (R, lme4 package) with repeated measures. The model accounted for the fixed effects of treatment, week, parity, treatment × week, and treatment × parity and the random effect of cow. If treatment effect or treatment × week was significant, then the Pairs function (R, emmeans package) was used to compare treatment differences at individual weeks.

The least-square means and standard errors are reported in all analyses. $P \leq 0.05$ was used as the significance level for the treatment effect, and $P \leq 0.10$ was used to indicate a trend.

RESULTS AND DISCUSSION

Body Condition Score, BHB

The BCS collected between 4-10 DIM for RAL cows was 3.18 ± 0.22 and CTL cows was 3.21 ± 0.21, which did not differ ($P = 0.23$). The RAL-MP cows and CTL-MP cows had averages of 3.15 ± 0.22 and 3.17 ± 0.20, respectively, and did not differ ($P = 0.59$). The RAL-PP cows and CTL-PP cows had averages of 3.23 ± 0.21 and 3.29 ± 0.19, respectively, and did not differ ($P = 0.25$). The BCS collected between 24-30 DIM for RAL cows was 3.09 ± 0.23 and CTL cows was 3.13 ± 0.22 and were similar (*P* = 0.22). The RAL-MP cows and CTL-MP cows had averages of 3.03 ± 0.23 and 3.06 ± 0.22, respectively, and did not differ (P = 0.44). Also, RAL-PP cows and CTL-PP cows had averages of 3.21 ± 0.16 and 3.24 ± 0.15, respectively, and did not differ (P = 0.39).

The BHB concentration between 4-10 DIM for RAL cows was 0.61 ± 0.33 mmol/L and CTL cows was 0.55 ± 0.34 mmol/L, which were similar (P = 0.19). RAL-MP cows and CTL-MP cows were 0.68 ± 0.35 mmol/L and 0.59 ± 0.35 mmol/L, respectively, and did not differ (P = 0.11). Also, RAL-PP cows and CTL-PP cows had averages of 0.44 ± 0.21 mmol/L and 0.47 ± 0.31 mmol/L, respectively, and did not differ (P = 0.66). The BHB concentration between 24-30 DIM for RAL cows was 0.54 ± 0.23 mmol/L and CTL cows was 0.57 ± 0.22 mmol/L, which were similar (P = 0.53). RAL-MP cows and CTL-MP cows were 0.59 ± 0.23 mmol/L and 0.62 ± 0.22 mmol/L, respectively, and did not differ (P = 0.67). RAL-PP cows and CTL-PP cows had averages of 0.41 ± 0.16 mmol/L and 0.46 ± 0.15 mmol/L, respectively, and did not differ (P = 0.32).

No BCS or BHB sampling showed a difference between treatments. Average BHB within treatments was below 1.2 mmol/L, the most commonly accepted value of ketosis diagnosis (Benedet et al., 2019). Porter et al. (2004) showed that 10 DIM BHB levels were similar in MP animals supplemented with RAL and those in CTL, also shown in the current study. BCS and BHB being similar shows that treatments were balanced within these two measures.

Supplementation Period

Production performance data during the supplementation and post-supplementation period are presented in Table 3, Table 4, and Table 5, for RAL vs CTL, RAL-MP vs CTL-MP, and RAL-PP and CTL-PP, respectively. AMS metric performance data during the supplementation and post-supplementation period are presented in Table 6, Table 7, and Table 8, for RAL vs CTL, RAL-MP vs CTL-MP, and RAL-PP and CTL-PP, respectively. During RAL supplementation for 30 days, RAL cows produced 2.29 ± 1.04 kg/day more milk than CTL cows ($P = 0.03$), and a treatment × week interaction was detected. The RAL-MP cows produced 3.00 ± 1.19 kg/ day more milk than CTL-MP cows ($P = 0.01$); meanwhile RAL-PP cows and CTL-PP cows were similar ($P = 0.35$). In addition, RAL-MP cows tended to produce more milk on week 2 ($P = 0.06$) and produced more milk on weeks 3, 4, and 5 ($P < 0.01$) (Figure 1).

Our study shows that RAL supplementation increased milk yield for multiparous cows. The increase in milk yield began at 2 weeks and continued throughout the supplementation period. The detection of an effect not beginning on week 1 may result from an adaptation to lactation or the time for RAL to have an effect. Supplementation with RAL has been shown to improve MP cows' milk yield and not affect PP cows' milk yield (Porter et al., 2004), but this was from an evaluation of production records, not a controlled experiment. In addition to the evaluation of production records, Porter et al. (2004) fed RAL at 21 days pre-calving through 21 days post-calving and showed an increase in milk yield. The feeding of RAL before calving may not be needed as there was an increase in milk yield in the current study, which fed RAL starting at 1 DIM. Also, the diets for all pens were formulated the same. It is likely that the diet may have met the required energy demand for both PP groups.

Meanwhile, RAL-MP cows may have experienced improved feed efficiency from the supplementation of RAL, possibly explaining the increase in milk yield. Improved feed efficiency has been shown in beef bull calves and finishing steers supplemented with sorbitol (Fontenot and Huchette, 1993; Geay et al., 1992) which could potentially explain an increase in milk yield for RAL-MP cows. Also, sorbitol may explain the increase in milk yield as readily fermented carbohydrates may increase milk yield (Schingoethe, 1996). However, it may not have been seen in RAL-PP cows as they were consuming a similar diet as MP, which provides greater energy than a diet rationed solely for PP cows. In addition, the sample size was smaller for PP in the current study.

During RAL supplementation for 30 days, RAL cows produced 2.33 ± 1.13 kg/ day more ECM compared to CTL cows ($P = 0.04$). A treatment × week interaction was detected ($P = 0.10$). The RAL-MP cows produced 3.52 ± 1.29 kg/ day more ECM than CTL-MP cows ($P = 0.01$), meanwhile RAL-PP cows and CTL-PP cows were similar ($P = 0.54$). The RAL-MP cows tended to yield more ECM on week 1 ($P = 0.07$) and produced more ECM on weeks 2, 3, 4, and 5 ($P < 0.02$) than CTL-MP cows (Figure 2).

Similarly to milk yield, our study shows that ECM yield was increased by RAL supplementation for MP cows. The ECM yield had a tendency to be higher on week 1and was increased following throughout the supplementation period. RAL started having a positive effect on ECM yield starting at week 1, but an increase in milk yield became detected on week 2, implying an increase in fat and/or protein yield occurring during week 1.

During RAL supplementation for 30 days, RAL cows produced 0.08 ± 0.03 kg/ day more protein than CTL cows (P = 0.02). The RAL-MP cows produced 0.10 ± 0.04 kg/ day more protein than CTL-MP cows (P = 0.01), meanwhile RAL-PP cows and CTL-PP cows were similar (P = 0.29). The RAL-MP cows tended to yield more protein on week 1 (P = 0.07) and produced more on weeks 2, 3, 4, and 5 (P < 0.04) (Figure 3).

Protein yield was higher for RAL-MP cows starting week 1 and maintained higher throughout the supplementation period than for CTL-MP cows. Again, sorbitol may explain the increase in protein yield for RAL-MP cows was readily fermented carbohydrates increase milk protein content (Schingoethe, 1996). Alternatively, a study showed that sheep rumen fluid supplemented with polyol compared to pre-polyol supplementation had an increase in propionate production (Lister and Smithard, 1984), and propionate is correlated to an increase in protein yield (Seymour et al., 2005). Though the increase in propionate was found in sheep, we suggest that this may also occur in the lactating cow rumen. . Increased milk protein yield may be due to improved cows energy supply and the flow of microbial protein entering the lower intestinal tract (Doepel et al., 2004; Emery, 1978), though the mammary glands blood flow and its ability to use amino acids play a role in milk protein yield (Mcdonald et al., 2002). Propionate assists in sparing glucogeneic amino acids intended for gluconeogenesis (Seal & Parker,

1994) and reduces the maintenance costs of metabolizable protein (van Soest, 1994). Although DMI was not measured in this study, increased rumen function, amino acid sparing, increased DMI, or a combination of these factors may contribute to an increase in milk protein yield.

During RAL supplementation for 30 days, RAL cows fat yield was similar to CTL cows ($P = 0.11$). However, RAL-MP cows produced 0.14 ± 0.05 kg/ day more fat than CTL-MP cows ($P = 0.01$) and RAL-PP cows and CTL-PP cows were similar ($P = 0.85$). The RAL-MP cows tended to yield more fat on week 1 ($P = 0.07$) and produced more fat on weeks 2, 3, 4, and 5 ($P < 0.02$) (Figure 4.).

The RAL-MP cows had greater milk fat yield on week 1, and this increase continued throughout the supplementation period. As noted earlier, propionate production or absorption does increase with polyols being fed. However, it should be noted that after 3 weeks of sorbitol supplementation, fermentation shifts from propionate to acetate (Lister and Smithard, 1984), and propionate numerically decreases from its pre-exposure level. Acetate production by fermentation supplied an estimated 55% of net energy absorbed as short chain fatty acids (Sutton et al., 2003). Ruminant adipose and mammary tissue utilize acetate as the major carbon source for lipid synthesis (Bauman et al., 1970; Hanson & Ballard, 1967) and is suggested that acetate may impact milk fat yield (Urrutia & Harvatine, 2017). A potential increase in acetate may explain the increase in fat yield as acetate is correlated to fat yield in milk (Seymour et al., 2005), and it was found that fat yield is increased quadratically from acetate supplementation (Urrutia and Harvatine, 2017). . Milk fatty acid profile may be of interest in further studies to identify if the increase in milk fat yield is coming from preformed fatty acids or de novo synthesis.

During RAL supplementation for 30 days, RAL cows rumination was similar to CTL cows (P =0.84). Likewise, RAL-MP cows was rumination time was similar to CTL-MP cows (P = 0.20), along with RAL-PP cows being similar to CTL-PP cows (P = 0.52). However, rumination time tended to be 18 ± 11.1 minutes less on week 1 for RAL-MP cows compared to CTL-MP cows (P = 0.10). Rumination time may not have a detected difference between treatments or between treatments within parity as the sample size may not be large enough to detect a difference. A difference in rumination time may be detected in a larger sample size.

During RAL supplementation for 30 days, RAL cows box time was similar to CTL cows (P = 0.34). The RAL-MP cows box time was similar to CTL-MP cows (P = 0.67), as was RAL-PP cows to CTL-PP cows (P = 0.38).

During the supplementation period, no week showed any difference in box time. However, with the current amount of records the authors do not believe the sample size is large enough to detect a difference. A similar box time may indicate that RAL may be assisting with keeping cows more quiet with quicker teat cup attachment as RAL-MP cows resulted in greater milk yield but had similar box time to CTL-MP cows. Future studies may examine cow interactions within the box to test this hypothesis.

During RAL supplementation for 30 days, RAL cows milking interval did not differ compared to CTL cows (P = 0.71). The RAL-MP cows milking interval was similar to CTL-MP cows (P = 0.54), as was RAL-PP cows compared to CTL-PP cows (P = 0.98). During the supplementation period, no week showed any difference in milking interval. Milking interval is influenced by the producers set milking interval permission and the frequency of fetching cows. However, individual cow milking interval is given flexibility by producers during early lactation.

During RAL supplementation for 30 days, RAL cows number of milkings did not differ from CTL cows (P = 0.65). The RAL-MP cows number of milkings was similar to CTL-MP cows (P = 0.54), and the same result was found for RAL-PP cows compared to CTL-PP cows (P = 0.91). During the supplementation period, no week showed any difference in number of milkings. With the number of milkings being similar along with the milking interval, the producer’s milking permissions may be playing a role in limiting the number of milkings and the milking interval duration.

During RAL supplementation for 30 days, RAL cows milking time did not differ compared to CTL cows (P = 0.29). Likewise, the RAL-MP cows milking time did not differ from CTL-MP cows (P = 0.63), nor did RAL-PP cows compared to CTL-PP cows (P = 0.34). During the supplementation period, no week showed any difference in milking time. Similarly to box time, the sample size may not be large enough to detect a difference between RAL cows and CTL cows. Milking time is influenced by total milk and the speed of which milk is released. Similar times but an increase in total milk yield by RAL cows may indicate an increase in milking speed or that milking time was increased for RAL cows but was not detected. A study utilizing a larger sample size is suggested for further investigation to possibly detect a difference.

During RAL supplementation for 30 days, RAL cows milking speed did not differ compared to CTL cows (P = 0.83). Likewise, the RAL-MP cows milking speed did not differ from CTL-MP cows (P = 0.32), nor did RAL-PP cows compared to CTL-PP cows (P = 0.66). During the supplementation period, no week showed any difference in milking speed. The RAL cows produced greater milk than CTL cows, but had similar milking time, so authors speculate that the sample size is not large enough to detect a difference in milking speed or a difference in milking time. If the theory that box time is decreased due to RAL helping cows remain calmer during treatment may show a pleasure sensation reflex from an increase in release of oxytocin secretions(Chen & Sato, 2017) Oxytocin release results in the continual ejection of milk (Bruckmaier & Blum, 1998) and an increase in oxytocin stimulation may result in faster milk let down. However, milking speed may be the same, but milking time is increased but not detectable.

During RAL supplementation for 30 days, RAL cows tended to have 0.35 ± 0.21 fewer AMS refusal visits/ day compared to CTL cows (P = 0.10). The RAL-MP cows had 0.66 ± 0.24 fewer refusal visits/ day than CTL-MP cows (P = 0.01). Meanwhile, RAL-PP cows and CTL-PP cows had a number of refusal visits/ day (P = 0.88). The RAL-MP cows had fewer refusal visits/ day on weeks 1, 2, and 4 (P < 0.04) and tended to have fewer visits on week 5 (P = 0.10) (Figure 5).

Overall, RAL cows experienced fewer AMS refusal visits/ day compared to CTL cows, as well as RAL-MP cows having fewer refusal visits/ day than CTL-

MP cows. The decrease in refusal visits may be due to increased feed efficiency (Fontenot and Huchette, 1993; Geay et al., 1992). McFadden et al. (2008) speculated that sorbitol may increase papillae growth by an unknown mechanism, or sorbitol may be shifting rumen microbiome into populations of higher microbes with degradation products of propionate and acetate (Lister & Smithard, 1984). Sorbitol may be acting similar to the mechanism of Monensin. Monensin is an ionophore and increases propionate producing bacteria (Ogunade et al., 2018) while decreasing methane (Appuhamy et al., 2013) and lactate production (Dennis et al., 1981). An study showed that supplementing RAL and Monensin in combination increased DMI pre fresh, fat-corrected milk during the first 4 weeks of lactation, with similar BCS score changes compared to Monensin alone (LOL-Purina, pers. comm, Arden Hills, MN).These results may indicate that cows in the current study may be consuming more PMR, reducing the need for concentrate intake from the AMS, or that satiety is increased by RAL supplementation, leading to decreased visits as evidence shows that feeding is the main incentive for entering the AMS (Bach et al., 2007; Prescott et al., 1998; Scott et al., 2014). Future studies using RAL in AMS should measure DMI in both the PMR and the AMS.

Post Supplementation Period

During the post supplementation period for 60 days, RAL cows tended to yield 1.89 ± 1.0 kg/ day more milk than CTL cow ($P = 0.06$). A treatment × week interaction tended to be detected ($P = 0.06$). The RAL-MP cows tended to yield 1.99 ± 1.15 kg/ day more milk than CTL-MP cows ($P = 0.08$). Meanwhile, RAL-PP cows and CTL-PP cows were similar ($P = 0.27$). The RAL-MP cows produced greater milk on weeks 5, 6, and 7 ($P < 0.05$) and tended to yield more on week 8 ($P = 0.07$) (Figure 6).

The RAL cows tended to show an increase in milk yield over the 60 days after supplementation ceased, but the effect was lost 4 weeks after stopping RAL supplementation. The carryover effect of RAL supplementation was no longer observed at week 9 for MP cows. The loss of carryover effect may be due to a change of the rumen microorganisms, as suggested by Lister and Smithard (1984), who reported that it took 3 weeks to see a change after supplementation of polyols. Current literature recommends rumen adaptation periods from 14 d (Machado et al., 2016) to 28 d (Molero et al., 2004), which may explain the effects no longer being observed after 4 weeks. Halting RAL supplementation appears to have returned milk yield to CTL levels, and we suggest that if RAL supplementation continued, milk yield would continue to be greater for MP cows. The mechanism behind RAL is not currently understood, although the authors speculate a change in the rumen microbiome favoring milk yield but further supplementation may maintain the increasing milk yield environment. However, further research is needed to test this hypothesis.

During the post supplementation period for 60 days, RAL cow ECM yield was similar to CTL cows ($P = 0.12$). A treatment × week interaction was detected ($P = 0.01$). The RAL-MP cows produced 2.17 ± 1.11 kg/ day more ECM than CTL-MP cows ($P = 0.05$), meanwhile RAL-PP cows and CTL-PP cows ECM yield were similar ($P = 0.58$). The RAL-MP cows produced greater ECM on weeks 5, 6, 7, and 8 ($P < 0.05$) (Figure 7).

The RAL cows showed an increase in ECM yield over 60 days after stopping supplementation. However, similarly to milk yield, the increase in milk yield was no longer detected starting in week 9 for MP cows, indicating that RAL supplementation may have a carryover effect up to a point. Similarly to the increase in milk yield, the RAL cows' rumen microbiome may be reverting back to a similar population as CTL cows showing the cessation of an increase in ECM.

During the post supplementation period for 60 days, RAL cows produced 0.07 ± 0.03 kg/ day more protein than CTL cows ($P = 0.03$). The RAL-MP cows produced 0.07 ± 0.03 kg/ day more protein than CTL-MP cows ($P = 0.04$). Meanwhile, RAL-PP cows protein yield was similar to CTL-PP cows ($P = 0.22$). The RAL-MP cows yielded greater protein on weeks 5, 6, 7, 8 and tended to yield more on week 9 ($P = 0.09$) (Figure 8).

The RAL cows showed an increased protein yield during the post supplementation period and is detected in the protein yield of MP cows. The increase in protein yield was detected on week 5 and continued until the end of week 9. The carryover effect of RAL supplementation on protein yield was no longer observed at week 10 for MP cows. Though milk yield and ECM yield were similar on wk 9, there may be a delay in reverting the rumen microbiome back to similar microbes as CTL cows for milk protein yield when supplemented with RAL.

During the post supplementation period for 60 days, RAL cows milk fat yield was similar to CTL cows ($P = 0.42$). A treatment × week interaction was detected ($P = 0.003$). The RAL-MP cows tended to yield 0.08 ± 0.05 kg/ day more fat than

CTL-MP cows (P = 0.10), meanwhile RAL-PP cows was similar to CTL-MP cows (P = 0.87). The RAL-MP cows yielded greater fat on weeks 5, 6, and 7 (P < 0.04) and tended to yield greater fat on week 8 (P = 0.09) (Figure 9).

There was an increase in milk fat yield for RAL-MP cows compared to CTL-MP cows that was detected on week 5 and continued through week 8. The carryover effect of RAL supplementation on fat yield vanishes at week 9 for MP cows, which was the same as milk yield and ECM yield but was 1 week earlier than protein yield. Fat yield increase after stopping supplementation ceasing at week 9 may explain why ECM was the same, although protein yield was higher in week 10. Again, sorbitol supplementation for 3 weeks resulted in a decrease in propionate and an increase in acetate (Lister and Smithard, 1984). So, the rumen may be reverting to increased propionate levels as lower acetate levels are associated with lower fat yield (Seymour et al., 2005) which would be seen with increased protein yield and a decrease in fat yield. .

During the post supplementation period for 60 days, RAL cows rumination time was similar to CTL cows (P = 0.97). The RAL-MP cows rumination time tended to be 12.5 ± 7.69 minutes/ day less than CTL-MP cows (P = 0.10). Meanwhile, RAL-PP cows rumination time was similar to CTL-PP cows (P = 0.24). The RAL-MP cows tended to ruminate less on week 7 and 8 (P < 0.10) and ruminated less on week 9 (P = 0.05) (Figure 10).

Post supplementation of RAL, MP cows had a reduction in rumination, however the difference was small and most likely not biologically significant. The decrease in rumination may be due to the potential increase in feed efficiency resulting in less DMI. Again, a limitation of this study is that the PMR intake is unknown.

During the post supplementation period for 60 days, RAL cows box time was similar to CTL (P = 0.77). Likewise, RAL-MP cows box time was similar to CTL-MP cows (P = 0.93), as was RAL-PP cows to CTL-PP cows (P = 0.76) during the post supplementation period; no week showed any difference in box time. Mentioned earlier, on weeks where milk yield was greater for RAL cows, the authors suggest a similar box time may indicate that RAL is having an effect on the cows to allow quicker teat cup attachment. RAL may be serving a pleasure response reflex in cows supplemented with RAL explaining calmer cows; however, this was not measured in this study. Future studies could monitor cow activity within the box.

During the post supplementation period for 60 days, the milking interval was similar between RAL cows and CTL cows (P = 0.93). Likewise, the RAL-MP cows milking interval was similar to CTL-MP cows (P = 0.59), as was RAL-PP cows compared to CTL-PP cows (P = 0.63). During the post supplementation period, no week showed any difference in milking interval. As mentioned earlier, producers may set a milking interval permission and set a frequency of fetching cows, and these may influence the individual cows milking interval. However, later in lactation there is less flexibility with the milking interval compared to early lactation.

During the post supplementation period for 60 days, the RAL cows number of milkings was similar to CTL cows (P = 0.96). Likewise, the RAL-MP cows number of milkings was similar to CTL-MP cows (P = 0.49), as was RAL-PP cows compared to CTL-PP cows (P = 0.58). During the post supplementation period, no week showed any difference in number of milkings. Similarly to the milking interval, the number of milkings and the milking interval is preset by the producer, so these number may be caused to be similar by the producers used permissions.

During the post supplementation period for 60 days, the RAL cows milking time was similar to CTL cows (P = 0.71). Likewise, the RAL-MP cows milking time was similar to CTL-MP cows (P = 0.93), as was RAL-PP cows compared to CTL-PP cows (P = 0.69). During the post supplementation period, no week showed any difference in milking time. Mentioned earlier during the supplementation period, on weeks where milk yield was greater for RAL cows, the authors suggest that either the sample size was too small to detect a difference in milking time or RAL is influencing the total time spent milking. The milking time or milking speed would have to be different as there is an increase in milk yield from the cow.

During the post supplementation period for 60 days, the RAL cows milking speed was similar to CTL cows (P = 0.93). Likewise, the RAL-MP cows number of milkings was similar to CTL-MP cows (P = 0.59), as was RAL-PP cows compared to CTL-PP cows (P = 0.63). During the post supplementation period, no week showed any difference in milking speed. An increase in milking speed would serve as a way to explain why RAL cows and CTL cows have similar milking times but RAL cows having an increase in milk yield. An increase in sample size may be able to detect a difference in box time and milking time or detect a difference in milking speed as the authors suggest that there biologically has to be a difference in one of the variables mentioned.

During the post supplementation period for 60 days, the RAL cows number of refusal visits/ day were similar to CTL cows ($P = 0.39$). The RAL-MP cows had 0.59 ± 0.29 fewer refusal visits/ day than CTL-MP cows ($P = 0.04$), meanwhile, RAL-PP cows number of refusal visits/ day were similar to CTL-PP cows ($P = 0.72$). The RAL-MP cows tended to have fewer refusal visits/ day on weeks 5, 7, and 12 ($P < 0.10$) and had fewer refusal visits/ day on weeks 9, 10, and 13 ($P < 0.04$) (Figure 11).

The RAL-MP cows was detected to have fewer refusal visits/ day than CTL-MP cows. Continuing with the thought process of RAL supplementation increasing satiety and feed efficiency, RAL-MP cows may not be visiting the AMS as frequently as CTL-MP cows. The CTL-PP cows may enter the AMS frequently to obtain feed, and the RAL-MP cows may try to enter due to increased udder fill. These speculations would align with evidence indicating that feed is the main incentive for entering the AMS (Bach et al., 2007; Prescott et al., 1998; Scott et al., 2014).

CONCLUSIONS

Feeding a sorbitol-containing supplement has beneficial applications, including increasing milk yield, ECM yield, fat yield, and protein yield for multiparous cows. The supplement also had an effect on some AMS metrics that could influence management strategies while increasing revenue for dairy farms.

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Appendix 1. Tables

Table 1: Multivariate analysis of farm-level factors and their associations with milk yield per cow (kg/d) on 35 automatic milking system (AMS) dairy farms in Minnesota and Wisconsin

Variable	Estimate	SE	P-value
Average DIM	-0.051	0.008	P<0.0001
Cows per AMS	-0.272	0.027	P<0.0001

Table 2: Multivariate analysis of farm-level factors and their associations with milk yield per automatic milking system (AMS) (kg/d) on 35 AMS dairy farms in Minnesota and Wisconsin

Variable	Estimate	SE	P-value
Average DIM	-3.22	0.46	P<0.0001
Cows per AMS	22.13	1.60	P<0.0001

Table 3: Least squares means production measurements during the supplementation period and the post-supplementation period

	Supplementation[a]						**Post-supplementation[b]**					
	Treatment				***P*-value**		**Treatment**				***P*-value**	
Variable	**RAL**	**SE**	**CTL**	**SE**	**Trt**	**Trt x Time**	**RAL**	**SE**	**CTL**	**SE**	**Trt**	**Trt x Time**
Animals, n	109		110				109		110			
Milk yield, kg/d	39.7	0.74	37.4	0.72	0.03	0.01	46.4	0.72	44.5	0.70	0.06	0.06
ECM[c], kg/d	42.1	0.81	39.8	0.79	0.04	0.10	45.2	0.70	43.7	0.67	0.01	0.01
Milk fat yield, kg/d	1.50	0.03	1.43	0.03	0.11	0.36	1.52	0.03	1.48	0.03	0.42	0.003
Milk protein yield kg/d	1.34	0.02	1.26	0.02	0.02	0.18	1.45	0.02	1.38	0.02	0.03	0.16

[a] Data represent daily values condensed to weekly means collected during the supplementation period (1 – 30 DIM).

[b] Data represent daily values condensed to weekly means collected after the supplementation period through 90 DIM (31 – 90 DIM).

[c] Energy corrected milk, calculated as (0.327 *milk lbs + 12.95*Fat lbs + 7.2*Protein lbs).

Table 4: Least squares means multiparous production measurements during the- supplementation period and the post supplementation period

	Supplementation[a]					Post-supplementation[b]				
	Treatment				*P*-value	Treatment				*P*-value
Variable	**RAL**	**SE**	**CTL**	**SE**	**Trt**	**RAL**	**SE**	**CTL**	**SE**	**Trt**
Animals, n	75		72			75		72		
Milk yield, kg/d	49.0	0.83	46.0	0.85	0.01	54.5	0.8	52.5	0.82	0.09
ECM[c], kg/d	52.5	0.90	49.0	0.92	0.01	53.5	0.78	51.3	0.79	0.05
Milk fat yield, kg/d	1.90	0.04	1.77	0.04	0.01	1.81	0.03	1.73	0.03	0.10
Milk protein yield kg/d	1.64	0.03	1.54	0.03	0.01	1.70	0.02	1.62	0.02	0.04

[a] Data represent daily values condensed to weekly means collected during the supplementation period (1 – 30 DIM).

[b] Data represent daily values condensed to weekly means collected after the supplementation period through 90 DIM (31 – 90 DIM).

[c] Energy corrected milk, calculated as (0.327 *milk lbs + 12.95*Fat lbs + 7.2*Protein lbs).

Table 5: Least squares means primiparous production measurements during the supplementation period and the post-supplementation period

	Supplementation[a]				**Post-supplementation**[b]					
	Treatment				***P*-value**	**Treatment**				***P*-value**
Variable	**RAL**	**SE**	**CTL**	**SE**	**Trt**	**RAL**	**SE**	**CTL**	**SE**	**Trt**
Animals, n	34		38			34		38		
Milk yield, kg/d	30.4	1.23	28.8	1.17	0.35	38.3	1.19	36.5	1.13	0.27
ECM[c], kg/d	31.7	1.34	30.6	1.27	0.54	36.9	1.15	36.1	1.10	0.58
Milk fat yield, kg/d	1.10	0.06	1.09	0.05	0.85	1.22	0.05	1.23	0.05	0.87
Milk protein yield kg/d	1.04	0.04	0.98	0.04	0.29	1.20	0.04	1.13	0.03	0.22

[a] Data represent daily values condensed to weekly means collected during the supplementation period (1 – 30 DIM).

[b] Data represent daily values condensed to weekly means collected after the supplementation period through 90 DIM (31 – 90 DIM).

[c] Energy corrected milk, calculated as (0.327 *milk lbs + 12.95*Fat lbs + 7.2*Protein lbs).

Table 6: Least squares means AMS metric measurements during the supplementation period and the post-supplementation period

	Supplementation[a]						**Post-supplementation[b]**					
	Treatment				***P*-value**		**Treatment**				***P*-value**	
Variable	**RAL**	**SE**	**CTL**	**SE**	**Trt**	**Trt x Time**	**RAL**	**SE**	**CTL**	**SE**	**Trt**	**Trt x Time**
Animals, n	109		110				109		110			
Milking time (s)	329	9.78	315	9.50	0.30	0.63	338	10.1	333	9.82	0.71	0.24
Milk speed (kg/min)	2.90	0.08	2.88	0.08	0.83	0.67	2.96	0.08	2.95	0.08	0.94	0.05
Milking interval (min)	507	10.3	502	9.93	0.71	0.61	449	8.55	450	8.28	0.93	0.93
Box time (s)	427	9.72	414	9.44	0.34	0.73	434	10.0	430	10.0	0.77	0.26
Rumination time (min)	464	5.75	466	5.58	0.84	0.77	519	4.82	519	4.67	0.97	0.85
Number of milkings (visits/d)	3.03	0.06	3.07	0.62	0.65	0.37	3.30	0.61	3.29	0.06	0.96	0.76
Number of refusals (visits/d)	1.25	0.15	1.61	0.15	0.10	0.30	2.08	0.18	1.83	0.18	0.39	0.79

[a] Data represent daily values condensed to weekly means collected during the supplementation period (1 – 30 DIM).

[b] Data represent daily values condensed to weekly means collected after the supplementation period through 90 DIM (31 – 90 DIM).

Table 7: Least squares means multiparous AMS metric measurements during the supplementation period and the post-supplementation period

	Supplementation^{a}					**Post-supplementation**^{b}				
	Treatment				***P*-value**	**Treatment**				***P*-value**
Variable	**RAL**	**SE**	**CTL**	**SE**	**Trt**	**RAL**	**SE**	**CTL**	**SE**	**Trt**
Animals, n	75		72			75		72		
Milking time (s)	333	10.9	325	11.2	0.63	350	11.3	348	11.5	0.93
Milk Speed (kg/min)	3.25	0.09	3.13	0.09	0.32	3.35	0.09	3.25	0.09	0.43
Milking interval (min)	473	11.4	463	11.6	0.54	459	9.52	452	9.72	0.59
Box time (s)	429	10.9	422	11.1	0.67	446	11.2	445	11.4	0.93
Rumination time (min)	489	6.43	501	6.56	0.20	534	5.38	4.46	5.49	0.10
Number of milkings (visits/ d)	3.22	0.07	3.28	0.73	0.54	3.26	0.07	3.32	0.07	0.49
Number of refusals (visits/d)	1.15	0.17	1.81	0.17	0.01	1.16	0.20	1.75	0.21	0.04

[a] Data represent daily values condensed to weekly means collected during the supplementation period (1 – 30 DIM).

[b] Data represent daily values condensed to weekly means collected after the supplementation period through 90 DIM (31 – 90 DIM).

Table 8: Least squares means primiparous AMS metric measurements during the supplementation period and the post-supplementation period

	Supplementation[a]					Post-supplementation[b]				
	Treatment				P-value	Treatment				P-value
Variable	RAL	SE	CTL	SE	Trt	RAL	SE	CTL	SE	Trt
Animals, n	34		38			34		38		
Milking time (s)	326	16.2	305	15.4	0.34	326	16.8	317	15.9	0.69
Milk Speed (kg/min)	2.55	0.13	2.62	0.12	0.66	2.57	0.13	2.66	0.28	0.65
Milking interval (min)	542	17.0	541	16.1	0.98	438	14.2	448	13.4	0.63
Box time (s)	425	16.1	406	15.3	0.38	421	16.6	414	15.7	0.76
Rumination time (min)	440	9.55	432	9.03	0.52	504	7.99	491	7.56	0.24
Number of milkings (visits/ d)	2.83	0.11	2.85	0.10	0.91	3.34	0.10	3.26	0.10	0.58
Number of refusals (visits/d)	1.35	0.25	1.41	0.24	0.88	2.57	0.32	2.42	0.29	0.72

[a] Data represent daily values condensed to weekly means collected during the supplementation period (1 – 30 DIM).

[b] Data represent daily values condensed to weekly means collected after the supplementation period through 90 DIM (31 – 90 DIM).

Appendix 2. Figures

Figure 1: Effect of Rally on multiparous milk yield during the supplementation period

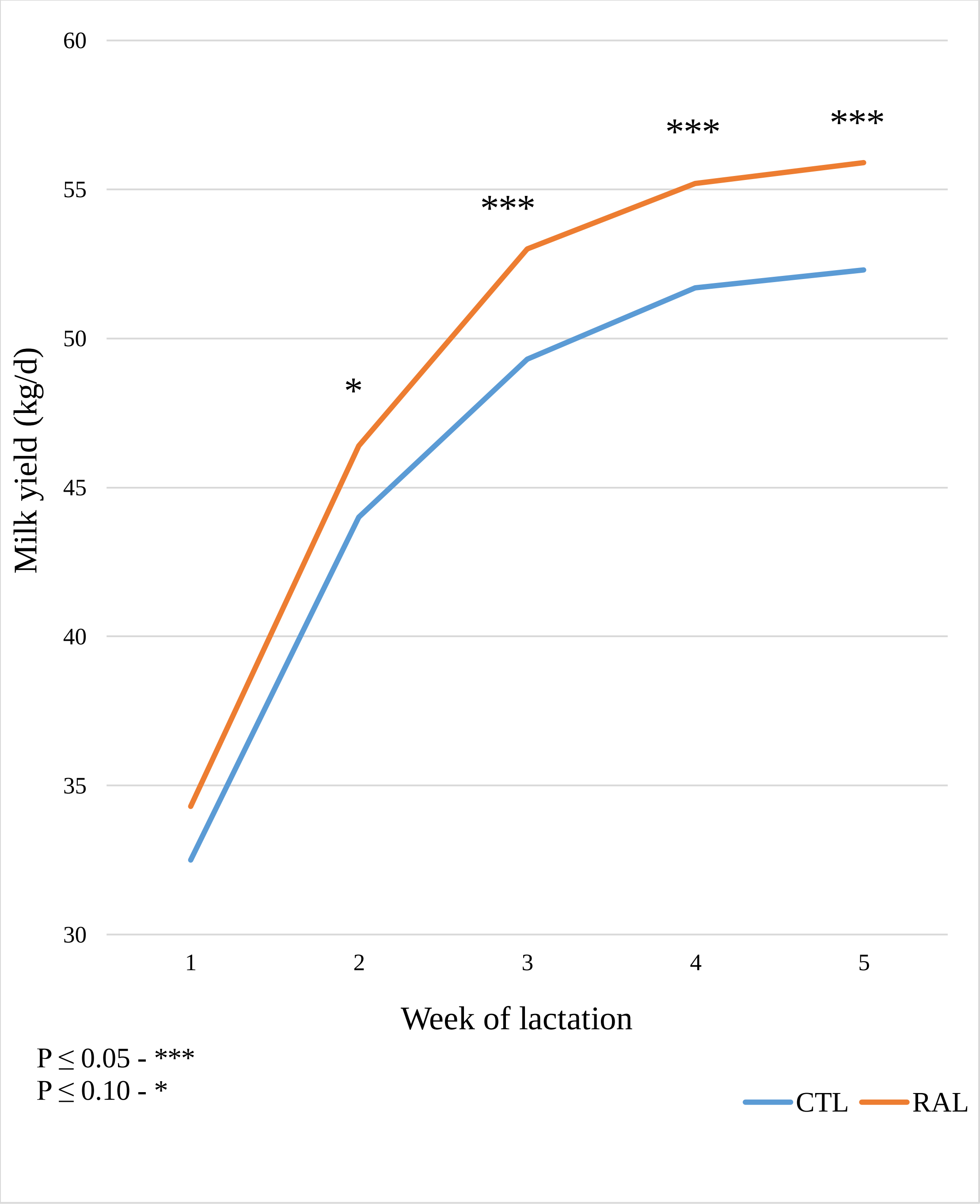

Figure 2: Effect of Rally on multiparous ECM yield during the supplementation period

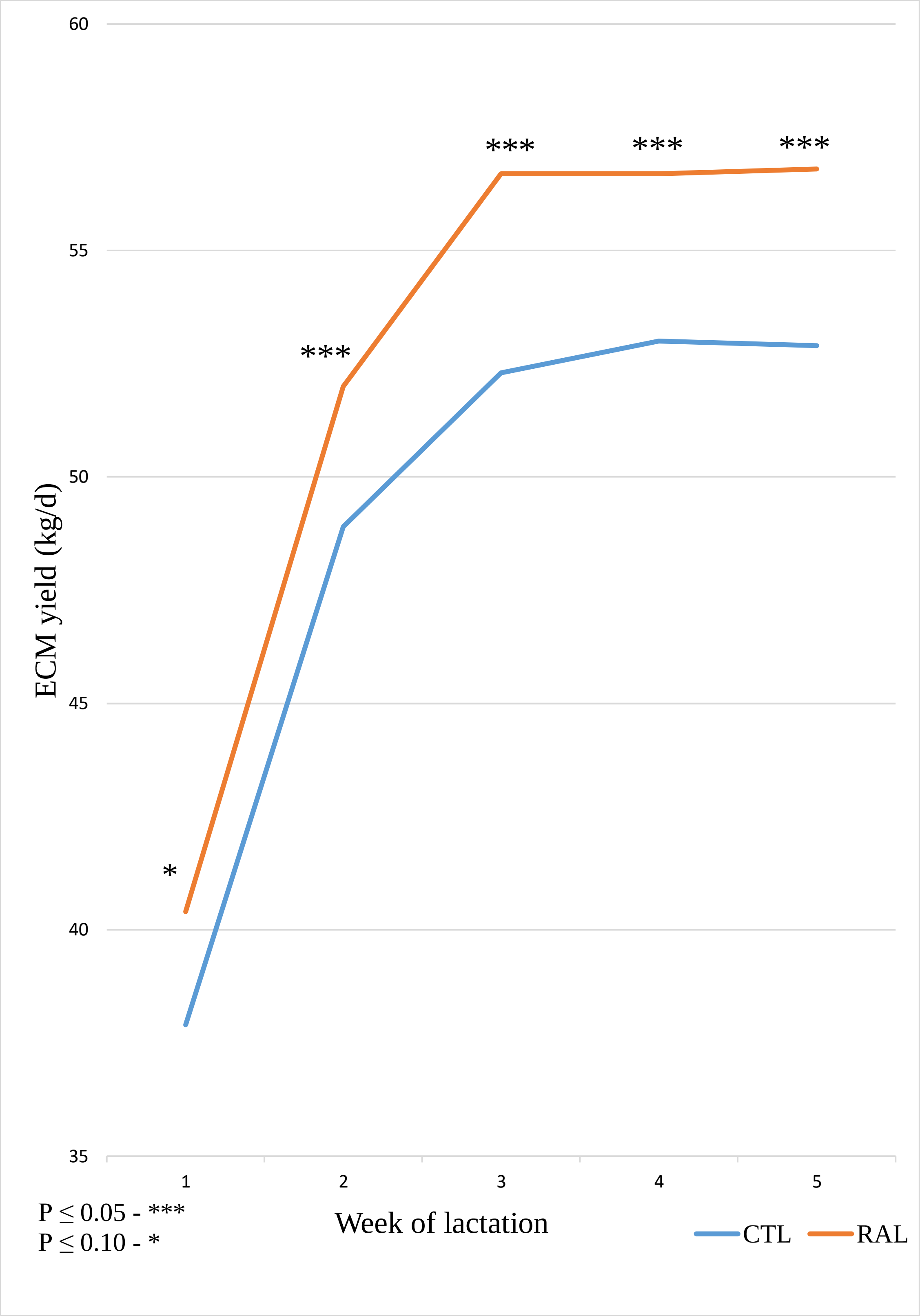

Figure 3: Effect of Rally on multiparous milk protein yield during the supplementation period

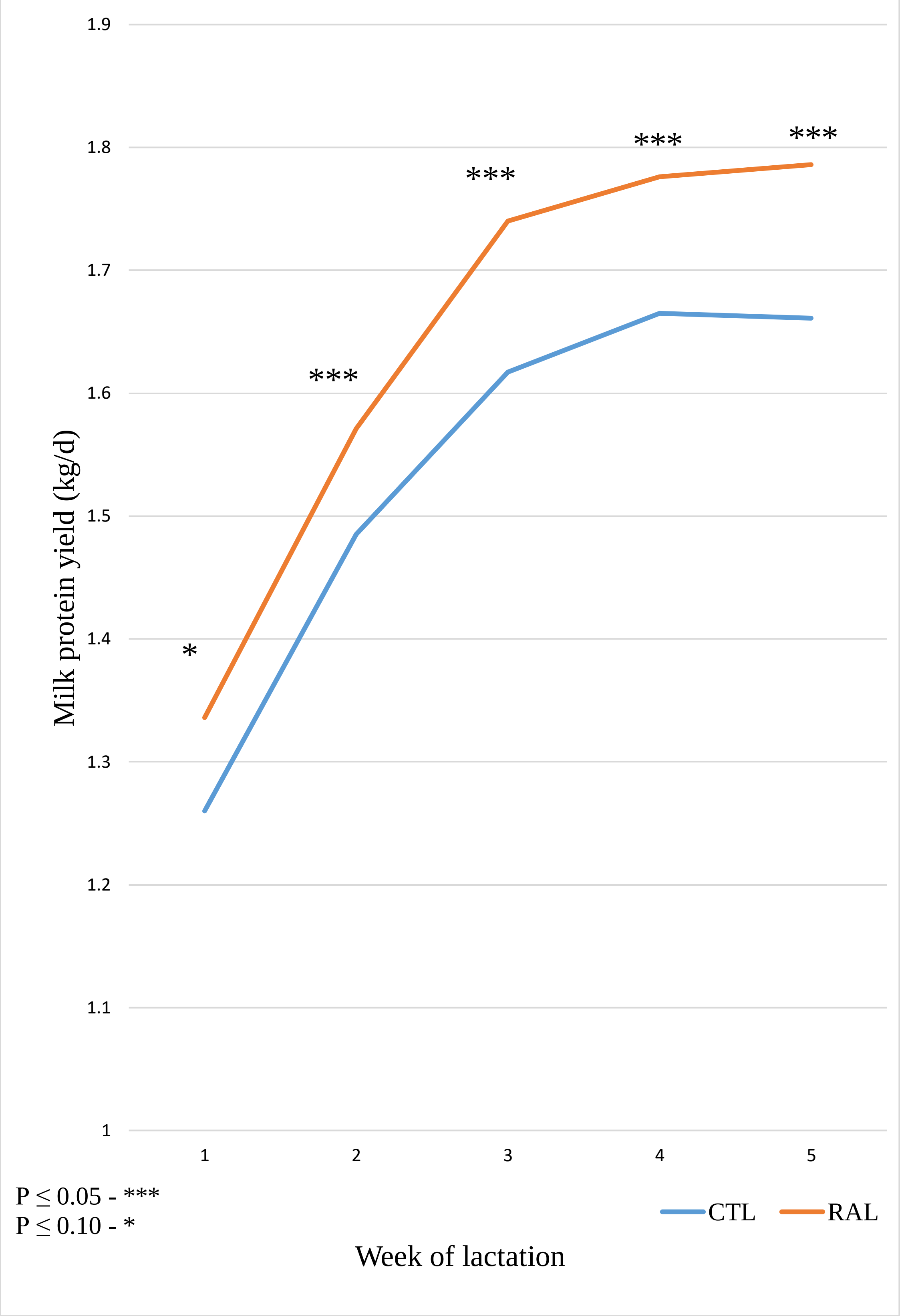

Figure 4: Effect of Rally on multiparous milk protein yield during the supplementation period

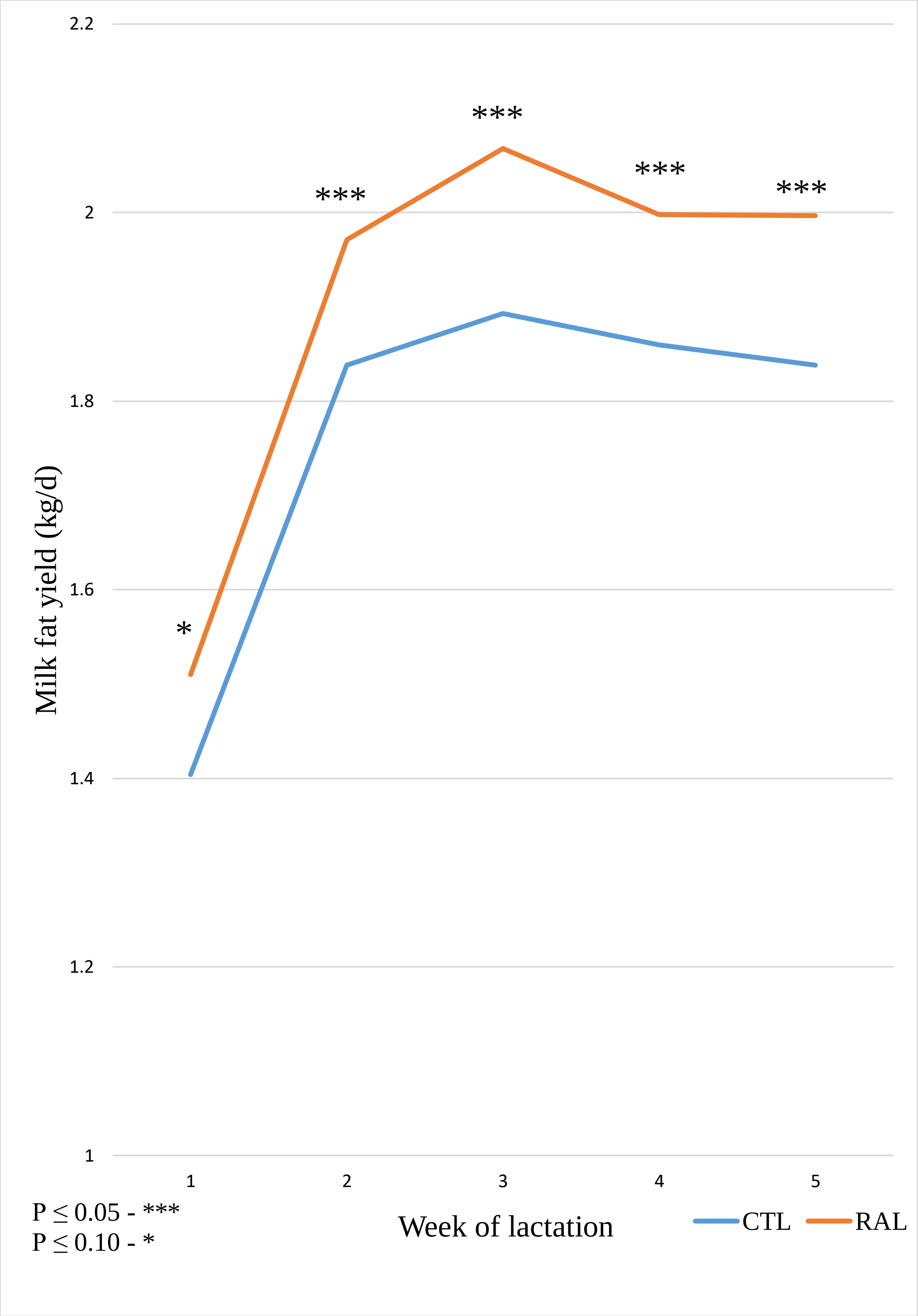

Figure 5: Effect of Rally on multiparous refusal visits per day during the supplementation period

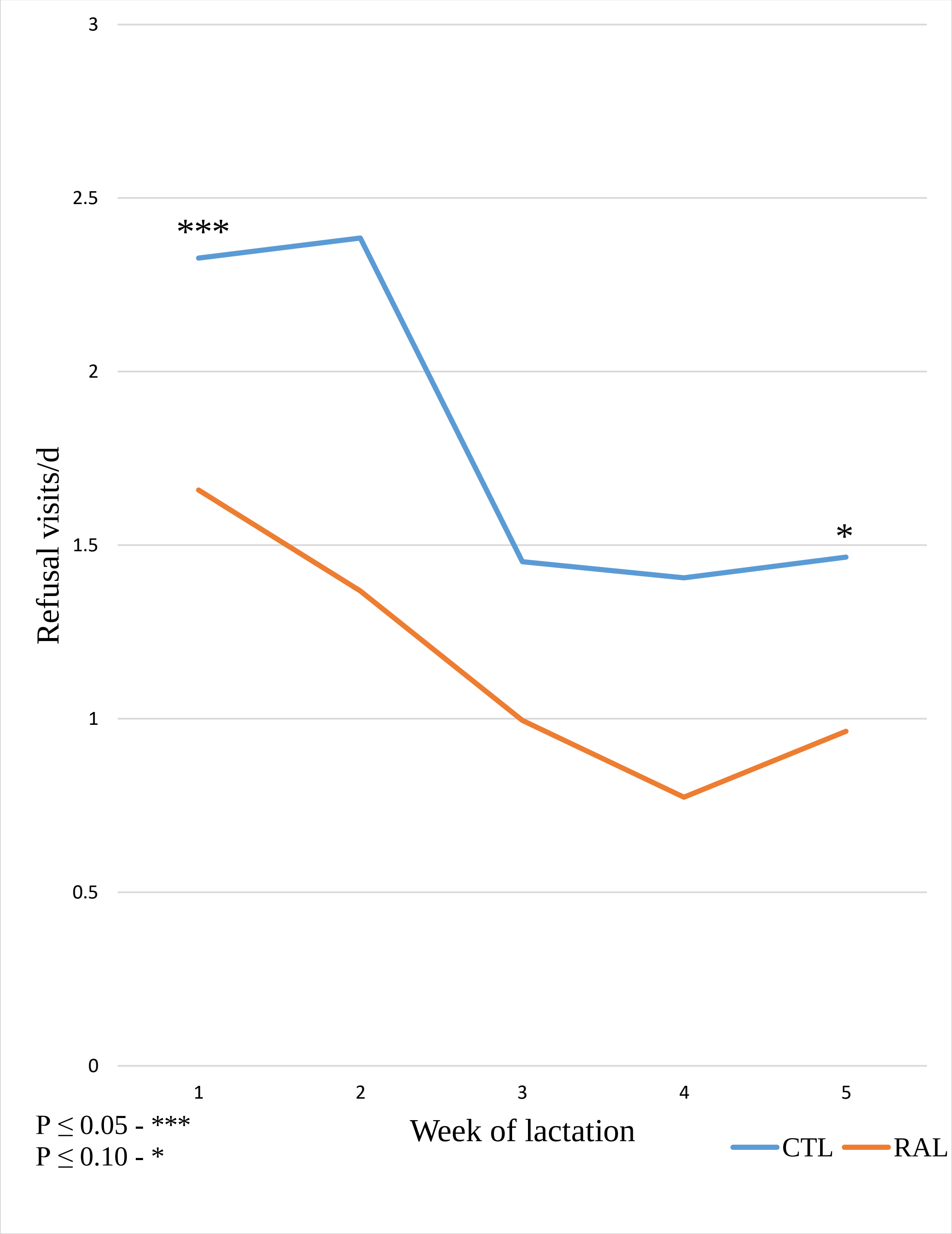

Figure 6: Carryover effect of Rally on multiparous milk yield during the post supplementation period

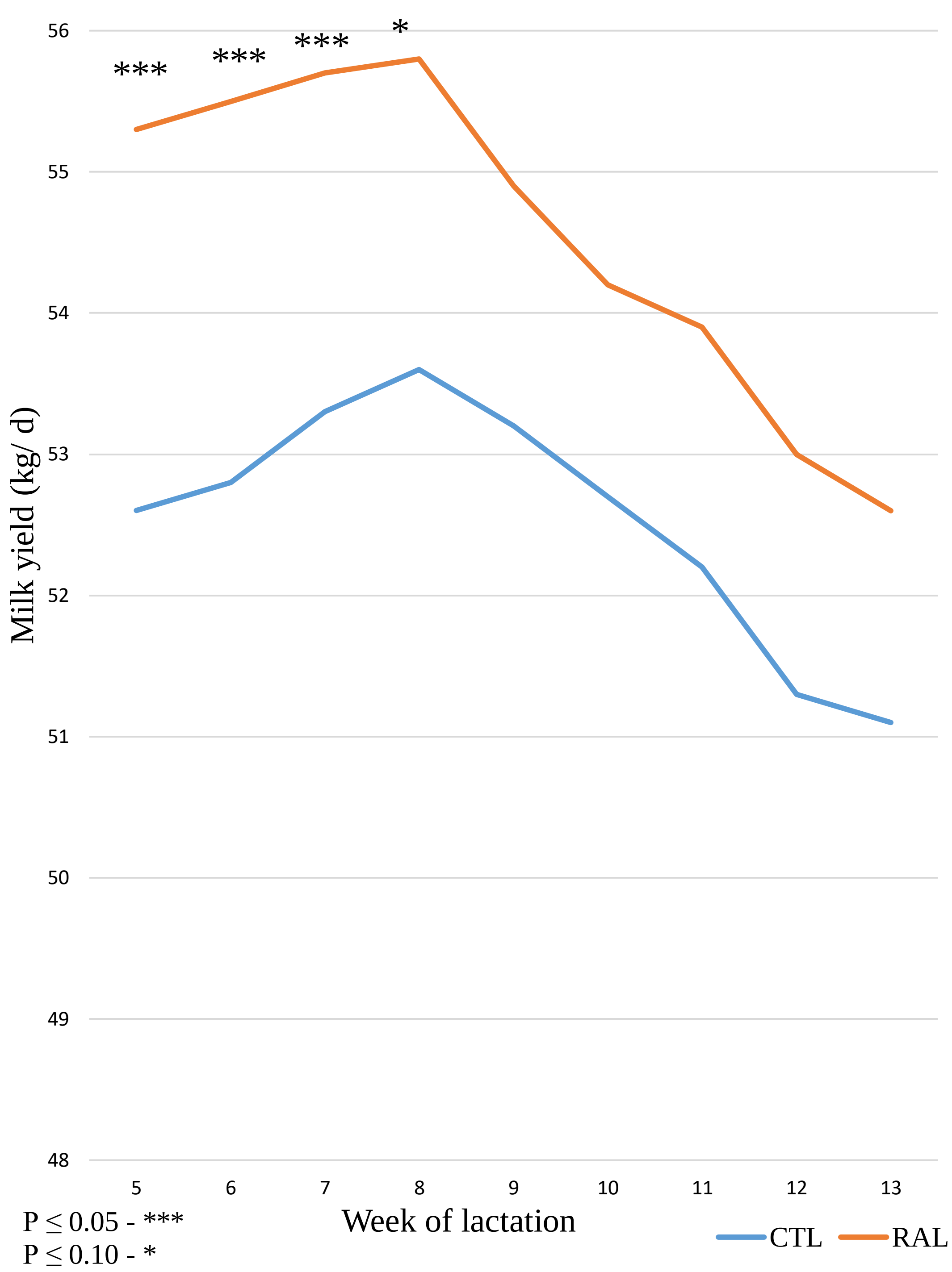

Figure 7: Carryover effect of Rally on multiparous ECM yield during the post supplementation period

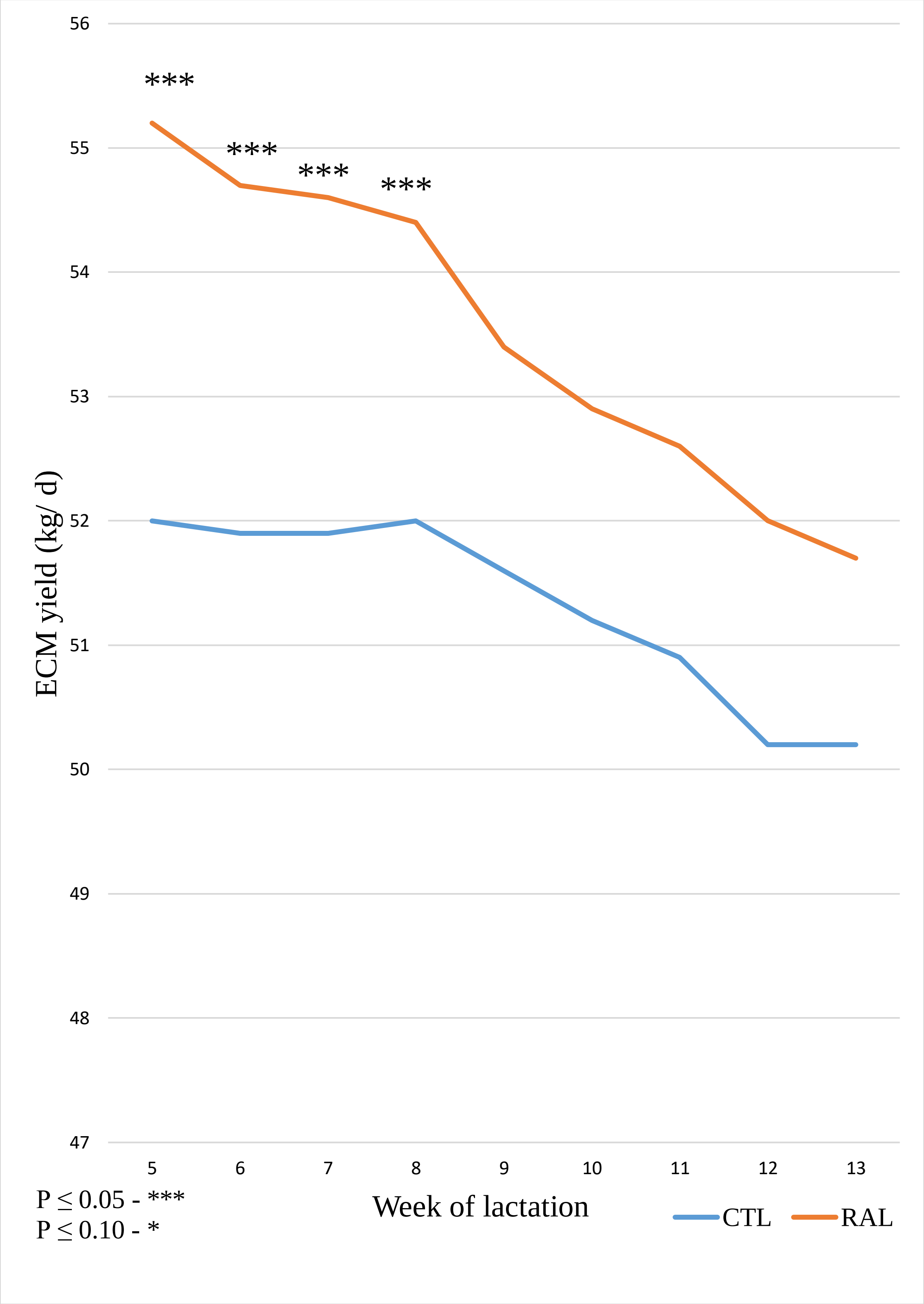

Figure 8: Carryover effect of Rally on multiparous milk protein yield during the post supplementation period

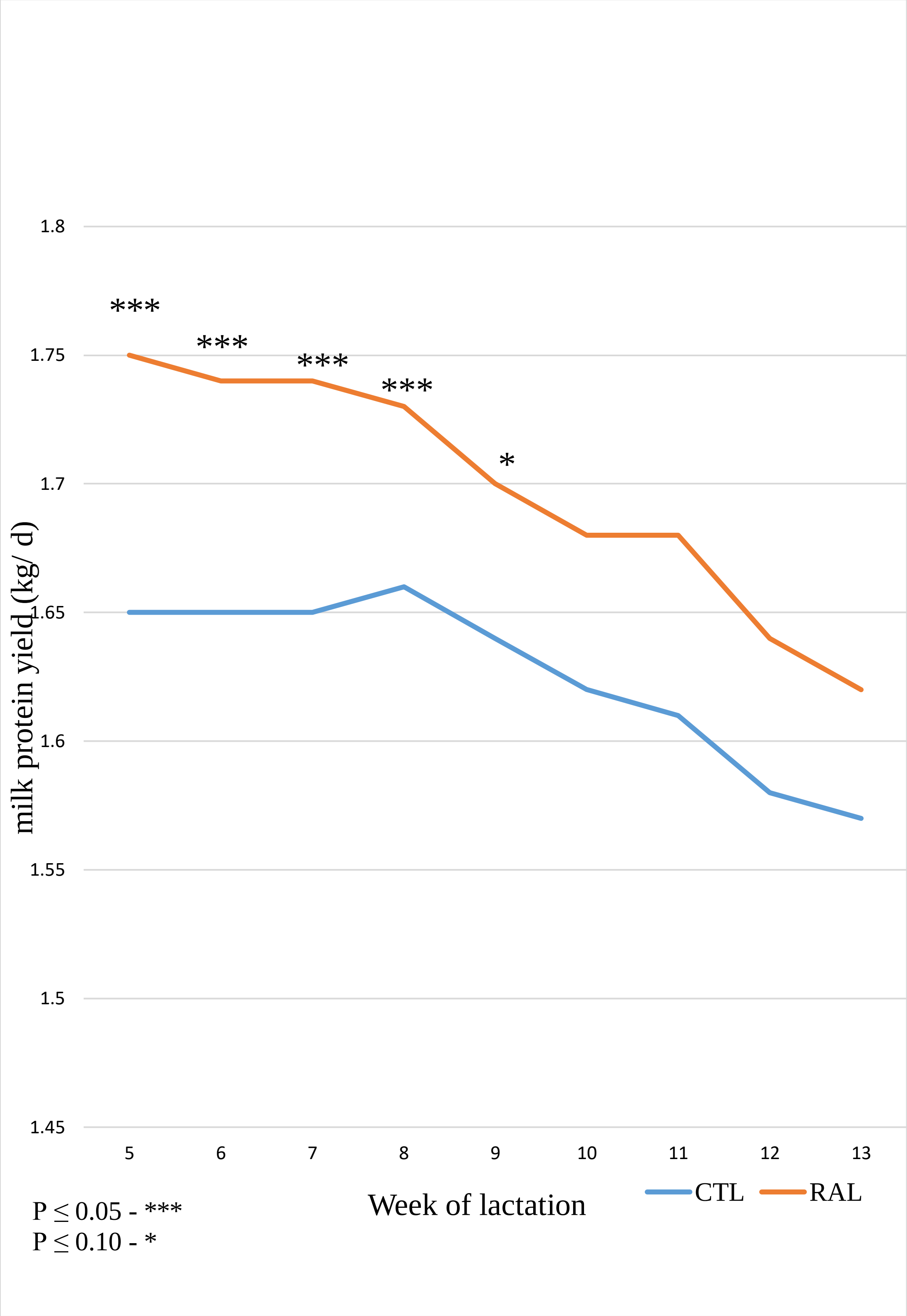

Figure 9: Carryover effect of Rally on multiparous milk fat yield during the post supplementation period

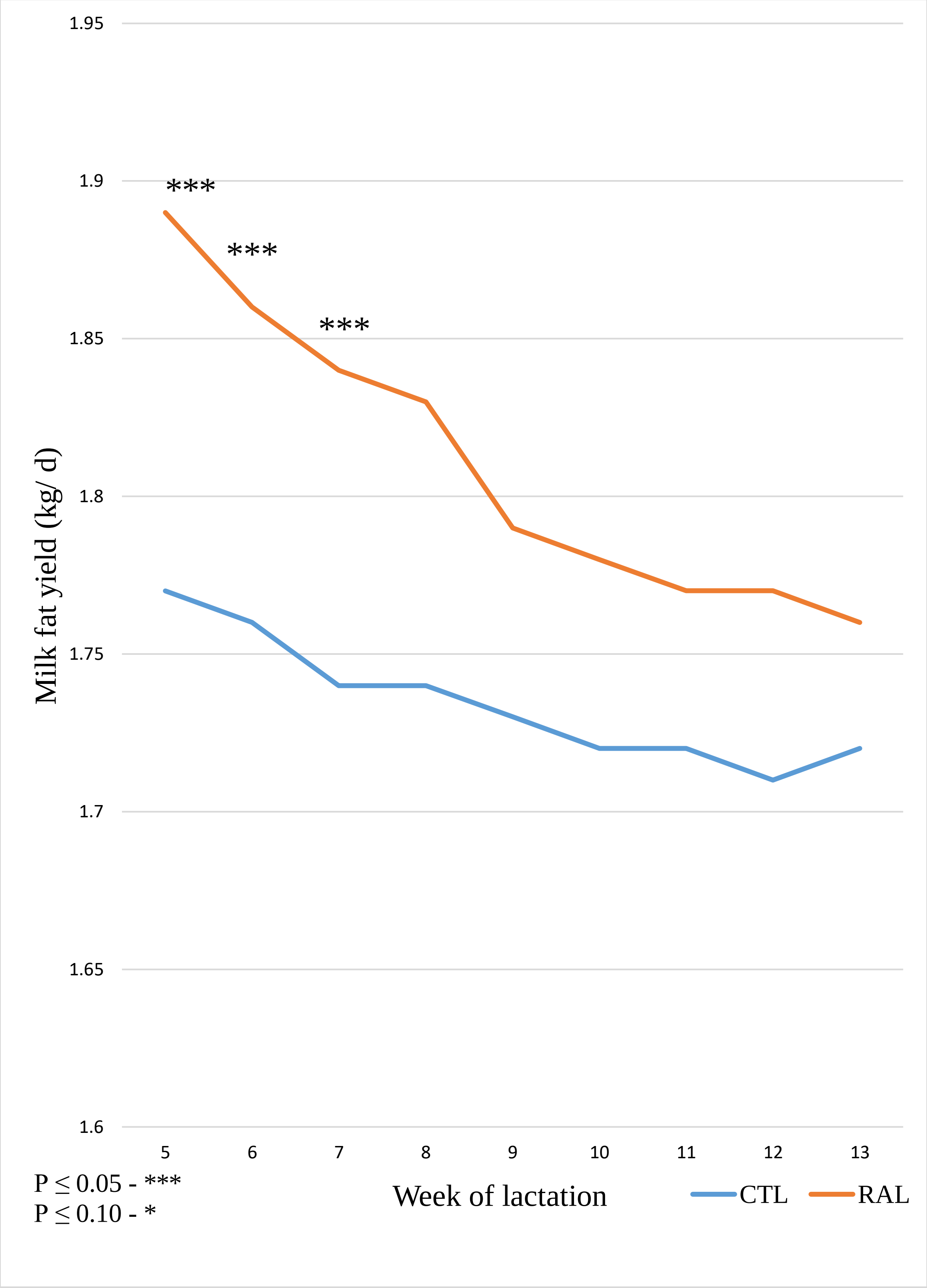

Figure 10: Carryover effect of Rally on multiparous rumination time during the post supplementation period

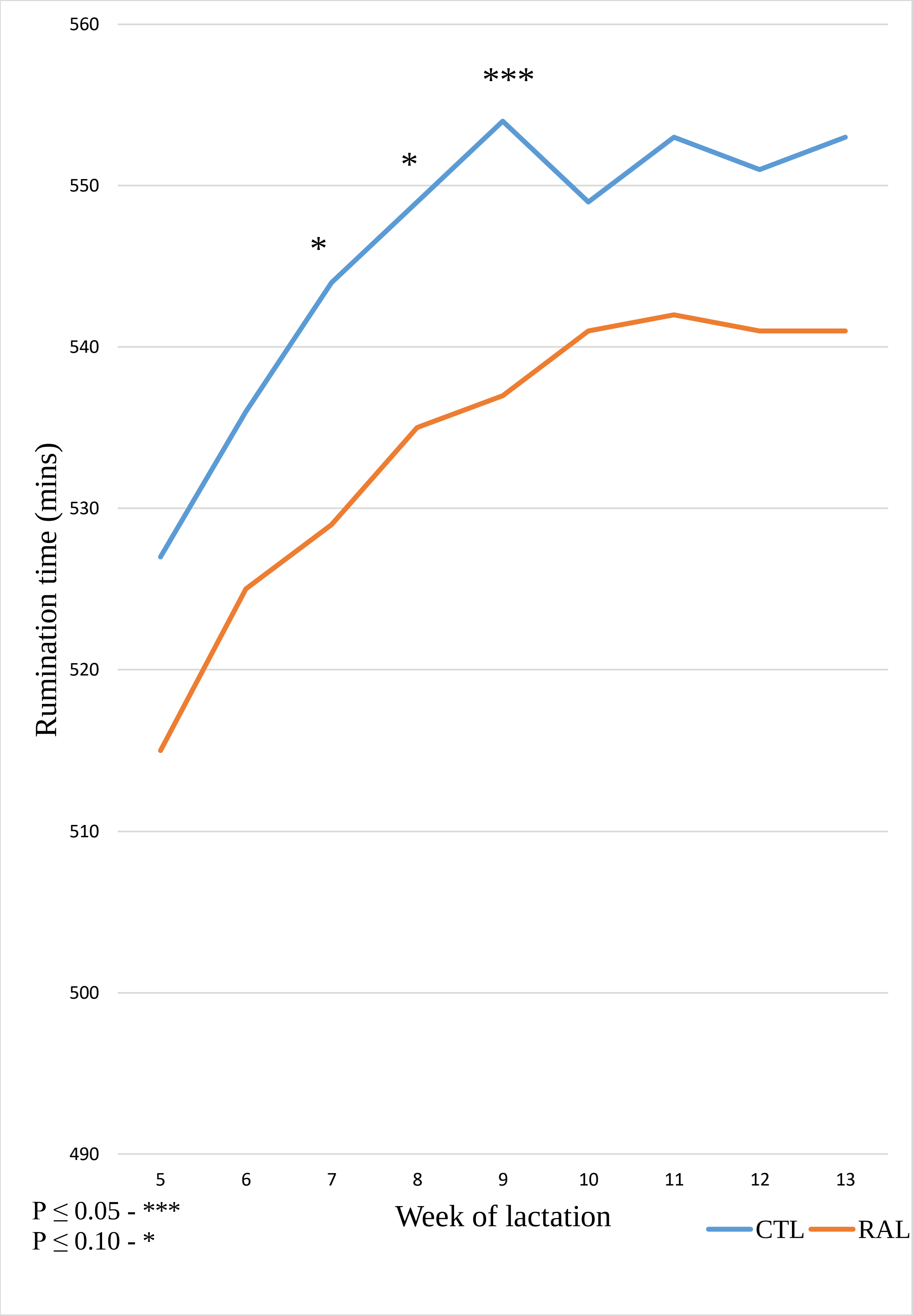

Figure 11: Carryover effect of Rally on multiparous refusal visits per day during the post supplementation period