Modelling of normal and extended lactation for milk, fat and protein yields of New Zealand dairy goats

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Abstract

The use of extended lactation has been introduced as a management practice to minimise the high number of surplus young born in the dairy industry while still meeting the growing demand for high milk yields (MY) worldwide. Extended lactation has been looked at previously in dairy cows globally and in New Zealand. While extended lactation in dairy goats has only been studied overseas, not in New Zealand. Therefore, this thesis aims to investigate whether extended lactation could be employed as a future management practice in New Zealand dairy goat farming. To achieve this, the main objective of this thesis was to model and compare MY, fat yield (FY) and protein yield (PY) data collected from New Zealand dairy goats in extended lactation (670d) with goats in normal lactation (270d). The influence of pregnancy, parity number, lactation year and the month starts lactation was explored. The data analysed were collected from a large commercial farm in Waikato, New Zealand. The main findings suggest that extended lactation would be a beneficial management practice for New Zealand Dairy goat farms. This thesis discovered that New Zealand dairy goats in extended lactation produced a higher average total MY (657.24 kg higher), FY (16.7 kg higher) and PY (22.63 kg higher) than goats in two normal lactations. This likely reflects the effect of an absence of a dry period for extended lactation and/or the effect of pregnancy on a normal lactation. Indeed, the present results illustrated an effect of pregnancy, as when goats in normal lactation were dried off after 270 days their average on day 270 was only 2.81 kg (c.f., 3.35 kg for goats in extended lactation at this time). Milk production for both normal and extended lactations were also affected by parity, lactation year and lactation start month. All goats' MY, FY and PY increased from parity one to peak at parity three or four, before gradually declining thereafter. For lactation year, all three yields increased from 2013 until 2019, most likely representing genetic gain. The lactation start month with the lowest yields for normal and extended lactation goats was June, with peak yields occurring for normal and extended lactations starting in August and September, respectively. This was likely due to an effect of photoperiod or feed availability on milk production. Ultimately, this thesis supports extended lactation as a beneficial management practice in New Zealand dairy goat farms as there was greater milk production than by normal lactation goats and reduced surplus offspring. Further studies are required to determine the effect of extended lactation on other milk components, farm profitability and goat health.

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List of Abbreviations

bST = bovine somatorophin

DIM = days in milk from parturition

MEC= mammary epithelial cells

ECM= energy corrected milk

MY = MY

FY = FY

PY = PY

Chapter 1: General introduction

There has been a global increase in commercial dairy goat farming since 1960, with the worldwide production of goat milk more than doubling over the last 50 years and this trend is expected to continue (Pulina et al., 2018). The growth of the dairy goat industry has been primarily driven by the growing purchaser demand for non-bovine milk alternatives for people with intolerances or allergies to cow milk (Bevilacqua et al., 2001; Lara-Villoslada et al., 2006). Due to the different components that allow it to be more readily digestible, goat milk is often more suitable for people suffering from eczema, asthma and stomach ulcers (Jandal, 1996; Haenlein, 2004).

Historically, goats were farmed to sustain individual families or villages (Dubeuf et al., 2004). This is still the primary use of dairy goat farming in developing countries, predominantly in Asia and Africa. However, the development of a purpose-built dairy goat industry has risen across Europe (particularly in Greece, Italy, France, and Spain) and Latin America (de Rancourt et al., 2006; Scholtens, 2020). The main production focus of these rising dairy goat industries is the production of milk for sale or further processing into cheese and candies (Escareño et al., 2013).

The dairy goat industry in New Zealand is small but growing and well-established, with a strong focus on producing high-quality dairy products for export (Scholtens, 2020). Goat farming in New Zealand is often chosen for dairy production as it provides an option that meets environmental compliance conditions while having a low impact on agricultural diversification and being economically favourable. New Zealand dairy goat milking regimes mimic those used for most dairy cow operations, with milking beginning in July and finishing in May (Scholtens et al., 2017). New management practices must be explored to allow New Zealand to continue to meet the growing demand for goat milk and meet new welfare focuses (e.g., reduced the number offspring sent for slaughter). One practice that has been suggested to complete this is extended lactation.

Extended lactation is when lactation is extended to include at least two full lactation seasons before a dry period (~670d), rather than drying them off after a normal ~270-day lactation and remating for the following year. Lactation in dairy goats can be extended (670 d) beyond the normal 270-d lactation) by delaying rebreeding and maintaining milking leading to a prolonged kidding interval (Scholtens, 2020). While the use of extended lactation in dairy goats has been studied worldwide, it has only recently been introduced into New Zealand. Extended lactation could have many economic, welfare, and environmental benefits (Capuco et al., 2003; Bach et al., 2008; de Souza Castagnino et al., 2015). Employing extended lactation as a management practice could be possible to maintain milking for two years for year-round milk production, increasing farm income, meeting the year-round demand for milk, and reducing the production of offspring that are sent to slaughter.

This thesis will provide a summary on the current literature available on extended of lactation primarily in the dairy goat industry but where limited resources are available will look at all literature available in all dairy industries (Chapter 2). The materials and methods for this study will be outlined in Chapter 3, the results are presented in Chapter 4 and the discussion (Chapter 5) will investigate the results. The main objective of this thesis was to model the lactation curves for milk yield (MY), fat yield (FY) and PY (PY) of normal and extended lactations of dairy goats in a large herd in New Zealand. The influence of parity number, lactation year and the month in which lactation begins was also explored. The results from this thesis will assist on the decision to use of extended lactation is a valid management technique to employ in a range of New Zealand dairy goat farms.

Chapter 2: Literature review

2.1 Dairy farming

Throughout the world, the focus of the agricultural industry has changed. The emphasis during the 1960s was placed on attaining a maximum peak daily output and minimising the birthing interval. This has evolved to include a high priority placed on production efficiency and a demand to improve welfare. One aspect of animal welfare particularly focused on in modern times is that there are a large number of production animals; therefore, so many young are born to meet such high milk production demands. Many of the young born are surplus to the number required for annual replacements (Knight, 1997). This welfare issue has highlighted a focus on finding ways to minimise the number of surplus young born while still meeting milk demands. One idea for a newer practice to meet these new focuses is extending lactation (e.g., have production animals give birth every two or three years rather than annually).

A hypothetical extended lactation mathematical model has shown that it would have a very economically favourable outcome (Knight, 1997). These benefits include enhancing lactation efficiency by decreasing the rate at which milk yield (MY) declines following peak MY. The lengthened lactation would result in a smaller proportion of the ruminant's life spent in the periparturient period, with increased health risks and greater costs. Extended lactation could also improve lifetime productivity, as the goats would spend less time in the dry period not producing milk. The delayed breeding could also show increased reproductive efficiency (Capuco et al., 2003). This has been researched in dairy cattle (Bertilsson et al., 1997; van Amburgh et al., 1997; Österman and Bertilsson, 2003; Christiansen et al., 2005; Auldist et al., 2007; Kolver et al., 2007; Sorensen et al., 2008), but there has been little research into this practice in dairy goats.

2.2 Dairy goat farming worldwide

Dairy goats are used worldwide for milk production, and the subsequent products produced are highly popular. Globally, dairy goats are mainly chosen for milk production due to their ability to survive and reproduce under harsh environmental conditions and perform well even when nutrition is restricted (Escareño et al., 2013). Goats are not only resilient but are also often selected above other production ruminants for their early maturity, higher prolificacy, longer lactation (270 - 300 days of milking compared to 250 for sheep), and shorter gestation period (Scholtens, 2020), and benefit the environment through weed control and fire prevention (Miller and Lu, 2019). Goats are seasonal breeders and, therefore, commonly exhibit seasonal lactation. Goats can be induced to complete three lactations in the time taken for two lactations in some other dairy animals (Knight & Wilde, 1988). This is important for the dairy goat industry as it often competes against other dairy industries, such as cattle, sheep, buffalo, and camel milk products (Dubeuf et al., 2004).

Cattle (83.1%) and buffalos (13.1%) are the most important milk producers in terms of global production, with goat milk representing only 1.9% (FAO, 2018). However, there is a growing demand for non-bovine milks due to a growing desire for alternatives suitable for people with intolerances or allergies to cow milk (Bevilacqua et al., 2001; Lara-Villoslada et al., 2006). When goat milk is compared to cow milk, it has been found that it is more readily digestible, more alkaline, lower in lactose, and higher in protein (specifically casein) (Jandal, 1996; Haenlein, 2004). Goat milk also has different allergic properties as it has been found to be less immunoglobulin E-reactivity than cows' milk (Mansor et al., 2023). Therefore, goat milk is more suitable for people suffering from eczema, asthma, and stomach ulcers (Jandal, 1996; Haenlein, 2004). Unlike cow milk, which is consumed as liquid milk, goat milk is used to produce niche dairy foods and is sold as high-quality dairy products, such as cheese and primarily infant formula (FAO, 2020). The use of goat milk rather than cow's milk in infant formula is because it contains more medium-chain fatty acids (C6-C14), omega three and six polyunsaturated fatty acids, conjugated linoleic acid, calcium, phosphorus, magnesium, and copper (Ceballos et al., 2009). Which is important for membrane permeability, and brain development (Ward & Singh, 2005). This has led to worldwide goat milk production more than doubling throughout the last 50 years. If this trend is maintained, it is expected to increase further by approximately 9.7 Mt (+53%) by 2030 (Figure 2.1) (Pulina et al., 2018).

Figure 2.1 Global goat milk production (tonnes; t) trends from 1960 to 2016 (solid line) and forecast to 2030 using a time-series model (dashed line) (Pulina et al., 2018).

The use of goats for production originated in the Middle East from a handful of ancestral wild goat breeds. Goats have since then descended and evolved into hundreds of different breeds around the world (Haenlein, 2001). In 2018, the world's population was estimated to be about 203 million goats (FAO, 2018). Approximately 97% of the world's goat population is in Asia, Africa, and Latin America. Asia accounts for the largest share at approximately 51% of the total population (FAO, 2022). Historically, goats were farmed to sustain individual families or villages (Dubeuf et al., 2004). This is still the primary use of dairy goat farming in the developing countries where goat populations are most prominent, p such as Asia and Africa. However, the development of a purpose-built dairy goat industry has risen across Europe and (particularly in Greece, Italy, France and Spain) and Latin America (de Rancourt et al., 2006; Scholtens, 2020).

The main production focus of these rising dairy goat industries is the production of milk for sale or further processing into cheese and candies (Escareño et al., 2013). Throughout Europe, in the last 20 years, dairy goat operations have become very specialised and contributed 16.6% of whole goat milk produced worldwide in 2018 (Scholtens, 2020). This is mainly due to intensification of goat farming systems by incorporating breeds with high production potential and trying to eliminate the seasonality of milk production (Castel et al., 2011). European dairy goats are farmed under two types of housing systems: either traditional, where goats are kept at pasture in spring and autumn and then housed indoors in winter with vertical transhumance in the summer, or in intensive/semi-intensive systems, where goats are housed indoors with controlled feeding of hay and concentrates (Nicoloso et al., 2015). Within France, following the establishment of national professional organizations, technical centres, breeding and selection organizations, along with the steady growth of export markets for goat cheese, 90% of all goat milk produced is sold as cheese (Dubeuf et al., 2004).

The global popularity of dairy goat farming continues to rise, with the global dairy goat population increasing by 21.5% from 2002-2017. Africa has experienced the most significant population increase (32% increase; Figure 2.2) (Miller and Lu, 2019). The dairy goat industry in Australia has also dramatically grown recently. The population of milking goats and production volume increased by more than 62% from 2010-2018 (Zalcman and Cowled, 2018). The Australian dairy goat sector was estimated to grow at around 20% per year (Cameron, 2014). This growing popularity of dairy goat farming to provide non-bovine milk alternatives worldwide has encouraged and driven the growth of the dairy goat industry in New Zealand.

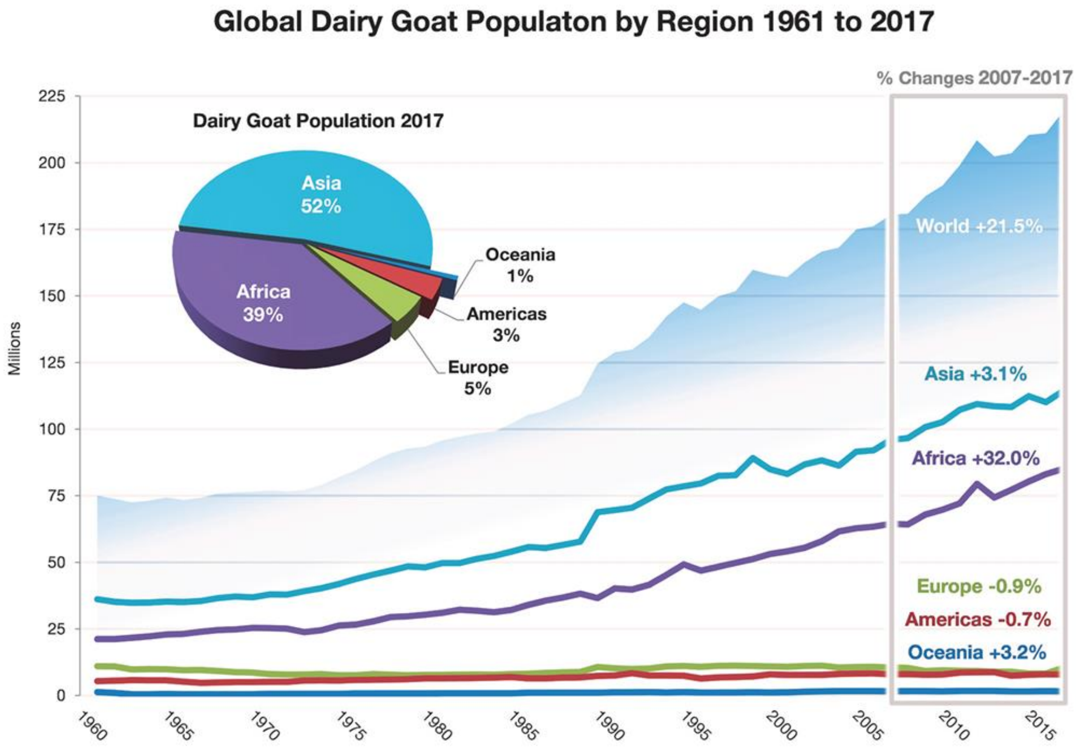

Figure 2.2 World dairy goat population (heads) from 1961 to 2017 (Miller and Lu, 2019).

2.3 Dairy goat farming in New Zealand

New Zealand’s dairy goat industry is small, but well-established and profitable. It is primarily producing high-quality and niche products for export (Scholtens et al., 2020). Goat farming in New Zealand is often chosen as it provides an option that meets environmental compliance conditions, while having a low impact on agricultural diversification and being economically favourable. New Zealand’s dairy goat industry’s strengths can be seen in high-value products (e.g., cheeses and infant formula) sold domestically and internationally in over 30 countries (Dairy Goat Co-operative, 2023).

New Zealand’s dairy goat industry depends on producing goat milk with high total milk solids and low bacterial count to produce high-quality products (Scholtens et al., 2019). Within New Zealand farmers are paid for milk per kg of milk solid (Commerce Commission New Zealand, 2023). The dairy goat population in New Zealand is estimated at 66,100 goats and is distributed across 92 farms (Scholtens et al., 2017). However, the exact population is unknown as there is no census (Stafford and Prosser, 2016). The large majority (80%) of the nation’s dairy goat population is collectively managed by the New Zealand Dairy Goat Cooperative (Scholtens et al., 2017). The dairy goat population in New Zealand is located mainly in the Waikato region, approximately 72%, with the remaining 28% distributed throughout New Zealand (Orr et al., 2010). The cooperative is the leading international manufacturer of nutritional powders for infants and young children from goat milk (Stafford & Prosser, 2016). Within New Zealand, the goat population is predominantly comprised of Saanen-bred goats (85%), but also includes British Alpine, Toggenburg and Anglo-Nubian breeds. Larger dairy goat farms supply goat milk processing plants and have an average herd size of 750 milking goats. While the smaller farms focus more on making their own cheese or supplying local cheese makers, they have approximately 50 goats per farm (Scholtens, 2020).

There are two farming system types practised in the New Zealand goat industry: (1) goats are either kept in an outdoor system where they live and graze in paddocks or (2) are housed indoors with a cut-and-carry feeding system (Robertson et al., 2015). Many dairy goat herds are managed intensively and housed in open-sided barns (Morris et al., 1997). These goats are fed fresh pasture or crops grown and harvested on-farm, then cut and carried to the side of the barn and fed two to three times a day (Solis-Ramirez et al., 2011). Goats kept in the outdoor system live and graze in paddocks with supplemental feeding throughout the year as needed. Indoor cut and carry systems are often favoured because they decrease particular health challenges, such as internal parasites (Trichostrongylus, Haemonchus and Ostertagia the most prevalent; Kettle et al., 1983) which occur with outdoor systems (Sholtens, 2020).

2.4 Extended lactation

Within New Zealand and worldwide farming, the focus of dairy farming as a whole has changed, from the focus during the 1960s on attaining a maximum peak daily output and minimising the calving interval, to include a high priority placed on the efficiency of production and the consumer's demand to improve welfare. One aspect of animal welfare that is of particular focus in modern times is that to meet such high milk production demands in the dairy industry, there are very high numbers of cows giving birth and, therefore, many calves being born. Many of these calves being born are surplus to the number required for replacements each year and, thus, are typically slaughtered (Knight, 1997). This welfare issue has highlighted a focus on minimising the number of surplus young born while still meeting milk demands in all dairy industries. One idea for a newer practice to meet these new focuses is extended lactation. A mathematical model of hypothetical lengthened lactation has shown that it would have a very favourable economic outcome (Knight, 1997). These possible benefits include enhancing the efficiency of the lactation by decreasing the rate at which MY declines, a smaller proportion of the ruminant's life being spent in the periparturient period, where there are increased health risks, and higher costs and delayed breeding could also show an increase in reproductive efficiency (Capuco et al., 2003).

Extended lactation could also be used to meet purchasers' growing demands for the popularity of fresh dairy goat products throughout the year. This trend has been witnessed throughout Australia (Stubbs and Abud, 2009) and is likely to influence dairy product consumption trends in New Zealand and export requirements. Within Australia, 60% of the national goat milk production is utilised for fresh cheese making, which requires a constant supply of milk year-round and is not currently sustainable with the current system of seasonal milk production (Zamuner et al., 2020). Under a seasonal milking system, there are production surpluses in spring–summer and shortfalls in winter (Cameron, 2003; Celi and White, 2012). The use of extended lactation in both Australia and New Zealand could be employed to mitigate seasonal effects on dairy production to meet the year-round demand for milk production.

2.4.1 Definition of extended lactation

Extended lactation is when lactation is extended to 670-d to include two full lactation seasons and the dry period between rather than drying them off and remating for the following year. Lactation in dairy goats can be extended beyond the normal 270-d lactation by delayed rebreeding leasing to an extended kidding interval. The use of extended lactation has been looked at previously in dairy cows throughout the world and in New Zealand. While the use of extended lactation in dairy goats has been studied worldwide, it has only recently been introduced into New Zealand. By employing extended lactation as a management practice, it could potentially be possible to eliminate the dry period (95 days) between successive lactations that occurs during a normal lactation in dairy goats. The possibility of this effect being higher in dairy goats than in dairy cows, as the importance of this dry period for MEC renewal has not been seen in dairy goats. This differs from dairy cattle in which the importance of the dry period has been shown to allow the accelerated renewal of MEC to ensure the next lactation to have a MY of the same or greater MY (Capuco et al., 2003). In cattle, extended lactation has been associated with a noteworthy reduction in daily MY in the second year of lactation (Capuco et al., 2003). However, this decrease is much less apparent or even absent in goat herds (Capuco et al., 2003). Therefore, there may be a greater economic benefit for using extended lactations in dairy goats than in dairy cows. The total MY and profit of extended lactation (670d) may be greater than for the accumulated MYs of two subsequent lactations, as there will be a cost for the dry period between them.

Since the 1990s, various strategies for extended lactation have been studied in several experiments conducted primarily on dairy cows (Bertilsson et al., 1997; van Amburgh et al., 1997; Österman and Bertilsson, 2003; Christiansen et al., 2005; Auldist et al., 2007; Kolver et al., 2007; Sorensen et al., 2008). Extended lactation has been studied for dairy cows in both confinement and pastoral systems. It has been discovered that primiparous cows in confinement systems are able to produce equal or more milk per feeding with unchanged or improved properties during extended lactation compared with cows being milked for a normal 305-d lactation, but only if managed correctly (van Amburg et al., 1997; Rehn et al., 2000; Arbel et al., 2001; Östermann and Bertilsson, 2003; Christiansen et al., 2005; Lehmann et al., 2016; Sehested et al., 2019). However, results for milk production by multiparous cows are inconsistent and limited to two studies. Arbel et al. (2001) and Lehmann et al. (2016) used experimental herds where the cows put forward for extended lactation were selected rather than randomly allocated, potentially creating a bias in their results. However, these studies still demonstrated that high MY could be achieved when cows are in extended lactation. For cows living in pastoral, season-based systems, it had been observed that cows produced less milk per feeding during an extended lactation (Auldist et al., 2007; Grainger et al., 2009; Kolver et al., 2007). This is believed to be due to seasonal feed availability and quality changes, which can be mitigated by supplementary feeding (Grainger et al., 2009).

Two aspects control the duration and productivity of extended lactation: the number and activity of milk-secretory mammary epithelial cells (MEC) as lactation progresses (Knight, 1997; Capuco et al., 2003). Typically, as lactation progresses after peak lactation, the MY begins to decline due to the decreasing number of MEC by apoptosis (programmed cell death) (Capuco et al., 2003; Stefanon et al., 2002). Enhancing the yield, shifting the lactation curve upwards or changing the shape of the lactation curve by decreasing the rate of decline in MY following peak lactation can increase the extension of lactation (Knight, 1997). Total MY can be increased by promoting the regeneration of MEC and decreasing the regression of MEC (Knight, 1997). The factors that influence these two determinants of the persistency of lactation could be an important focus for adapting future management practices throughout the dairy industry to improve the economic gain and welfare of the animals involved.

2.4.2 How lactation can be extended

The length and frequency of lactation can be changed, and indeed, the lactation length observed in production animals likely differs from the biological norms of these animals. The ascending, peak, and descending phases of MY curve during the lactation of a dairy goat characterise the course of milk production from kidding through drying off (Knight, 1997). The rate of decline in MY after the peak phase broadly defines the persistency of milk production. Therefore, a combination of peak yield and lactation persistency defines total lactation milk production (Sehested et al., 2019). As milk production consists of many coordinated metabolic adaptations, limitations are imposed at many levels, from the animal as a whole to the molecular level (Knight, 1989).

The effects of changing the milking frequency on the MEC can be seen when the milking frequency is increased from two to three times per day. This has generally increased daily milk production by 10% to 15% (Stockdale, 2006). Two studies confirm this response for extended lactation (Östermann and Bertilsson, 2003; Sorensen et al., 2008). These studies not only showed that the increased milking frequency increased overall MY but produced an increase in energy-corrected milk (ECM) yield per feeding by 13.2%. The idea that continuous lactation can be achieved by preventing this loss of MECs, due to either increasing cell longevity or cell proliferation is supported by experiments in which yield has been increased and the cellular events studied (Stefanon et al., 2002).

The persistency of the lactation can be increased by enhancing the MY of the lactation. One common practice for achieving this in other countries, such as America, is by administering bovine somatotropin (bST) to cows (Knight, 1997: Capuco et al., 2003). The use of bST has been shown to have a negligible effect on increasing lactation persistency in cattle (Knight, 1997). A more dramatic effect has been reported in dairy goats, where the conjoint administration of bST and increasing milking frequency can dramatically increase peak MY and maintain this high yield for a much longer period (Knight, 1997: Stefanon et al., 2003). While the administration of bST could potentially increase lactation persistency, it is not allowed to be administered in New Zealand to animals that produce milk or meat for human consumption (MPI, 2023).

Hormonal treatments such as bST are not the only ways discovered to increase MY. In both rats and mice, an increase in MY has been demonstrated to be influenced by both litter size and age (Grigor et al., 1984; Shipman et al., 1987). Lactation persistency could potentially occur by increasing milking frequency in goats. Short-term (days to weeks) MY can be increased through enhanced activity of the pre-existing tissue, but MEC number must be increased to enhance MY in the long-term (weeks to months) (Knight, 1989). In dairy cows, a higher milking frequency in the first few weeks of lactation is associated with a higher MY for the whole lactation, with the authors suggesting that this was likely due to increases in the number of MEC present in the mammary gland (Capuco et al., 2003). It was found that the glands milked three times a day had a greater number of MEC than those milked twice daily, but only after 37 weeks of lactation (Stefanon et al., 2003; Wilde et al., 1987). This suggests that increasing milking frequency may decrease the MEC apoptosis rate near the end of the normal lactation period.

The rate of decline in yield is strongly influenced by the rate of apoptosis of the MECs (Stefanon et al., 2003). The loss of MECs has been found to be almost entirely responsible for the decline in the MY of dairy goats after the peak (Knight and Peaker, 1984; Wilde et al., 1986). Knight and Peaker (1984) first found that the proportional decreases in MY and MEC numbers were very similar. Interestingly, in goats Wilde et al. (1986) then showed that the activity of the remaining cells does not decrease by measuring enzyme activities (acetyl-CoA carboxylase, fatty acid synthetase, galactosyltransferase, lactate dehydrogenase, isocitrate dehydrogenase, and phosphofructokinase) and in vitro lactose and casein synthesis rates. In rats and mice, it has been found that maintaining a strong suckling stimulus by swapping in younger litters can lengthen lactation (Flint et al., 1984). The effect of the suckling stimulus in rats and mice appears to be controlled by prolactin (Flint et al., 1984). This leads to the question that there may then be a link between suckling stimulus (or milking frequency) and lengthening lactation in ruminants. However, this process may be more complicated in ruminants as galactopoiesis is not as strongly driven by prolactin (Plaut et al., 1987), although there is research to suggest that prolactin reduces MEC apoptosis in late lactation and does play a role in lactation for dairy goats (Logan et al., 2020).

In ruminants, the lengthening of lactation due to suckling or milking stimuli seems to be influenced by oxytocin as well. This has been seen when oxytocin is administered after each milking for the duration of the lactation. There has been a positive increase in lactation persistency in cows (Nostrand et al., 1991). While the mechanisms by which oxytocin achieves this are not fully understood, it is believed that oxytocin increases milk removal, and so decreases the effect of feedback inhibitor of lactation (now known as serotonin) (Knight, 1997). Serotonin is a hormone and neurotransmitter which opposes endocrine stimulation of mammary development and milk secretion (Wilde et al., 1995; Matsuda et al., 2004). Serotonin is a negative regulator of lactation by downregulating milk protein mRNA expression (Hernandez et al., 2008). Oxytocin is known to mediate the milk ejection reflex in cows and so induces myoepithelial cell contraction allowing more milk to be removed therefore reducing the feedback inhibitor. Oxytocin may also have other actions that directly affect the MECs affecting their proliferation and differentiation (Lollivier et al., 2002). Ballou et al. (1993) found that an intramuscular injection of 20 IU exogenous oxytocin increased milk production by 3% in dairy cows. However, they speculated that this increase in milk production might not be caused by the removal of residual milk and thus decreasing the lactation feedback inhibitor, but rather by increasing gland output (Ballou et al., 1993). The effect of oxytocin on increasing milk production and, therefore, lactation length has been explored in dairy cattle but not entirely within dairy goats.

2.4.3 Possible benefits of employing extended lactation

There are many possible benefits of extended lactation. These include enhancing the efficiency of the lactation by decreasing the rate at which MY declines following peak MY. This lengthens lactation resulting in a smaller proportion of the ruminant's life spent in the periparturient period where there are increased health risks and greater costs as a result and the delayed breeding could also show an increase in reproductive efficiency (Capuco et al., 2003). Extended lactation has already been implemented as a management in many dairy farms as it decreases the number of births per year and the high health risks associated with late pregnancy and parturition, lameness, and many metabolic problems in early lactation (Ingvartsen et al., 2003). Therefore, using extended lactation as a management strategy holds the potential to improve dairy goat longevity and lifetime efficiency (Sehested et al., 2019). It is also believed that the use of extended lactation in dairy cow farms could improve reproductive performance by delaying insemination. As this is known to enhance mounting behaviour and allow insemination to occur after the cow's energy balance has become positive. However, most studies on extended lactation to date have not found a significant positive effect on reproduction (Sehested et al., 2019). To the authors knowledge, the effects of extended lactation on the reproductive performance of goats remains to be investigated.

The use of extended lactation in goats and cattle could also have economic and environmental benefits. Extended lactation could achieve this by reduced costs of insemination, reduced veterinary costs and reduced costs of rearing replacement young, which represent the second-largest annual expense of a dairy farm after the feed costs (Bach et al., 2008). Feed costs will also be affected as pregnant goats require a higher feed intake than those that are not rebred (de Souza Castagnino et al., 2015). By employing extended lactation as a management practice, it could potentially be possible to eliminate the dry period between successive lactations in dairy goats. Goats may be particularly well-suited to this as the drying off between lactations appears to be less important for maintaining high MY in dairy goats than cows (Capuco et al., 2003). In dairy cows, a dry period is necessary to allow the accelerated renewal of MECs to for the next lactation in order to target a MY of the same of greater MY (Capuco et al., 2003). Therefore, there may be a greater economic benefit for using persistent lactations in dairy goats than in dairy cows. As the biennial profit from the MY of the extended lactation may be greater than the profit from the accumulated MY of two subsequent lactations as there will be a no milk production during the dry period for goats in normal lactation. The hypothetical economic outcome for a longer lactation has shown to be very favourable based on a mathematical model done (Knight, 1997). Extended lactation can also contribute to a reduced environmental impact at the farm level by reducing beef production (Sehested et al., 2019). However, the decrease in carbon emissions due to less goats being used for meat production would be small (Robertson et al., 2015).

The New Zealand Code of Welfare is undergoing many changes with a new code of welfare for dairy cattle made in 2019 and a current proposal for amendments to this code being conducted. One area that is being looked at by the National Animal Welfare Advisory Committee is the continuation of the bobby calf industry due to its wide opposition by society. Alternatives to sending the unwanted calves to slaughter is being currently investigated (MPI, 2022).

There are possible disadvantages to the use of extended lactation. These include a decrease in genetic gain for the herd due to less replacements being born each year (Lehmann et al., 2019) therefore increasing the generation interval (Carolino et al., 2017). There will also be increased but more evenly spread labour costs as milking will be year-round (Borman et al., 2004).

2.5 Effect of pregnancy on lactation

The effect of pregnancy on lactation is the main driver for a normal lactation length, largely because late pregnancy puts such a high metabolic demand on the animal that continued lactation is undesirable (Salama et al., 2005). However, this is eliminated in the case of an extended lactation. Understanding the effects of pregnancy on lactation is necessary to understand extended lactation. The effect of pregnancy on lactation length has been seen in dairy cows, where pregnancy caused a significant decline in MY of dairy cows in late lactation from mid-gestation onwards (Olori et al., 1997; Brotherstone et al., 2004), or even as early as from month three of pregnancy (Bormann et al., 2002). Salama et al. (2005)

also demonstrated that pregnancy also affects milk production in goats by observing a dramatic decrease in MY after mating (Figure 2.3).

Figure 2.3. Daily MY in dairy goats kidded annually (●) or biennially (○). Values are means with SE indicated by vertical bars (Salama et al., 2005).

Knight and Wilde (1988) found that pregnancy had no effect on MY during the first eight weeks of pregnancy in twice-daily milked Saanen goats but had a significant impact on MY as the pregnancy progressed. In fact, MY rapidly decreased after the first eight weeks and was 57% of the value of non-pregnant goats in the last week of pregnancy (Knight and Wilde, 1988). At week 13 of pregnancy (week 42 of lactation), the MY in the goats kidding yearly was only 21% of the value of the goats kidding at 24-month intervals (0.31 ± 0.09 vs. 1.41 ± 0.14 L/d, respectively) (Knight and Wilde, 1988). Salama et al. (2005) milked goats once daily and mated them relatively late in lactation (week 29). It was found this resulted in greater MY losses than when goats were mated in early lactation (Salama et al., 2005; Knight and Wilde, 1988). This indicates that pregnancy has a greater effect on late lactation, and this effect is exacerbated if late lactation and late pregnancy occur simultaneously. Some authors have suggested that the more dramatic effect is likely due to the suppression of galactopoietic hormones (e.g., prolactin) as lactation advanced (Lacasse et al., 2012; Tucker, 1981). Milk production is also reduced in late pregnancy due to the rise in progesterone that is present throughout late pregnancy (Tucker, 1981). Plasma progesterone concentration in goats has been seen to increase from (2.5-3.5 ng/ml during early pregnancy (day eight to day 60) to 4.5-5.5 ng/ml in late pregnancy and is maintained until just prior to parturition (Thorburn and Schneider, 1972). Changes in some of these hormones have been recorded Sorensen and Knight (2002) reported that blood concentration of GH decreased whereas insulin concentration increased as lactation advanced in dairy cows.

The mechanism by which pregnancy influences MY and lactation length is not fully understood, but it is believed to be caused by the hormones released during pregnancy, especially oestrogen in ruminants (Bachman et al., 1988; Akers, 2002). Circulating oestradiol concentrations remain low until week nine of pregnancy in goats and then increases gradually until one week before kidding. In goats, oestradiol concentrations increase rapidly and peak in the week prior to kidding and are dependent on the number of foetuses (Dhindsa et al., 1981; Manalu et al., 1996; de Souza Castagnino et al., 2015. The effect of oestrogen on the mammary gland has been seen in many studies. When oestrogen is administered to lactating goats, mammary gland regression can be seen alongside a significant decline in MY in lactating goats (Peaker and Linzell, 1974). Furthermore, mammary gland involution can be stimulated by an exogenous intramuscular injection of oestradiol in both dairy cows and goats (Athie et al., 1997, Mellado et al., 1998). It is believed the involution is accelerated by oestrogen promoting plasminogen activation (Athie et al., 1997), which is a part of the tissue remodelling process that occurs during mammary gland involution (Fantuz et al., 2001). Another pregnancy hormone that is thought to have an effect on milk production is placental lactogen, which peaks during the last third of pregnancy and as a result may influence mammogenesis and lactogenesis, as it alters the maternal metabolism to accommodate the growth and development of the foetus before parturition (Akers, 2002). Thus, many of the hormones associated with pregnancy have been found to affect lactation. However, the hormonal aspect of pregnancy is unlikely to be the only factor that decreases the MY of goats.

The nutrient requirements of the gravid uterus and foetus during late pregnancy will also contribute to the decrease in MY (Bell et al., 1995). This is because the energy requirements for pregnancy not only include the energy deposited in the conceptus, but also the energy used for the conceptus metabolism and the energy used by maternal tissues such as the placenta to support the conceptus (Freetly and Ferrell, 1998). Indeed, there is a negative correlation (R2 = 0.35) between litter birth weight and MY at week 13 of pregnancy (week 42 of lactation) (Salama et al., 2005). This is believed to indicate that there is competition for energy between milk production and conceptus. The competition between the gravid uterus and mammary gland in pregnant lactating ewes has also been seen as in a study comparing blood glucose levels in pregnant and non-pregnant ewes (Freetly and Ferrell, 1998). This study found that there was a net increase in hepatic glucose release from day 40 of pregnancy onwards in ewes. However, despite hepatic glucose releases being higher in pregnant than non-pregnant goats in goats, blood glucose concentrations were lower in in nonpregnant ewes (Khan and Lurdi, 2002). This suggests that there is more competition for glucose partitioning between the mammary gland for lactose synthesis and the gravid uterus that result in milk losses due to pregnancy (Salama et al., 2005).

2.6 Summary

The use of extended lactation has been looked at previously in dairy cows throughout the world and in New Zealand. While the use of extended lactation in dairy goats has been studied around the world it has only recently been introduced into New Zealand. This thesis will begin to look at the potential use of extended lactation in the New Zealand dairy industry. The length or persistency of lactation is dependent on maintaining the number and activity of milk-secreting cells as lactation progresses. The factors that influence these two determinants of the persistency of lactation could be an important focus for adapting future management practices throughout the dairy industry to improve the economic gain and welfare of the animals involved. The possible benefits of extended lactation include enhancing the efficiency of the lactation, a smaller proportion of the ruminant's life spent in the periparturient period where there are increased health risks, and the delayed breeding could also increase reproductive efficiency. Not only does the use of extended lactation potentially increase the health of dairy goats it could also have economic and environmental benefits. By reduced costs of insemination, reduced veterinary costs and reduced costs of rearing replacement young increasing revenue due to the MY of the persistent lactation may be greater than the profit from the accumulated MYs of two subsequent lactations. Extended lactation can also contribute to a reduced environmental impact at the farm level by reducing beef production.

The effect of pregnancy on lactation is the driver for a normal lactation length and so to achieve extended lactation this effect is removed. The effect of pregnancy on lactation length has been seen in dairy cows where pregnancy caused a significant decline in MY of dairy cows in late lactation. The mechanism by which pregnancy influences MY and lactation length is not fully understood, but it is believed to be caused by the hormones released during pregnancy, especially oestrogen and placental lactogen. The nutrient requirements of the gravid uterus most likely also contribute to the decrease in MY witnessed during pregnancy.

2.7 Research questions for extended lactation in New Zealand

The literature review chapter provided a summary of global dairy goat farming and throughout New Zealand. It will then explore literature available explaining what extended lactation is, how it can be achieved and the possible benefits for employing it in New Zealand dairy farms. Finally, the review looked at how pregnancy effects milk production. The current literature available has led to the research questions: “If extended lactation could be a beneficial management practice to be employed throughout New Zealand dairy goat farms?” and “What is the effect of extended lactation on milk production?”

Chapter 3: Materials and methods

3.1 Data

The herd test records of 5457 New Zealand dairy goats for Milk yield (MY), Fat yield (FY), and Protein Yield (PY) were recorded from 2009 to 2021, and pedigree information was provided by Dairy Goat Cooperative, New Zealand. The data was provided by a large commercial dairy goat farm in New Zealand and primarily consisted of Saanen pure or part-bred goats.

Initial data were restricted as follows (Figure 3.1). Firstly, herd-test records were sorted based on Doe_parity code provided by Dairy Goat Cooperative goats milked either for a normal 270d lactation or a 670-d lactation. Goats milked for less than 270d or milked for 290 – 630d were excluded. Goats which kidded before 2013 were labelled as 2013 and for those that kidded after 2019 were removed as they had not completed the lactation by data collection. Also, goats in parity eight and above were grouped as parity eight.

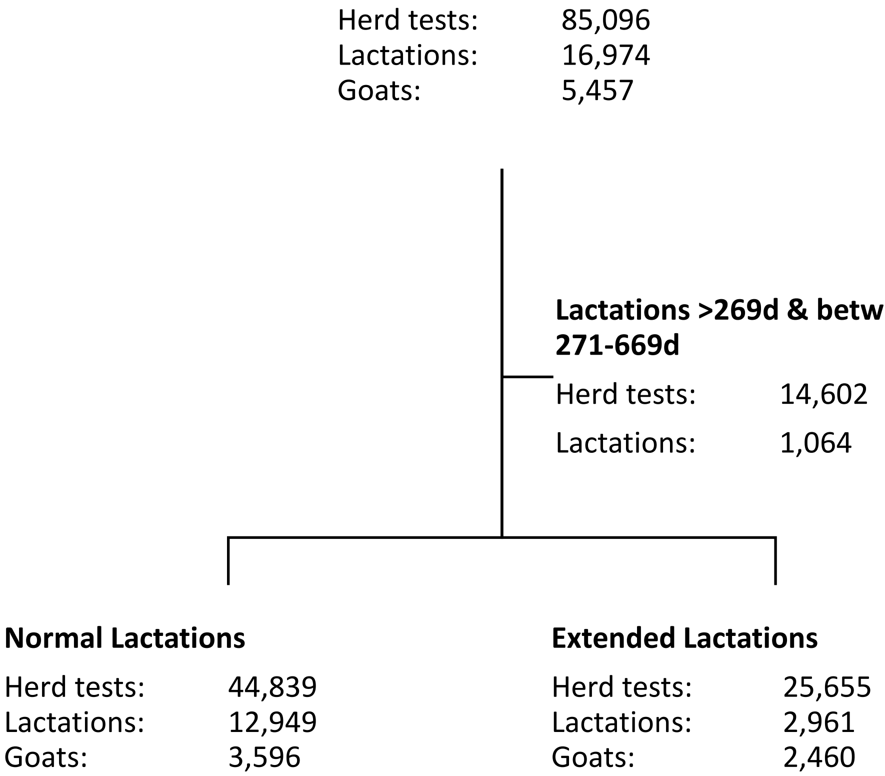

Figure 3.1 Diagrammatic representation of the number (n) of animals in the dataset for New Zealand Dairy Goats from 2013 – 2019 made from 5,457 goats, these were then divided into goats milked for 270-d normal lactations and 670-d extended lactations.

3.2 Lactation curves

A data set with herd-test records and animal information was obtained from the Dairy Goat Cooperative database. There were 85,096 herd-test records for daily yields of milk and fat, and protein from 16,974 lactations of 5,457 dairy goats kidding between 2013 and 2019 in a large commercial herd (Figure 3.1). Daily yields of fat and protein were obtained by multiplying daily MYs by respective percentages obtained from herd tests. The animal information included unique identification of animal, sire and dam, date of birth and parturition, parity number in which the lactation started, proportion of Saanen, Toggenburg, Alpine, Nubian, and “unknown” and “other” breeds.

The data set was split into two data sets, one with normal lactations and the other with extended lactations. A normal lactation was considered when herd-tests occurred between 15 and 270 days in milk and the animal in that lactation did not have herd-tests after 270 days in milk. This data set contained 44,839 herd-tests corresponding to 12,949 lactations (Figure 3.1). An extended lactation was considered when the herd-tests occurred between 15 and 670 days in milk. Some animals in one specific lactation had herd-test after 670 days in milk, that lactation was considered as extended lactation, but herd-test taken before 670 days in milk were considered for this analysis. This data set contained 25,655 herd-test records corresponding to 2961 lactations (Figure 3.1).

3.2.1 Modelling lactation curve

Modelling of 2,961 extended lactations up to 670 days was based on 25,655 herd-tests for daily yields of milk, fat, and protein using a random regression model fitting a fifth order Legendre polynomial. The random regression model was represented as follow:

$$Y_{ti} = (\beta_0 P_0 + \beta_1 P_{1t} + \beta_2 P_{2t} + + \beta_3 P_{3t} + + \beta_4 P_{4t} + \beta_5 P_{5t}) + (\alpha_{0j} P_0 + \alpha_{1j} P_{1t} + \alpha_{2j} P_{2t} + \alpha_{3j} P_{3t} + \alpha_{4j} P_{4t} + \alpha_{5i} P_{5i}) + e_{ti}$$

where y jt represents the daily yield for doe-parity j in day t of the lactation after kidding, β 0 to β 5 are fixed regression coefficients representing the lactation curve of the population, α 0j to α 5j are random regression coefficients for doe-parity j, P 0 to P 5t are orthogonal polynomial functions of order 0 to 5 as defined below, and e jt is the random residual error.

Legendre polynomials were chosen to normalise values to the interval [−1, …., 1], and the coefficients were then calculated using the Rodrigues formula:

$P0(t)=1,P0(t)=1,$

$P1(t)=x,P1(t)=x,$

$P2(t)=12(3x2-1),P2(t)=12(3x2-1),$

$P3(t)=12(5x3-3x),P3(t)=12(5x3-3x),$

$P4(t)=18(35x4-30x2+3),P4(t)=18(35x4-30x2+3),$

$P5(t)=18(63x5-70x3+15x)P5(t)=18(63x5-70x3+15x)$

where x = −1 + 2, and (t − tmin) (tmax − tmin)t − tmin tmax − tmin, with tmin = 1 and tmax = 130. Day 1 corresponded to day 1 of lactation.

Modelling of 12,949 normal lactations up to 270 days in milk was based on 44,839 herd-tests for daily yields of MY, FY, PY using a random regression model fitting a 3rd order Legendre polynomial (Kirkpatrick et al., 1990). The estimates of β's and α's was obtained using the Restricted Maximum Likelihood procedure in ASReml version 4.2 (Gilmour et al., 2021). The polynomials of order 2, 3, 4, 5 and 6 were tested. Based on the Akaike (AIC) information criterion (Akaike, 1973), an orthogonal polynomial of order 3 was considered the best fit for modelling lactation curves of milk, fat, and protein for normal lactations. An orthogonal polynomial of order 5 was considered the best fit for modelling lactation curves of milk, fat, and protein for extended lactations.

Estimates of random regressor coefficients (α0 to α3 or α0 to α5, depending on the trait) of each doe-parity were used to estimate the daily yields at each day of the lactation; 1 to 305 days for normal lactations and 1 to 670 days for extended lactations. Then, the predicted yields at each day of the lactation were summed to obtain an estimated total MY, FY and PY produced by each doe in the corresponding parity.

3.3 Statistical Analysis

Data set of normal and extended lactations were analysed separately. All statistical analysis were performed using the statistical package SAS version 9.4 (SAS, 2004). Descriptive statistics (mean, normal deviation, and coefficient of variation) for total yields and persistence were obtained with the MEAN procedure. Analysis of variances for the estimated total yields, persistence and estimates of regression coefficients were performed using the GLIMMIX procedure with a linear model that included the fixed effects of year (2013 to 2019) and month (Jun, Jul, Aug and Sep-Oct) of parturition and parity number as class effects, and the random effect of doe to account of repeated lactations in the same data set. Least-squares means for each class of the fixed effects and normal errors were obtained and used for mean comparisons using Fisher's least significant different test.

Chapter 4: Results

4.1 Descriptive statistics

Table 4.1 details the descriptive statistics for MY, FY, PY for goats in normal lactation and extended lactation. Goats in extended lactation produced more kg milk per day than goats in a normal lactation 3.68 kg/d and 3.25 kg/d, respectively (Table 4.1). The mean FY for goats in an extended lactation was higher than for goats in the extended lactation (Table 4.1), as was daily PY (Table 4.1). Unsurprisingly (due to the longer duration of lactation and higher daily MY), goats in extended lactation produced considerably more kg milk per lactation than goats in a normal lactation, 2433 kg and 888 kg, respectively (Table 4.1). Goats in extended lactation also had a higher total FY and total PY per lactation (Table 4.1).

Table 4.1. Descriptive statistics for 270-d normal and 670-d extended lactations in New Zealand dairy goats for the period 2013-2019.

Variable	N	Mean	SD	Min	Max
Normal lactations					
Daily yields					
Milk	44772	3.25	1.304	0.10	10.7
Fat	44122	0.11	0.043	0.01	0.38
Protein	44124	0.10	0.036	0.015	0.32
	270-d yields				
Milk	12943	887.87	260.563	174.49	2168.55
Fat	12943	30.38	8.128	10.30	73.85
Protein	12943	27.75	8.128	7.67	71.22
	Extended lactations				
	Daily yields				
Milk	25645	3.68	1.16	0.10	12.20
Fat	25567	0.12	0.04	0.02	0.39
Protein	25565	0.12	0.03	0.02	0.39
	670-d yields				
Milk	2961	2432.98	534.698	1093.46	4856.51
Fat	2961	77.46	16.639	33.33	143.70
Protein	2961	78.13	15.947	37.09	138.96

4.2 Normal lactation

4.2.1 Milk yield

Goats that were recorded in a normal 270-d lactation produced an average of 895 kg of milk when categorised by parity (Table 4.2), the total MY produced each lactation increasing from the goats in their first parity to peaking with goats in parity three and then slowly declining as the parity increases.

The year with the highest total MY produced by goats in normal lactation was 2018 with 1018 kg of milk (Table 4.2). The lowest MY was in 2014, 793 kg but then it increased each year until 2018 and then declined slightly in 2019.

The lactation starting month with the lowest total MY for normal lactation goats was June with only 852 kg produced for the season. The total MYs increased for goats starting in July and then peaked in August, 925 kg before then decreasing slightly for goat starting lactating in September (Table 4.2).

4.2.2. Fat yield

Goats that were recorded in a normal 270-d lactation produced an average of 29.7 kg of fat (Table 4.2). The total FY produced each lactation increasing from the goats in their first parity to peaking with goats in parity three and then slowly declining as the parity increases.

When looking at the average FY produced by two consecutive normal lactations 60.7 kgs this was lower than the average FY produced per doe in extended lactation per starting year (76.3 kg per lactation; Table 4.3). The year with the lowest FY was 2014, 27.6kg for goats in normal lactation this then increased until 2018, 32.6 kg, and declined slightly in 2019, 31.1 kg (Table 4.2).

The lactation starting month with the lowest total FY for normal lactation goats was June with only 29 kg produced for the season (Table 4.2). The total FYs produced increased for normal lactation goats starting in August had the highest FY with 30.3 kg produced before then decreasing slightly for goats staring lactating in September.

4.2.3 Protein yield

Goats that were recorded in a normal 270 d lactation produced an average of 27.1 kg of protein (Table 4.2). Total PY per lactation for normal lactation dairy goats increases from those in parity one to parity three before then decreasing as parity increases. The year with the lowest PY was 2014, 25.0 kg for goats in normal lactation this then increased until 2018, 30.0 kg, and declined slightly in 2019, 28.5 kg (Table 4.2). The lactation starting month with the lowest total PY for normal lactation goats was June with only 26.4 kg produced for the season this is the same lowest starting month as the PY from extended lactation goats (Table 4.2). The total PYs produced increased for normal lactation goats until August, which had the highest PY with 27.7 kg produced before then decreasing slightly for goats staring lactating in September.

Table 4.2. Least squares means and standard errors for 270-d normal lactation yields in by parity and year and month of kidding in New Zealand dairy goats for the period 2013-2019.

Factor	Milk (kg)		Fat (kg)		Protein (kg)	
Parity	Mean	SE	Mean	SE	Mean	SE
1	815^{e}	6.2	27.2^{f}	0.20	24.5^{f}	0.20
2	1024^{b}	6.6	33.8^{b}	0.21	31.2^{b}	0.21
3	1058^{a}	6.8	34.6^{a}	0.22	32.0_{a}	0.22
4	1019^{b}	7.4	33.1^{c}	0.24	30.5^{c}	0.24
5	944^{c}	8.4	31.0^{d}	0.27	28.4^{d}	0.27
6	853^{d}	9.9	28.4^{e}	0.32	25.8^{e}	0.32
7	788^{f}	11.8	26.6^{f}	0.39	23.9^{f}	0.39
8	659^{g}	12.3	22.8^{g}	0.40	20.2^{g}	0.40
Lactation year						
2013	795^{d}	5.333	28.1^{d}	0.17	25.5^{d}	0.17
2014	793^{d}	8.0	27.6^{e}	0.46	25.0^{e}	0.26
2015	824^{c}	9.6	27.9^{de}	0.31	25.3^{de}	0.31
2016	881^{b}	10.2	29.2^{c}	0.33	26.5^{c}	0.33
2017	979^{a}	11.3	31.3^{b}	0.37	28.6^{b}	0.37
2018	1018^{a}	14.3	32.6^{a}	0.46	30.0^{a}	0.46
2019	975^{a}	20.56	31.1^{b}	0.66	28.5^{b}	0.66
Lactation month						
June	852^{c}	13.6	29.0^{b}	0.44	26.4^{b}	0.44
July	907^{b}	5.5	29.7^{b}	0.18	27.1^{b}	0.18
August	925^{a}	6.7	30.3^{a}	0.22	27.7^{a}	0.22
September	896^{b}	8.3	29.7^{b}	0.27	27.1^{b}	0.27

$^{a, b, c, d, e, f, g}$ shows significant difference between the means within each factor for each yield.

4.3 Extended lactation

4.3.1 Milk yield

When the goats were divided by parity in extended lactation, they produced an average of 2396 kg per lactation (Table 4.3). With the least milk being produced by those that are in their first lactation, the total MY being produced in each lactation increased from the goats in their first lactation until they peaked in their fourth lactation and then continued to decrease from those that were in their fifth lactation. The trend seen in dairy goats milked for an extended lactation over lactation year differed slightly to normal lactation. The lowest total MY was seen 2013 with 2230 kg and increased each year until 2019 when 2613 kg was produced (Table 4.3). The pattern was similar for goats in extended lactation to goats in normal lactation. The month with the highest total MY produced for goats in extended lactation was September with goats that began lactating in September producing an average of 2503 kg for their 670d lactation (Table 4.3). For goats in extended lactation, we saw an increase in total MY produced from goats beginning their lactation in June 2293 kg increasing through July and August where it peaked in September.

4.3.2 Fat yield

Goats when in extended lactation produce more kgs of fat per lactation than goats in a normal lactation (Table 4.3). When investigating FY, the goats were divided by parity in extended lactation, they produced an average of 76.3 kg per lactation (Table 4.3). With the least fat being produced by those that are in their first lactation, the total FY being produced in each lactation increased from the goats in their first lactation until they peaked in their fourth lactation.

The pattern of FY produced by extended lactation (Table 4.3) differs slightly from that seen by goats in normal lactation. For goats in extended lactation the year with the lowest FY was 2013 with 74.2 kg and then increased in 2014 and 2015 then dipped in 2016 before increasing once again until 2019 with 78.9 kg produced.

The pattern was similar for goats in extended lactation to goats in normal lactation however the month with the highest total differed. The month with the highest total FY produced for goats in extended lactation was with goats that began lactating in September producing an average of 79.5 kg for their 670-d lactation (Table 4.3). For goats in extended lactation, there was an increase in total FY produced from goats beginning their lactation in June, 73.9 kg increasing through July and August where it peaked in September.

4.3.3 Protein yield

Table 4.3 shows that goats when in extended lactation produce more kgs of protein per lactation than goats in a normal lactation. When investigating PY the goats were divided by parity in extended lactation, they produced an average of 76.9 kg per lactation. With the least protein being produced by those that are in their first lactation, the total PY being produced in each lactation increased from the goats in their first lactation until peaking in their fourth lactation and then continued to decrease from those that were in their fifth lactation.

The pattern of PY produced by extended lactation differs slightly from that seen by goats in normal lactation. For goats in extended lactation the year with the lowest PY was 2013 with 69.2 kg and then increased in 2014 and 2015 then dipped in 2016 before increasing once again until 2019 with 83.2 kg produced (Table 4.3).

Table 4.3. Least squares means and standard errors for 670-d extended lactation yields in by parity and year and month of kidding in New Zealand dairy goats for the period 2013-2019.

Factor	Milk (kg)		Fat (kg)		Protein (kg)	
Parity	Mean	SE	Mean	SE	Mean	SE
1	2064^{d}	21	68.5^{d}	0.70	66.7^{c}	0.61
2	2559^{bc}	24	82.2^{ab}	0.77	82.6^{a}	0.72
3	2583^{ab}	24	82.6^{a}	0.77	82.9^{a}	0.71
4	2620^{a}	26	82.9^{a}	0.83	83.7^{a}	0.76
5	2570^{ab}	31	80.3^{bc}	0.10	81.8^{a}	0.92
6	2471^{c}	44	78.3^{c}	1.42	78.8^{b}	1.32
7	2182^{d}	72	67.3^{d}	2.31	69.8^{c}	2.14
8	2121^{d}	90	68.4^{d}	2.93	68.5^{c}	2.68
Lactation year						
2013	2230^{d}	60	74.2^{bc}	1.94	69.2^{e}	1.77
2014	2260^{d}	28	74.9^{bc}	0.89	74.2^{d}	0.82
2015	2363^{c}	31	76.4^{b}	0.99	76.6^{c}	0.91
2016	2304^{cd}	31	73.5^{c}	1.01	74.5^{d}	0.93
2017	2489^{b}	29	77.9^{ab}	0.94	79.7^{b}	0.87
2018	2515^{b}	28	78.4^{a}	0.91	80.4^{b}	0.84
2019	2613^{a}	26	78.9^{a}	0.84	83.2^{a}	0.77
Lactation month						
June	2293^{b}	40	73.9^{b}	1.27	74.7^{b}	1.18
July	2341^{b}	19	74.5^{b}	0.62	74.8^{b}	0.57
August	2447^{a}	28	77.3^{a}	0.92	77.9^{a}	0.84
September	2503^{a}	41	79.5^{a}	1.33	79.9^{a}	1.22

$^{a, b, c, d, e, f, g}$ shows significant difference between the means within each factor for each yield.

The pattern was similar for goats in extended lactation however the month with the highest total differed. The month with the highest total PY produced for goats in extended lactation was with goats that began lactating in September producing an average of 79.9 kg for their 670-d lactation. For goats in extended lactation, there was an increase in total PY produced from goats beginning their lactation in June, 74.7 kg increasing through July and August where it peaked in September (Table 4.3).

4.4 Depiction of parity and lactation start month effects

Figures 4.1 and 4.2 depict the lactation curves for MY, FY and PY for goats in extended or normal lactation when categorised by parity (Figure 4.1), and lactation month (Figure 4.2). At the beginning of the lactations (intercept), goats milked for extended lactation had higher values for MY and PY. However, the intercept for FY was slightly higher in normal lactation goats than in extended lactation. The estimate of regression coefficients describing the lactation curves of MY, FY and PY by parity number, lactation year and month in which the lactation starts for the goats under the two different lactation lengths are shown in the appendices 2-8.

For normal lactation goats their peak MY occurred between 100-120d, however, the goats in their first parity peaked slightly later at around 130-160d of lactation. This peak was earlier than the peak seen in goats in extended lactation where the first peak occurred between 50 – 80 days of lactation. However, the peak was lower for goats in normal lactation. For both goats in normal lactation and goats in extended lactation their peak FY occurred within the first days of lactation. For normal lactation goats their peak PY occurred between days 25 – 70 of lactation with goats in parity one having a peak PY slightly later at approximately 105 days of lactation. This was later than the peak protein witnessed in extended lactation goats where the peak was before 25 days of lactation. Importantly for all three milk aspects being analysed the values for goats in parity one was much lower than for goats in other parities in both normal and extended lactation.

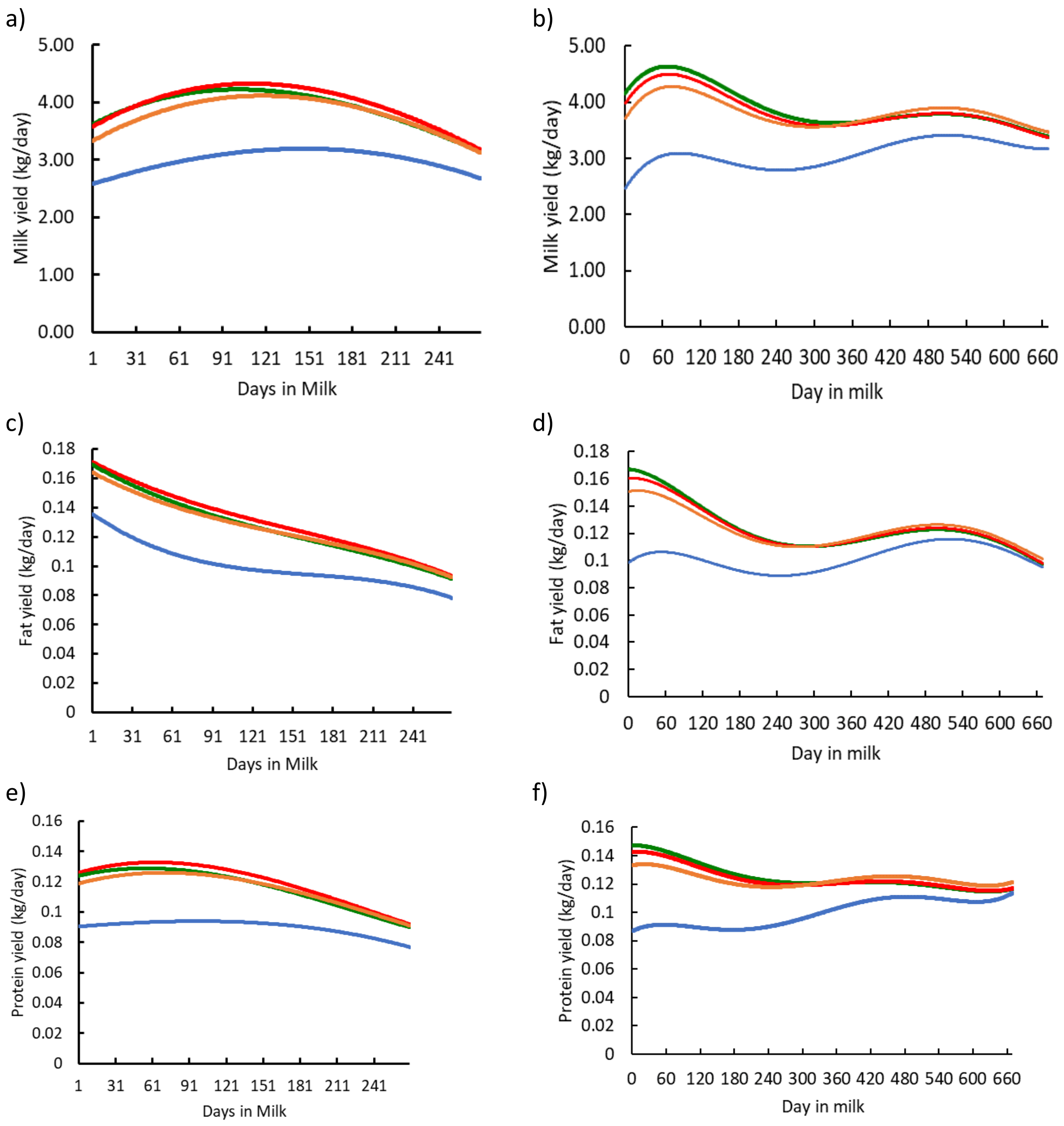

Figure 4.1 Lactation curves for milk yield, fat yield and protein yield for goats in normal lactation (a, c, e, respectively) and extended lactation (b, d, e, respectively) for parity one (blue), two (orange), three (red), and four (green).

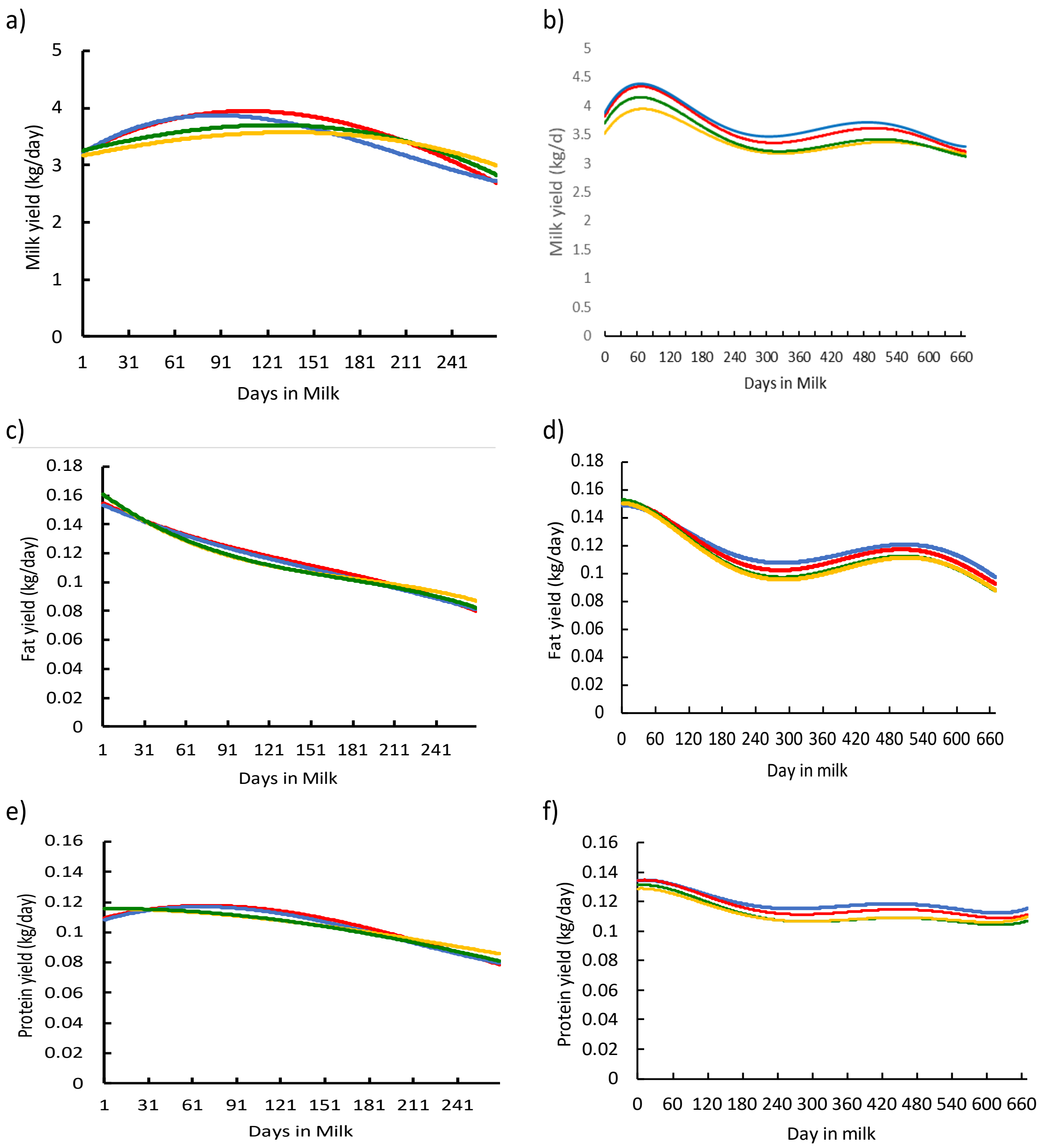

Figure 4.2 Lactation curves for milk yield, fat yield and protein yield for goats in normal lactation (a, c, e, respectively) and extended lactation (b, d, e, respectively) for June (yellow), July (green), August (red), and September (blue).

Chapter 5: Discussion

In order to begin looking at the possibility of employing extended lactation as a more beneficial management in New Zealand dairy goat farms. This study was carried out to investigate the milk production of New Zealand dairy goats for either a normal lactation (270d) or extended lactation (670d). To achieve these three aspects of milk production were analysed: MY, FY, and PY were analysed. The effects of lactation type, and also parity, year of lactation, and month of starting lactation, on these milk production parameters were assessed. To the authors knowledge, this is the first study doing this in a commercial herd of dairy goats (c.f., experimental herds). As such, the findings of this research provide a more practical analysis of extended lactation than those seen in experimental herds data in which experimental animals were systematically selected for extended lactation, potentially biasing the results (Wolber et al., 2021).

5.1 Comparison of milk production in extended or normal lactations

Goats in extended lactation produced more kg milk than goats in two normal lactations 2433 kg/ lactation and 1776 kg/ two lactations, respectively. The mean total FY for goats in an extended lactation (77 kg/lactation) was higher than for goats in two normal lactations (61 kg/two lactations). The higher FY goats produce in extended lactation agrees with results reported for dairy cows in extended lactation, which showed that cows in extended lactation had a total FY higher than those in normal lactation (Auldist et al., 2010). The high-fat production from extended-lactation dairy goats encourages using extended lactation milking for cheese production. The same was seen for total protein yields, 78 kg/lactation for goats in extended lactation and 55.5 kg/two lactations. The higher protein production in goats with extended lactation has been witnessed in previous studies comparing extended lactation to normal lactation milk production of dairy cows (Auldist et al., 2010; Sehested et al., 2019). These observations of greater milk production by those in extended lactation rather than two normal lactations is agreed with in multiple studies (Goetsch et al., 2011; Gendron and Reveau, 1995). This higher MY, FY, and PY of goats in extended lactation than normal was not only due to more days in milk, since there average daily MY of goats in extended lactation was also higher.

Firstly, looking at MY, the mean MY for goats in a normal lactation was 3.25 kg/d, while for goats in the extended lactation was 3.68 kg/d (Table 4.1). This shows that goats in extended lactation produce more kg of milk per day than goats in normal lactation. The average daily MY produced by a goat in normal lactation was higher than the average value recorded by Salama et al. (2005), where they found that an average of 2.23 ± 0.13 L/d was recorded for the first 29 weeks of their first lactation before mating. The mean daily MY from this study was also higher than the mean daily MY reported on by Zalcman and Cowled (2018), 2.5 L/day. Where the MY was then seen to decrease, exhibiting the effect of pregnancy on MY, this study also recorded higher average MY for goats in extended lactation than was found in a study by Salama et al. (2005), where they discovered that goats in extended lactation during the dry period for the normal lactation goat produced an average of 1.53 ± 0.10 L/d. The average MY for weeks 80 -92 in this study for goats in extended lactation was 3.36 L/d, and for goats in their second normal lactation (every second lactation year), the average was 3.49 L/d. This agrees with another study that found that MY between weeks 80-92 of extended lactation and the same time in a second normal lactation are similar (Salama et al., 2005). The difference in the results collected in this study to those observed in Salama et al. (2005) is most likely due to this study being conducted using data collected from commercial farms while the herd used in Salama et al. (2005) was an experimental herd, and so the goats selected for extended lactation in this study were most likely higher producing goats already.

The mean FY for goats in a normal lactation was 0.11 kg/d, while for goats in extended lactation was 0.12 kg/d (Table 4.1). This shows that goats in extended lactation produce slightly more kgs of fat per day than goats in normal lactation. Salama et al. (2005) also found that goats in normal lactation produced milk that contained lower fat and protein content than those in extended lactation; however, they found that the normal lactation goats produced a higher MY.

The mean PY for goats in a normal lactation was 0.10 kg/d, while for goats in the extended lactation was 0.12 kg/d (Table 4.1). This shows that goats in extended lactation produce more kg of protein per day than goats in normal lactation. Salama et al. (2005) also found that goats in extended lactation produce more protein than goats in normal lactation.

Interestingly, goats that completed two normal 270-d lactations over the duration of single extended lactation only produced an average of 1790 kg of milk. This result differs from another study comparing dairy goat milk production, which found that MY was lower by 8.2% in goats in extended lactation (Salama et al., 2005).

Overall, the results from this study displayed that New Zealand dairy goats in extended lactation produced an average higher daily MY, higher daily PY, and slightly lower FY than dairy goats in normal lactation. Throughout a single lactation, it was found that extended lactation dairy goats' milk was 6.39% fat and protein, while goats in normal lactation produced milk that contained 6.28% fat and protein. The increase in fat and protein content of milk produced by goats in extended lactation agrees with a study conducted comparing milk composition in dairy cows (Maciel et al., 2016; Auldist et al., 2010; Sorensen et al., 2008). The slightly higher solids content in the extended dairy goat milk may allow a greater contribution to cheese yield (Salama et al., 2005).

5.2 Effect of parity

5.2.1 Milk yield by parity number

Parity had a significant effect on the MY, FY, and PY in both normal (Table 4.2) and extended (Table 4.3) lactation. As reported in another study (Carnicella et al., 2008), the least milk was produced by those in their first lactation, with the total MY produced in each lactation increasing from the goats first lactation until the fourth lactation, then decreased in the fifth lactation until parity eight (Figure 4.1). A similar effect of parity was observed in goats in normal lactation, although lactation peaked in lactation three rather than four Zamuner et al. (2020) discovered that goats in the first parity had a 26% lower MY than goats in their third lactation. They also agree with my results for goats in normal lactation, where peak MY occurs in third lactation (Zamuner et al., 2020; Arnal et al., 2018; Ciappesoni et al., 2004). However, it slightly differs from the results collected for extended lactation in the present study, where they peaked in their fourth parity. In saying that, Goetsch et al. (2011) stated that milk production in goats peaks in either parity three or four.

The number of goats to successfully complete a 670d extended lactation decreased as parity increased after the fourth parity. In this study, 473 goats completed an extended lactation in parity four, decreasing to only 29 goats completing an extended lactation in parity eight and above. Several other studies also show this negative correlation between the success rate of extended lactation and parity (Gipson and Grossman, 1990; León et al., 2012; Arnal et al., 2018).

5.2.2 Fat and protein yields by parity number

Much like total MY, the total FY and PY was also lowest in both normal (Table 4.2) extended (Table 4.3) lactation goats in their first lactation, then the total FY per lactation progressively increased in their second and third lactation until they peaked in their fourth lactation and decrease from those that were in their fifth lactation (Figure 4.1). An effect of parity on total FY and PY has been reported previously in cattle, with peak total FY and PY occurring in either lactation three or four (Auldist et al., 2010; Sehested et al., 2019). The results from this study also concur past studies, which all found that fat content did increase until parity four in dairy goats. (Šlyžius et al., 2017; Carnicella et al., 2008; Ciappesoni et al., 2004). Šlyžius et al. (2017) also reported that fat percentages then decrease from the fourth-sixth parity, agreeing with the present study. In contrast, both Mioč et al. (2008) and Zamuner et al. (2020) found that fat content was not affected by parity in goats and Zamuner et al. (2020) found that protein content was not affected. Collectively, these studies suggest that the effects of parity on fat and protein content in dairy goat milk are inconsistent. This discrepancy could be, in part, due to differences in milk production depending on the month in which lactation starts. Perhaps of more importance to the context of my research, is that both total FY and PY was higher for extended lactation than normal lactation irrespective of parity number.

5.2.3 How parity affects lactation

One explanation for increased MY, FY and PY, after the first lactation is that the increased body weight of the goats with a greater number of lactations, as they physically mature until 4 or 5 years of age (McGregor and Butler, 2010), allows a greater availability of body reserves for milk components. This is further supported by the fact that the variability in the MY of goats in different parities decreases in late lactation, as the contribution of body reserves to milk synthesis was reduced (Grummer, 1991). There is also an increase age with increased number of lactations, and therefore, physical maturity of the goats as parity increases could also result in an improved efficiency of the homeorhetic dynamics for the partitioning of nutrients to lactogenesis and galactopoiesis (Hart, 1983). The greater partitioning of nutrients to galactopoiesis at the expense of other body tissues in older dams is supported by a study on ewes where increased milk production was observed in higher parity ewes while average weight gains tended to decrease. Ewes in parity one had an average weight gain was 118 g/d, this was lower for goats in parity two and parity three (95 and 84 g/d, respectively) (Sevi et al., 2000). The fact that goats in their first lactation are still rapidly gaining weight themselves and this can limit lactation could explain why this was an increase in MY from the first to second lactation is larger than from the second to the fourth.

The trend of increasing milk production by parity until parity four could be explained by firstly that the number of lactations a doe undergoes results in greater development of the udder glandular tissue, which then increases the synthesis of milk constituents (Hart, 1983). The decrease in milk production after parity four agrees with other studies (Lush and Shrode, 1950) that found that as age progresses after physical maturity production declines.

5.3 Effect of lactation year

5.3.1 Milk yield by lactation year

When categorised by lactation year, the average total MY produced per goat was 1790 kg for two lactations, which is less than the average total MY of 2396 kg for goats in extended lactation. The year with the highest total MY produced by goats in normal lactation was 2018 (1018 L of milk) and lowest MY was 2014 (793 kg), which was slightly lower than the MY recorded for 2013, but then it increased yearly from 2014 to 2018 and declined slightly in 2019 (Table 4.2). This differed slightly from the trend in dairy goats milked for an extended lactation. The lowest total MY was seen in 2013 with 2230 kg and increased yearly until 2019, when 2613 kg was produced (Table 4.3). This increase could be due to more farmers introducing effective management practices to help optimise milk production in goats in extended lactation each year (van Knegsel et al., 2022), excluding 2016. More goats were selected to be kept in extended lactation than in the previous season. Initially, only 73 goats were milked for an extended lactation in 2013, increasing to 582 goats completing an extended lactation of at least 670 days starting in 2019. The increase in MY over the lactation years agrees with Miller & Lu (2019), which notes that goat milk production is increasing each year.

5.3.2 Fat and protein yields by lactation year

For both extended (Table 4.3) and normal (Table 4.2) lactations, lactation year affected total FY and total PY of the goats. In general, there was a progressive increase in both total FY and PY from 2013 to 2019, with the exception of a slight decrease in FY and PY from

2018 2019 for goats in a normal lactation (not observed in extended lactation). The increase in FY over time for both goats in normal and extended lactation agrees with Carnicella et al. (2008), which found that there was an increase in FY from 2000-2002 in goats in Southern Italy. García-Peniche et al. (2012) also reported a progressive increase in both total FY (3-4 kg) and PY (2 – 4 kg) from 1976–1984 to 1995–2005 in a range of goat breeds. From these studies we can see that FY and PY do have a general positive increase as lactation year increases.

5.3.3 How lactation year affects lactation

The positive trend of increased milk production as the lactation year increased seen in this study (Appendix 1) can probably be explained by genetic gain in milk production traits over time. Indeed, many studies have observed a positive and significant annual genetic change for MY and lactation length (Figure 5.1) (Aboul-Naga et al., 2012; Mohammad and Grossman, 1984). Aboul-Naga et al. (2012) estimated the total genetic progress as total change in the mean estimated breeding values in 2013 from those estimated in 1990 expressed as the proportion of genetic normal deviation, which was 1.76 for total MY. The genetic trend of milk production in Alpine and Saannen goats was 13.6 L/year and 12.5 L/year, respectively, in France during 1990–2000 (Clement et al., 2002). The genetic trends in Alpine and Saannen goat in USA from 1995 – 2000 was lower than this (8.6 L/year and 7.0 L/year, respectively), but a clear positive trend in increasing MY with genetic gain as still evident (Clement et al., 2002). This has also been seen in the dairy cattle industry, where milk production has more than doubled over the past five decades and as such the total number of cows has been reduced dramatically (Brito et al., 2021). Brito et al. (2021) summarised that this has been achieved through the intensification of production systems, the use of modern technologies (e.g., artificial insemination and genomic selection), and genetic selection for MY and a limited number of related traits.

Figure 5.1 Annual breeding value (ABV) for total MY (TMY) and lactation period (LP) (Aboul-Naga et al., 2012).

5.4 Effect of lactation start month

5.4.1 Milk yield by lactation start month

There was a clear effect of lactation start month on the total MY of goats in both extended (Table 4.3) and normal (Table 4.2) lactations. The lactation starting month with the lowest total MY for normal lactation goats was June, with only 852 kg per goat produced for the season. The total MYs produced increased for goats starting a normal lactation in July and peaking at 925 kg per goat in August, before decreasing slightly for goats starting lactation in September. The pattern was similar for goats in extended lactation, but the month with the highest total MY produced occurred when extended lactation started in September (Figure 4.2).

The effect of lactation start month on MY for normal lactation results differed slightly from a study done in Australia on dairy goats but largely agreed with the results for goats in extended lactation (Zamuner et al., 2020). Zamuner et al. (2020) found that goats kidding in spring averaged a greater MY in both early and mid-lactation than goats which kidded in June. However, goats that kidded in June had a higher peak MY than those that kidded in September (Zamuner et al., 2020). Zamuner et al. (2020) also differed when the peak MY occurred, with goats kidding in June reaching peak MY at around 40 DIM and goats that kidded in September reached peak MY at 90 DIM. The present study also found that September kidding goats reached a peak MY later than those that kidded in June. Furthermore, the time to reach peak MY was much longer for extended lactation (137 and 103DIM for June and September, respectively) than normal lactation (71 and 67 DIM for June and September kidding, respectively).

The difference observed between the two studies is most likely due to the difference in climate between their study conducted in Meredith, Australia, where the min and maximum temperatures recorded in the study were similar to the average minimum and maximum temperatures (NCEI, 2023) experienced throughout the North Island of New Zealand (Climates to travel, 2020) where the of the goats in this study are located with only 2-3° Celsius difference however the North Island of New Zealand has more days of rain each month on average than in Meredith, Australia. Another reason the results depicted by Zamuner et al. (2020) may differ from the results of this study is because of feeding and management practices. For the study by Zamuner et al. (2020), the goats were fed a TMR year-round, so the MYs were not influenced by changes in feed quality due to seasonal grazing and changes in grass quantity and quality throughout the seasons. Several studies have shown that many seasonal factors such as photoperiod (Arnal et al., 2018; Neville et al., 2002), solar radiation, relative humidity, rainfall, air temperature, and feed quality (Nardone et al., 2010; Salari et al., 2016; Clark and García, 2017) significantly affect MY.

This study did not investigate the combined effect of lactation start month and parity number on the MY of New Zealand dairy goats, so it is a matter for further research.

5.4.2 Fat and protein yields by lactation start month

Like MY, there was an effect of the month in which lactation started on the total FY and PY of goats. For normal lactations, the total FY and PY per lactation was lowest (29.0 kg and 26.4, respectively) when lactation was initiated in June and progressively increased to a maximum (30.3 kg and 27.7, respectively) in lactations starting in August, but decreased from August to September (29.7 kg and 27.1, respectively) (Table 4.2). The effect of lactation start month on total FY and PY in goats in extended lactation was similar to that of normal lactation, except peak FY and PY occurred when lactations started in September (c.f., August for normal lactation) (Table 4.3).This agrees with both Zamuner et al. (2020) and Ciappesoni et al. (2004), which found that the month goats begin to lactate impacts milk fat and protein due to changes in climatic conditions. However, the months with highest FY and PY did differ to the present study due to these studies being conducted in Australia and the Czech Republic. This illustrates that kidding month/lactation start month also impacts milk FY and PY however these changes in total FY and PY with lactation start month were most likely due to changes in the total MY in the present study.

5.4.3 How lactation start month affects lactation.

The trend witnessed in this study can potentially be explained by the effect of seasonal changes in photoperiod on lactation. Photoperiod has been seen to influence MY in a range of studies (Russo et al., 2013; Dahl et al., 2012), with long days significantly increases MY in ruminants and this effect being exacerbated in late lactation (Russo et al., 2013; Garcia-Hernandez et al., 2007). The effects of photoperiod on lactational physiology are largely mediated by the impact of light (detected by retinal photoreceptors) on the pineal gland. During night when light is low, the pineal gland then synthesises and secretes melatonin, but during daylight hours inhibits the activity of N-acetyltransferase (rate limiting enzyme in melatonin synthesis) is inhibited and melatonin cannot be produced (Reiter, 1991; Dahl et al., 2000). Thus, the duration of melatonin section is a physiological indicator of photoperiod. As photoperiod increases from June to September, there is a reduction in melatonin section (daylength in increasing) (Mousa-Balabel, 2011). These changes in melatonin subsequently affect the production of several hormones e.g., progesterone, prolactin and IGF-I), and can promote greater mammary parenchyma growth (Tucker et al., 1984).

Interestingly, plasma progesterone (a major inhibitor of lactation) concentrations not only decreased as lactation advanced in spring and summer but has also been found to be lower in goats exposed to increased photoperiod (16hrs daylight: 8hrs dark) (Logan et al., 2020). An increase in photoperiod has also been associated with an increase in plasma prolactin (a major simulator of lactation) concentrations (Logan et al., 2020; Dahl et al., 2012; Miller et al., 2000; Collier et al., 2006). While the role of prolactin in galactopoiesis in ruminants is often contentious, recent data suggests that prolactin may have a galactopoietic role as treatment of goats or cows with a dopamine agonist (inhibits the secretion of prolactin from pituitary lactotrophs) leads to a decrease in MY (Logan et al., 2020). Furthermore, administration with a dopamine antagonist, which increases prolactin secretion, leads to an increase in MY (Logan et al., 2020). These findings suggest that the effect of photoperiod is at least partially mediated by prolactin secretion in dairy goats (Logan et al., 2020).

Insulin-like-growth factor-I (IGF-I) is another galactopoietic hormone that may be involved in mediating the effects of photoperiod on MY. It has been found that the exposure of cows to a long day photoperiod increases IGF-I in dairy cows (Dahl et al., 2012), resulting in an increase in MY that is independent to circulating growth hormone (GH) concentrations (Dahl et al., 2000). In contrast, the treatment of red deer with melatonin implants that mimic the short-day photoperiodic leads to decreases circulating IGF-I concentrations, although MY was not evaluated in this study (Suttie et al., 1992). Heifers fed melatonin over 2 months to mimic a short-day photoperiod exhibited a decrease in circulating IGF-I concentrations, but there was no change in circulating GH or IGF-binding proteins (Smith, 1998). This suggests that the effect of photoperiod on IGF-I is at the secretion level rather than by IGF-I clearance or GH stimulation. The physiological responses to long days in heifers are consistent with IGF-I stimulation such as increased mammary parenchymal growth than seen in short days (Dahl et al., 2000; Dahl et al., 2004). Insulin-like growth factor I has been shown to have acute galactopoetic effects in goats and so photoperiod can influence milk production in goats through IGF-I. However, it is unlikely that the direct effects of changes in photoperiod on progesterone, prolactin and IGF-1 concentrations are the only reason the month of parturition/lactogenesis affects MY, FY, and PY.

Alongside photoperiod, feed intake can also contribute to the positive trend in milk production seen as lactation month increases. One aspect of increased feed intake is an increase in feed availability. This influences the trend in milk production seen as when lactation start month increases from June to September there is increased feed availability. Pasture growth in New Zealand increases from winter to spring increasing feed availability (Beukes et al., 2005). The increased MY witnessed as photoperiod increases must also be supported by additional energy being partitioned to the mammary gland either by increasing feed intake or the mobilisation of body reserves. The increase in feed intake as photoperiod increases is strongly supported. Russo et al. (2013) found that the mean liveweight increased as the long-day photoperiod increased, suggesting that the feed intake of these animals was increasing to meet the heightened demand placed on the body to produce more milk. This indicates that the animals are not mobilizing body reserves for the increased production due to increased voluntary dry matter that have been associated with increases in day length

(Peters et al., 1981; Dominigue et al., 1991). It has also been found that as photoperiod increased, plasma non-esterified fatty acids concentrations decreased and plasma glucose increased, which is indicative of a more positive energy balance (Dunshea et al., 1989: Dunshea et al., 1990).

5.5 Effect of pregnancy

From this study, the effect of pregnancy on MY can be witnessed as when normal lactation goats were dried off after 270 days, their average MY for day 270 was only 2.81 kg, while goats in extended lactation a day 270 produced an average MY of 3.35 kg. This study shows an increase in the rate of decline for normal lactation goats from around 200 days in milk compared to goats in extended lactation, where the rate of decline decreases during this period. This indicates the effect that pregnancy has on milk production. Indeed, Salama et al. (2005) reported a significant drop in the MY of goats during late pregnancy was seen after mating, with the decline in MY increased by 150% each week from weeks 10 to 13 of pregnancy. MY losses of 0.32, 0.51, 0.85, and 1.11 L/d for weeks 10, 11, 12, and 13 of pregnancy, respectively. While extended lactation, goats were machine-milked once daily under semi-extensive conditions and successfully lactated for two years consecutively without significant losses in MY. This is depicted in Figure 2.2. The higher MY witnessed at day 270 in extended lactation goats also agrees with studies by Knight and Wilde (1988) where they reported that there was a lower MY in goats after remating than those that were not.

Approximately two-thirds of foetal growth occurs in late pregnancy (last six weeks of gestation) (Mahboub et al., 2013). As a result, a high metabolic demand is placed on the doe. The metabolizable energy (ME) and protein intake (IP) for pregnant goats increases from ME (MJ/d)=4.23+0.713 and IP (g/d)=84.05-5.36 for lactating goats to ME (MJ/d)=5.92+0.96 and IP (g/d)=58.34+5.41 (Astuti et al., 2000). A shortage of energy or protein intake during late pregnancy can result in toxaemia, ketosis, or foetal developmental compromise (Rook, 2000; Dore et al., 2015; Dunlap et al., 2015; Herring et al., 2018).

5.6 Limitations

The main limitation of this study was that no data were collected investigating how the goats were selected for if and when they would be milked for extended lactation. Therefore, the farmers probably systematically selected which animals will be milked for an extended lactation. It has been suggested that by analysing a doe's first 120 days of lactation, her suitability for extended lactation can be discovered alongside her productive life, lifetime efficiency, and MY efficiency for the total number of lactating days (Wolber et al., 2021). If the farm had other management practices in place to accommodate goats in extended lactation such as providing supplemental grazing year-round and having bred goats which are genetically more likely to be more suited for extended lactation. The data collected were from a commercial farm's herd data and will be influenced by each farm's other management practices (e.g., feeding regimes, climate, and stocking rate).

This study did not consider how the herd test milk samples were collected and the type of herd test, classic or single. This study only looked at three components of milk production: MY, FY and PY, and did not look comprehensively into milk composition. Another limitation of this study was the limited resources available for extended lactation in dairy goats in New Zealand, so it primarily relied on previous studies into dairy cows in New Zealand and dairy goat research from other countries worldwide.

5.7 Further research

This study provides a starting point for further studies into extending lactation as a viable management practice in New Zealand dairy goat farms. Further research into other milk components such as lactose, Somatic cell count and protein types should also be conducted as they influence milk sale cost and suitability for further processing. Additionally, further research should be conducted into how goats are selected for being put forward for extended lactation and if there are identifiable and testable genetic parameters that predetermine certain animals to be more suitable for extended lactation or if certain breeds are more suitable. Research is beginning to be completed in this area recently by Scholtens (2020) and Wolber et al. (2021). However, more is needed. For dairy cows, it has been suggested that both production performance, such as previous and current milk production (Lehmann et al., 2017) and physiological stage, described by Insulin-like Growth Factor 1 (IGF-1) and non-esterified fatty acid (NEFA) blood levels (Kay et al., 2007), may prove to be helpful selection criteria for selecting which cows should be used in extended lactation systems (Sehested et al., 2019).

Additionally, further research is needed to be undertaken looking at the practical aspect of implementing extended lactation throughout dairy goat farms in New Zealand, including a cost analysis investigating the balance between the increased revenue from the milk produced, loss of kid sale, less breeding costs, increased feed costs to support full-year milking, environmental impact and management costs for full-year milking. Future research should investigate processes to mitigate decreases in genetic gain due to longer generation intervals that occur due to breeding less frequently. This negative aspect of implementing extended lactation has been identified in other studies around the world, such as in France, where when extended lactation was undergone, it was seen that high genetic merit females had fewer opportunities to contribute high-merit herd replacements (Desire et al., 2017). Finally, further research should investigate extended lactation health benefits and their impact on goat longevity.

Chapter 6: Conclusions

6.1 Summary

The results of this study indicated that the employment of extended lactation as a management practice in New Zealand Dairy farms would be beneficial. This study discovered that New Zealand dairy goats in extended lactation produced an average higher daily MY, PY, and slightly lower FY than dairy goats in normal lactation. The results indicate that the milk produced by dairy goats in extended lactation could allow a greater contribution to cheese yield as both the fat and PY were higher than the milk produced by goats in normal lactation.

This study also showed that parity, lactation year and lactation month all influenced MY, FY and PY for both goats in normal and extended lactation. All goats' milk, fat and PY increased from parity one to peak at parity three or four for goats in normal and extended lactation, respectively, and progressively declining thereafter. The same pattern for all three yields was observed when analysed by lactation year. The lowest yields for normal lactation goats were produced in 2014, but they increased yearly until 2018 and declined slightly in 2019. This differed slightly from the trend in dairy goats milked for an extended lactation. The lowest yields were seen in 2013, with 2230 kg, which increased yearly until 2019. The lactation starting month with the lowest yields for both normal and extended lactation goats was June. For normal lactation goats, August had the highest yields before decreasing slightly for goats starting lactating in September. The pattern was similar for goats in extended lactation; there was an increase in yields produced from goats beginning their lactation in June, increasing through July and August, where it peaked in September.

The results collected also illustrated the effect of pregnancy on lactation. As when normal lactation goats were dried off after 270 days, their average MY for day 270 was only 2.81 kg, while goats in extended lactation a day 270 produced an average MY of 3.35 kg. This study shows an increase in the rate of decline for normal lactation goats from around 200 days in milk compared to goats in extended lactation, where the rate of decline decreases during this period. This indicates the effect that pregnancy has on milk production.

This study gave an insight into the potential viability of employing extended lactation as a potential management practice on New Zealand dairy goat farms. It highlights that goats can produce a high MY in extended lactation and that goats in extended lactation produce more fat and protein content in their milk. The differences in the results collected for milk, fat and PYs between dairy goats in normal compared to extended lactation reflect the effect of pregnancy on milk production. Continuous studies are required to determine the effect of extended lactation on other milk components, farm profitability and goat health.

6.2 Implications

The results of this study found that the composition of milk produced by dairy goats in New Zealand that are milked for an extended lactation is similar to milk produced by normal lactation goats however may be more suited for cheese production due to slightly higher fat + protein percentage. The present study also indicates that a high MY for extended lactation can be produced, favouring the incorporation of extended lactation as a viable management practice for dairy goat farms in New Zealand. This study’s results indicate that extended lactation could be used to meet consumer demands for a year-round milk supply. This can lead to increased revenue for milk production as in autumn, milk prices are higher due to less supply (Ringdorfor, 2009). The results from this present study suggest that extended lactation is a valuable strategy for minimising the production of surplus males and simplifying herd management within the New Zealand dairy goat industry.

6.3 Conclusions

This study modelled lactation curves of milk yield, fat yield and protein yield for extended lactation and normal lactation in New Zealand Dairy goats. This study found that parity, lactation start year and lactation start month all have an effect on milk production. From this study it was found that extended lactation could be a viable management practice to be employed in New Zealand dairy goat farms. As the results from this study found that there is greater milk production by dairy goats in extended lactation than goats in two normal lactations.

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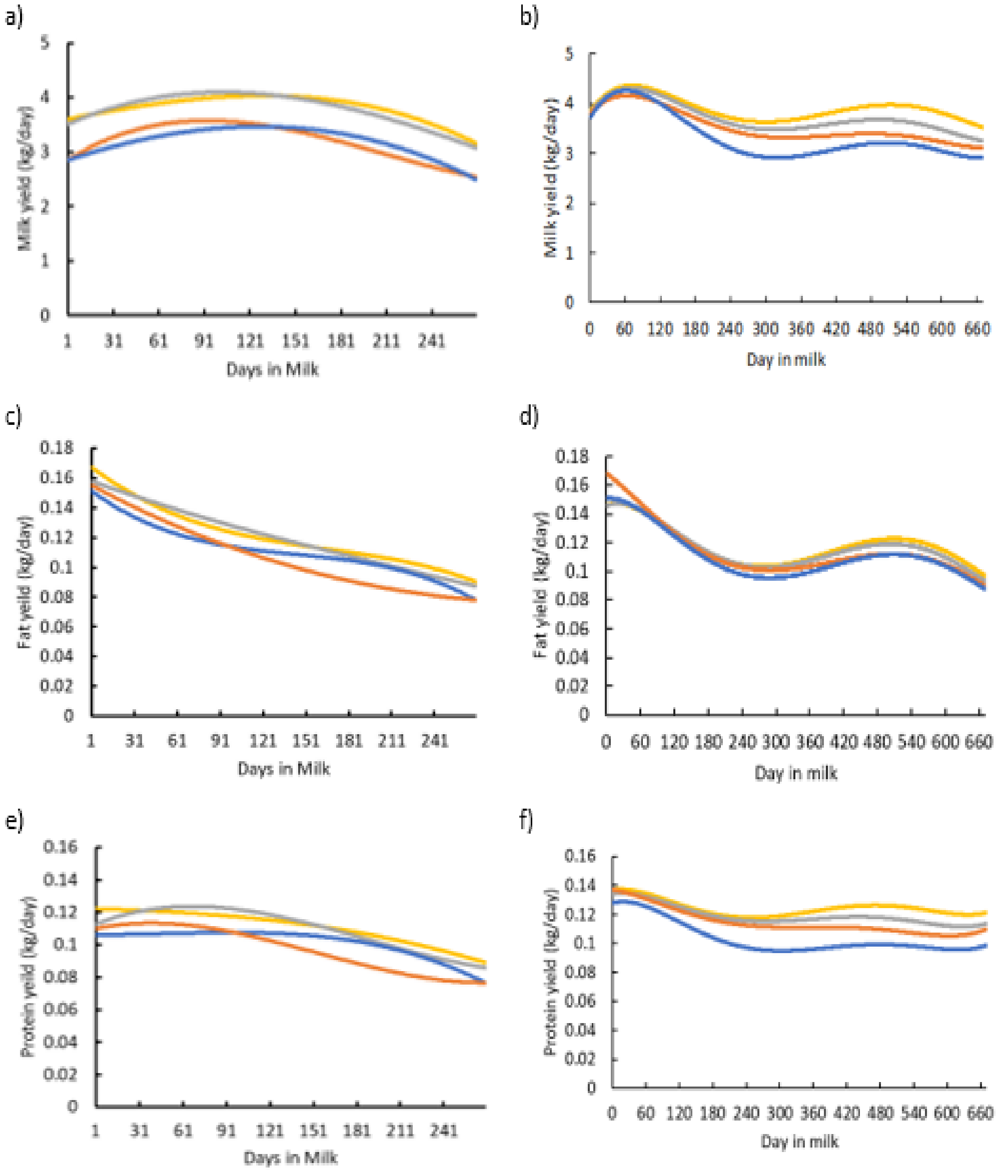
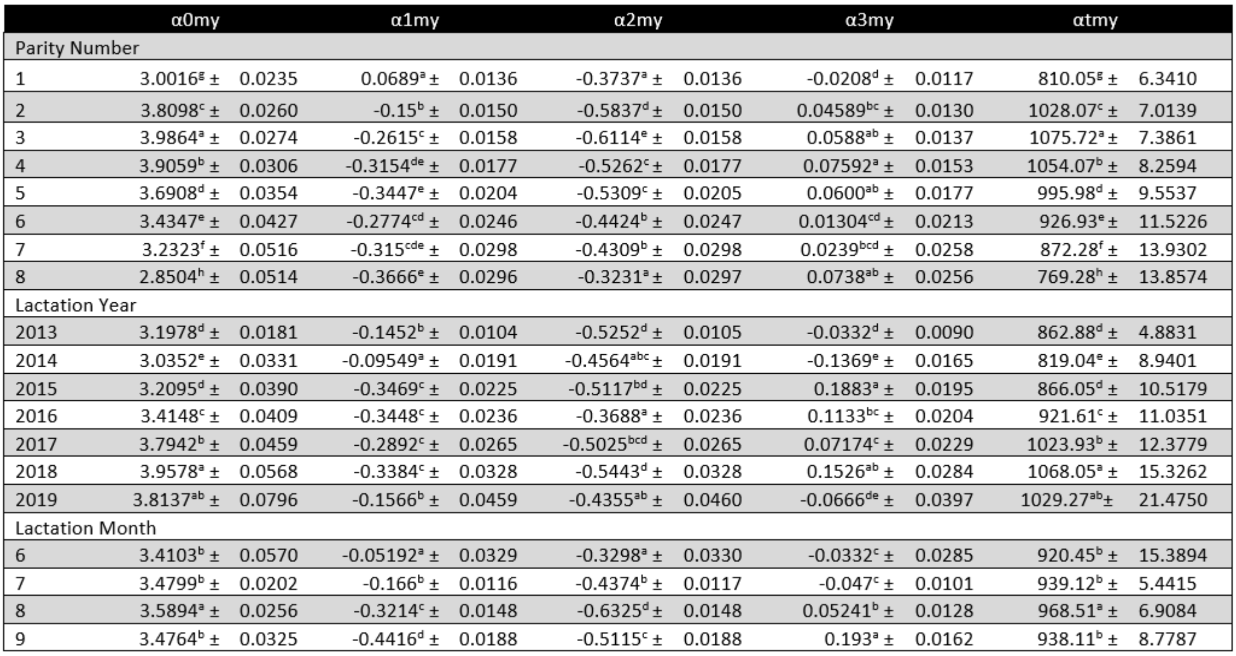
Appendices



Appendices 1. Lactation curves for milk yield, fat yield and protein yield for goats in normal lactation (a, c, e, respectively) and extended lactation (b, d, e, respectively) for 2013 (blue), 2015 (orange), 2017 (grey), and 2019 (yellow).

The estimate of regression coefficients describing the lactation curves of MY, FY and PY by parity number, lactation year and month in which the lactation starts for the does under the two lactation lengths.

Appendix 2. The estimate of regression coefficients describing lactation curve of milk yield by parity number, lactation year and month in which the lactation starts in 270-d normal lactation New Zealand dairy goats for the period 2013-2019.



	α0my		α1my		α2my		α3my		αtmy	
Parity Number										
1	3.0016^{g} ±	0.0235	0.0689^{a} ±	0.0136	-0.3737^{a} ±	0.0136	-0.0208^{d} ±	0.0117	810.05^{g} ±	6.3410
2	3.8098^{c} ±	0.0260	-0.15^{b} ±	0.0150	-0.5837^{d} ±	0.0150	0.04589^{bc} ±	0.0130	1028.07^{c} ±	7.0139
3	3.9864^{a} ±	0.0274	-0.2615^{c} ±	0.0158	-0.6114^{e} ±	0.0158	0.0588^{ab} ±	0.0137	1075.72^{a} ±	7.3861
4	3.9059^{b} ±	0.0306	-0.3154^{de} ±	0.0177	-0.5262^{c} ±	0.0177	0.07592^{a} ±	0.0153	1054.07^{b} ±	8.2594
5	3.6908^{d} ±	0.0354	-0.3447^{e} ±	0.0204	-0.5309^{c} ±	0.0205	0.0600^{ab} ±	0.0177	995.98^{d} ±	9.5537
6	3.4347^{e} ±	0.0427	-0.2774^{cd} ±	0.0246	-0.4424^{b} ±	0.0247	0.01304^{cd} ±	0.0213	926.93^{e} ±	11.5226
7	3.2323^{f} ±	0.0516	-0.315^{cde} ±	0.0298	-0.4309^{b} ±	0.0298	0.0239^{bcd} ±	0.0258	872.28^{f} ±	13.9302
8	2.8504^{h} ±	0.0514	-0.3666^{e} ±	0.0296	-0.3231^{a} ±	0.0297	0.0738^{ab} ±	0.0256	769.28^{h} ±	13.8574
Lactation Year										
2013	3.1978^{d} ±	0.0181	-0.1452^{b} ±	0.0104	-0.5252^{d} ±	0.0105	-0.0332^{d} ±	0.0090	862.88^{d} ±	4.8831
2014	3.0352^{e} ±	0.0331	-0.09549^{a} ±	0.0191	-0.4564^{abc} ±	0.0191	-0.1369^{e} ±	0.0165	819.04^{e} ±	8.9401
2015	3.2095^{d} ±	0.0390	-0.3469^{c} ±	0.0225	-0.5117^{bd} ±	0.0225	0.1883^{a} ±	0.0195	866.05^{d} ±	10.5179
2016	3.4148^{c} ±	0.0409	-0.3448^{c} ±	0.0236	-0.3688^{a} ±	0.0236	0.1133^{bc} ±	0.0204	921.61^{c} ±	11.0351
2017	3.7942^{b} ±	0.0459	-0.2892^{c} ±	0.0265	-0.5025^{bcd} ±	0.0265	0.07174^{c} ±	0.0229	1023.93^{b} ±	12.3779
2018	3.9578^{a} ±	0.0568	-0.3384^{c} ±	0.0328	-0.5443^{d} ±	0.0328	0.1526^{ab} ±	0.0284	1068.05^{a} ±	15.3262
2019	3.8137^{ab} ±	0.0796	-0.1566^{b} ±	0.0459	-0.4355^{ab} ±	0.0460	-0.0666^{de} ±	0.0397	1029.27^{ab}±	21.4750
Lactation Month										
6	3.4103^{b} ±	0.0570	-0.05192^{a} ±	0.0329	-0.3298^{a} ±	0.0330	-0.0332^{c} ±	0.0285	920.45^{b} ±	15.3894
7	3.4799^{b} ±	0.0202	-0.166^{b} ±	0.0116	-0.4374^{b} ±	0.0117	-0.047^{c} ±	0.0101	939.12^{b} ±	5.4415
8	3.5894^{a} ±	0.0256	-0.3214^{c} ±	0.0148	-0.6325^{d} ±	0.0148	0.05241^{b} ±	0.0128	968.51^{a} ±	6.9084
9	3.4764^{b} ±	0.0325	-0.4416^{d} ±	0.0188	-0.5115^{c} ±	0.0188	0.193^{a} ±	0.0162	938.11^{b} ±	8.7787

Appendix 3. The estimate of regression coefficients describing lactation curve of fat yield by parity number, lactation year and month in which the lactation starts in 270-d normal lactation New Zealand dairy goats for the period 2013-2019.

	α0fy		α1fy		α2fy		α3fy		αTfy	
Parity Number										
1	0.09976^{f} ±	0.0008	-0.02169^{a} ±	0.0005	0.007243^{bc} ±	0.0004	-0.00701^{d} ±	0.0004	26.942^{f} ±	0.2030
2	0.1253^{b} ±	0.0008	-0.03175^{b} ±	0.0005	0.003002^{e} ±	0.0005	-0.0041^{ac} ±	0.0004	33.843^{b} ±	0.2246
3	0.1298^{a} ±	0.0009	-0.03557^{c} ±	0.0005	0.002535^{e} ±	0.0005	-0.0034^{ab} ±	0.0004	35.0435^{a} ±	0.2365
4	0.126^{b} ±	0.0010	-0.0355^{c} ±	0.0006	0.004294^{d} ±	0.0005	-0.0035^{abc} ±	0.0005	34.0251^{b} ±	0.2644
5	0.1196^{c} ±	0.0011	-0.03606^{c} ±	0.0007	0.004303^{d} ±	0.0006	-0.0045^{c} ±	0.0005	32.2959^{c} ±	0.3059
6	0.112^{d} ±	0.0014	-0.03487^{c} ±	0.0008	0.007461^{bc} ±	0.0007	-0.00469^{c} ±	0.0007	30.2598^{d} ±	0.3689
7	0.1063^{e} ±	0.0017	-0.03403^{c} ±	0.0010	0.007566^{b} ±	0.0009	-0.00469^{c} ±	0.0008	28.7139^{e} ±	0.4460
8	0.0955^{g} ±	0.0016	-0.03581^{c} ±	0.0010	0.01047^{a} ±	0.0009	-0.00266^{a} ±	0.0008	25.8095^{g} ±	0.4437
Lactation Year										
2013	0.1112^{c} ±	0.0006	-0.02738^{a} ±	0.0004	0.003456^{c} ±	0.0003	-0.00942^{d} ±	0.0003	30.0342^{c} ±	0.1563
2014	0.1041^{e} ±	0.0011	-0.03111^{b} ±	0.0007	0.007784^{b} ±	0.0006	-0.00654^{c} ±	0.0005	28.1237^{e} ±	0.2862
2015	0.107^{d} ±	0.0012	-0.03824^{e} ±	0.0008	0.009571^{a} ±	0.0007	-0.00039^{a} ±	0.0006	28.9012^{d} ±	0.3368
2016	0.1113^{c} ±	0.0013	-0.03278^{bc} ±	0.0008	0.00585^{b} ±	0.0007	-0.00307^{b} ±	0.0006	30.044^{c} ±	0.3533
2017	0.12^{b} ±	0.0015	-0.03467^{cd} ±	0.0009	0.00267^{c} ±	0.0008	-0.00066^{a} ±	0.0007	32.3997^{b} ±	0.3963
2018	0.1258^{a} ±	0.0018	-0.0363^{de} ±	0.0011	0.003432^{c} ±	0.0010	-0.00315^{b} ±	0.0009	33.9655^{a} ±	0.4907
2019	0.1207^{ab} ±	0.0025	-0.03162^{bc} ±	0.0016	0.00826^{ab} ±	0.0014	-0.00695^{c} ±	0.0012	32.5977^{ab} ±	0.6876
Lactation Month										
6	0.114^{abc} ±	0.0018	-0.03122^{a} ±	0.0011	0.01014^{a} ±	0.0010	-0.00573^{c} ±	0.0009	30.803^{ab} ±	0.4927
7	0.1132^{bc} ±	0.0006	-0.03355^{ab} ±	0.0004	0.008509^{a} ±	0.0004	-0.00576^{c} ±	0.0003	30.5673^{b} ±	0.1742
8	0.1157^{a} ±	0.0008	-0.03377^{b} ±	0.0005	0.001787^{c} ±	0.0004	-0.00363^{b} ±	0.0004	31.2331^{a} ±	0.2212
9	0.1143^{ab} ±	0.0010	-0.03409^{b} ±	0.0006	0.003^{b} ±	0.0006	-0.00214^{a} ±	0.0005	30.863^{ab} ±	0.2811

Appendicx 4. The estimate of regression coefficients describing lactation curve of protein yield by parity number, lactation year and month in which the lactation starts in 270-d normal lactation New Zealand dairy goats for the period 2013-2019.

	α0py	α1py	α2py	α3py	αTpy
Parity Number					
1	0.09006^{f} ± 0.0008	-0.00603^{a} ± 0.0005	-0.0064^{bc} ± 0.0004	-0.00073^{d} ± 0.0004	24.309^{f} ± 0.2030
2	0.1156^{b} ± 0.0008	-0.01609^{b} ± 0.0005	-0.01067^{e} ± 0.0005	0.002183^{ac} ± 0.0004	31.2103^{b} ± 0.2246
3	0.1201^{a} ± 0.0009	-0.01991^{c} ± 0.0005	-0.01114^{e} ± 0.0005	0.002893^{ab} ± 0.0004	32.4108^{a} ± 0.2365
4	0.1163^{b} ± 0.0010	-0.01982^{c} ± 0.0006	-0.00938^{d} ± 0.0005	0.002813^{abc} ± 0.0005	31.3924^{b} ± 0.2644
5	0.1099^{c} ± 0.0011	-0.0204^{c} ± 0.0007	-0.00937^{d} ± 0.0006	0.001779^{c} ± 0.0005	29.6632^{c} ± 0.3059
6	0.1023^{d} ± 0.0014	-0.01921^{c} ± 0.0008	-0.00621^{bc} ± 0.0007	0.001586^{c} ± 0.0007	27.6271^{d} ± 0.3689
7	0.0966^{e} ± 0.0017	-0.01837^{c} ± 0.0010	-0.00611^{b} ± 0.0009	0.001591^{c} ± 0.0008	26.0812^{e} ± 0.4460
8	0.0859^{g} ± 0.0016	-0.02015^{c} ± 0.0010	-0.00321^{a} ± 0.0009	0.003624^{a} ± 0.0008	23.1768^{g} ± 0.4437
Lactation Year					
2013	0.1015^{c} ± 0.0006	-0.01172^{a} ± 0.0004	-0.01022^{c} ± 0.0003	-0.00314^{d} ± 0.0003	27.4015^{c} ± 0.1563
2014	0.0944^{e} ± 0.0011	-0.01545^{b} ± 0.0007	-0.00589^{b} ± 0.0006	-0.00026^{c} ± 0.0005	25.491^{e} ± 0.2862
2015	0.0973^{d} ± 0.0012	-0.02258^{f} ± 0.0008	-0.0041^{a} ± 0.0007	0.005892^{a} ± 0.0006	26.2685^{d} ± 0.3368
2016	0.1016^{c} ± 0.0013	-0.0171^{bcd} ± 0.0008	-0.00782^{b} ± 0.0007	0.003206^{b} ± 0.0006	27.4113^{c} ± 0.3533
2017	0.1103^{b} ± 0.0015	-0.0190^{cde} ± 0.0009	-0.01101^{c} ± 0.0008	0.005616^{a} ± 0.0007	29.7669^{b} ± 0.3963
2018	0.1161^{a} ± 0.0018	-0.02064^{ef} ± 0.0011	-0.01024^{c} ± 0.0010	0.003133^{b} ± 0.0009	31.3328^{a} ± 0.4907
2019	0.111^{ab} ± 0.0025	-0.01596^{bc} ± 0.0016	-0.00542^{ab} ± 0.0014	-0.00067^{c} ± 0.0012	29.965^{ab} ± 0.6876
lactation Month					
6	0.1043^{ab} ± 0.0018	-0.01556^{a} ± 0.0011	-0.00353^{a} ± 0.0010	0.000554^{c} ± 0.0009	28.170^{ab} ± 0.4927
7	0.1035^{b} ± 0.0006	-0.01789^{ab} ± 0.0004	-0.00516^{a} ± 0.0004	0.000519^{c} ± 0.0003	27.9345^{b} ± 0.1742
8	0.106^{a} ± 0.0008	-0.01811^{b} ± 0.0005	-0.01189^{c} ± 0.0004	0.002655^{b} ± 0.0004	28.6003^{a} ± 0.2212
9	0.1046^{ab} ± 0.0010	-0.01843^{b} ± 0.0006	-0.01067^{b} ± 0.0006	0.004143^{a} ± 0.0005	28.230^{ab} ± 0.2811

Appendix 5. The estimate of regression coefficients describing lactation curve of milk yield by parity number, lactation year and month in which the lactation starts in 670-d extended lactation New Zealand dairy goats for the period 2013-2019.

	α0my	α1my	α2my	α3my	α4my	α5my	αTmy
Parity Number							
1	0.10^{d} ± 0.0010	0.01^{a} ± 0.001	0.01^{d} ± 0.0010	-0.02^{a} ± 0.0000	-0.01^{b} ± 0.0000	0.01^{a} ± 0.0000	68.5^{d} ± 0.7000
2	0.12^{ab} ± 0.0010	-0.01^{b} ± 0.001	0.01^{c} ± 0.0010	-0.02^{b} ± 0.0000	-0.01^{b} ± 0.0000	0.01^{a} ± 0.0000	82.178^{ab} ± 0.7740
3	0.12^{a} ± 0.0010	-0.02^{c} ± 0.001	0.02^{b} ± 0.0010	-0.02^{b} ± 0.0000	-0.01^{b} ± 0.0000	0.01^{ab} ± 0.0000	82.6279^{a} ± 0.7660
4	0.12^{a} ± 0.0010	-0.02^{d} ± 0.001	0.02^{b} ± 0.0010	-0.02^{b} ± 0.0010	-0.01^{ab} ± 0.0000	0.01^{ab} ± 0.0000	82.8628^{a} ± 0.8260
5	0.12^{bc} ± 0.0010	-0.02^{d} ± 0.001	0.02^{ab} ± 0.0010	-0.02^{b} ± 0.0010	-0.01^{b} ± 0.0000	0.01^{ab} ± 0.0000	80.309^{bc} ± 0.9970
6	0.12^{c} ± 0.0020	-0.02^{cd} ± 0.002	0.02^{ab} ± 0.0010	-0.02^{b} ± 0.0010	-0.01^{a} ± 0.0010	0.01^{b} ± 0.0010	78.302^{c} ± 1.4180
7	0.10^{d} ± 0.0030	-0.02^{d} ± 0.003	0.02^{a} ± 0.0020	-0.02^{b} ± 0.0010	-0.01^{ab} ± 0.0010	0.00^{b} ± 0.0010	67.3421^{d} ± 2.3090
8	0.10^{d} ± 0.0040	-0.02^{cd} ± 0.003	0.02^{a} ± 0.0030	-0.02^{ab} ± 0.0020	-0.01^{b} ± 0.0010	0.01^{ab} ± 0.0010	68.3878^{d} ± 2.9290
Lactation Year							
2013	0.11^{bc} ± 0.0030	-0.02^{bc} ± 0.0020	0.02^{a} ± 0.0020	-0.02^{cd} ± 0.0010	-0.01^{cd} ± 0.0010	0.01^{ab} ± 0.0010	74.1588^{bc} ± 1.9420
2014	0.11^{bc} ± 0.0010	-0.02^{b} ± 0.0010	0.01^{b} ± 0.0010	-0.02^{bc} ± 0.0010	-0.01^{b} ± 0.0000	0.01^{ab} ± 0.0000	74.8563^{bc} ± 0.8910
2015	0.11^{b} ± 0.0010	-0.02^{c} ± 0.0010	0.02^{a} ± 0.0010	-0.02^{d} ± 0.0010	-0.01^{a} ± 0.0000	0.00371^{d} ± 0.0000	76.417^{b} ± 0.9900
2016	0.11^{c} ± 0.0020	-0.01^{b} ± 0.0010	0.02^{b} ± 0.0010	-0.02^{ab} ± 0.0010	-0.01^{bcd} ± 0.0000	0.0058^{bc} ± 0.0000	73.5321^{c} ± 1.0050
2017	0.12^{ab} ± 0.0010	-0.01^{b} ± 0.0010	0.01^{b} ± 0.0010	-0.02^{c} ± 0.0010	-0.01^{cd} ± 0.0000	0.0073^{a} ± 0.0000	77.876^{ab} ± 0.9380
2018	0.12^{a} ± 0.0010	-0.02^{c} ± 0.0010	0.02^{b} ± 0.0010	-0.02^{a} ± 0.0010	-0.01^{cb} ± 0.0000	0.0051^{c} ± 0.0000	78.404^{a} ± 0.9120
2019	0.12^{a} ± 0.0010	-0.01^{a} ± 0.0010	0.01^{b} ± 0.0010	-0.02^{c} ± 0.0010	-0.01^{d} ± 0.0000	0.0071^{a} ± 0.0000	78.9292^{a} ± 0.8350
Lactation Month							
6	0.11^{b} ± 0.0020	-0.02^{bc} ± 0.0010	0.02^{a} ± 0.0010	-0.02^{bc} ± 0.0010	-0.01^{a} ± 0.0010	0.0062^{a} ± 0.0010	73.8648^{b} ± 1.2670
7	0.11^{b} ± 0.0010	-0.02^{c} ± 0.0010	0.02^{a} ± 0.0010	-0.02^{c} ± 0.0000	-0.01^{a} ± 0.0000	0.0064^{a} ± 0.0000	74.5364^{b} ± 0.6240
8	0.12^{a} ± 0.0010	-0.02^{ab} ± 0.0010	0.02^{b} ± 0.0010	-0.02^{c} ± 0.0010	-0.01^{a} ± 0.0000	0.0067^{a} ± 0.0000	77.3129^{a} ± 0.9150
9	0.12^{a} ± 0.0020	-0.01^{a} ± 0.0010	0.01^{c} ± 0.0010	-0.02^{a} ± 0.0010	-0.01^{a} ± 0.0010	0.0047^{b} ± 0.0010	79.528^{a} ± 1.3320

Appendix 6. The estimate of regression coefficients describing lactation curve of fat yield by parity number, lactation year and month in which the lactation starts in 670-d extended lactation New Zealand dairy goats for the period 2013-2019.

	α0fy		α1fy		α2fy		α3fy		α4fy		α5fy		αTfy	
Parity Number														
1	0.102^{d} ±	0.0010	0.006812^{a} ±	0.0008	0.00561^{d} ±	0.0006	-0.01566^{a} ±	0.0004	-0.01083^{b} ±	0.0003	0.006927^{a} ±	0.0003	68.5^{d} ±	0.7000
2	0.123^{ab} ±	0.0012	-0.01269^{b} ±	0.0009	0.01251^{c} ±	0.0007	-0.01908^{b} ±	0.0005	-0.00922^{b} ±	0.0004	0.006941^{a} ±	0.0003	82.178^{ab} ±	0.7737
3	0.1233^{a} ±	0.0011	-0.01854^{c} ±	0.0009	0.01533^{b} ±	0.0007	-0.01924^{b} ±	0.0005	-0.00952^{b} ±	0.0004	0.00657^{ab} ±	0.0003	82.6279^{a} ±	0.7659
4	0.1237^{a} ±	0.0012	-0.02101^{d} ±	0.0009	0.01728^{b} ±	0.0007	-0.01983^{b} ±	0.0005	-0.00881^{ab} ±	0.0004	0.00602^{ab} ±	0.0003	82.8628^{a} ±	0.8264
5	0.1198^{bc} ±	0.0015	-0.02189^{d} ±	0.0012	0.01849^{ab} ±	0.0009	-0.02039^{b} ±	0.0006	-0.00927^{b} ±	0.0005	0.006411^{ab} ±	0.0004	80.3088^{bc} ±	0.9969
6	0.1169^{c} ±	0.0021	-0.02052^{cd} ±	0.0017	0.0181^{ab} ±	0.0013	-0.02025^{b} ±	0.0009	-0.00736^{a} ±	0.0007	0.005048^{b} ±	0.0006	78.302^{c} ±	1.4177
7	0.1005^{d} ±	0.0034	-0.02439^{d} ±	0.0027	0.02188^{a} ±	0.0021	-0.01981^{b} ±	0.0015	-0.00864^{ab} ±	0.0011	0.004713^{b} ±	0.0010	67.3421^{d} ±	2.3090
8	0.1021^{d} ±	0.0044	-0.02001^{cd} ±	0.0032	0.02021^{a} ±	0.0025	-0.01773^{ab} ±	0.0017	-0.01157^{b} ±	0.0014	0.005681^{ab} ±	0.0011	68.3878^{d} ±	2.9289
Lactation year														
2013	0.1107^{bc} ±	0.0029	-0.01804^{bc} ±	0.0021	0.0189^{a} ±	0.0016	-0.0201^{cd} ±	0.0011	-0.01024^{cd} ±	0.0009	0.006708^{ab} ±	0.0007	74.1588^{bc} ±	1.9421
2014	0.1117^{bc} ±	0.0013	-0.01524^{b} ±	0.0010	0.01452^{b} ±	0.0008	-0.0185^{bc} ±	0.0005	-0.00884^{b} ±	0.0004	0.006707^{ab} ±	0.0004	74.8563^{bc} ±	0.8913
2015	0.114^{b} ±	0.0015	-0.02126^{c} ±	0.0011	0.02009^{a} ±	0.0009	-0.02148^{d} ±	0.0006	-0.00507^{a} ±	0.0005	0.003708^{d} ±	0.0004	76.417^{b} ±	0.9901
2016	0.1097^{c} ±	0.0015	-0.01466^{b} ±	0.0012	0.01541^{b} ±	0.0009	-0.01751^{ab} ±	0.0006	-0.01015^{bcd} ±	0.0005	0.005783^{bc} ±	0.0004	73.5321^{c} ±	1.0050
2017	0.1162^{ab} ±	0.0014	-0.0147^{b} ±	0.0011	0.01416^{b} ±	0.0008	-0.0188^{c} ±	0.0006	-0.01076^{cd} ±	0.0005	0.007318^{a} ±	0.0004	77.8763^{ab} ±	0.9383
2018	0.117^{a} ±	0.0014	-0.02016^{c} ±	0.0010	0.01543^{b} ±	0.0008	-0.01666^{a} ±	0.0006	-0.00992^{cb} ±	0.0004	0.005036^{c} ±	0.0004	78.404^{a} ±	0.9116
2019	0.1178^{a} ±	0.0012	-0.01165^{a} ±	0.0010	0.01472^{b} ±	0.0007	-0.01993^{c} ±	0.0005	-0.01084^{d} ±	0.0004	0.007016^{a} ±	0.0003	78.9292^{a} ±	0.8349
Lactation Month														
6	0.1102^{b} ±	0.0019	-0.01763^{bc} ±	0.0015	0.0187^{a} ±	0.0012	-0.01979^{bc} ±	0.0008	-0.00992^{a} ±	0.0006	0.006242^{a} ±	0.0005	73.8648^{b} ±	1.2666
7	0.1112^{b} ±	0.0009	-0.01842^{c} ±	0.0007	0.01802^{a} ±	0.0005	-0.02029^{c} ±	0.0004	-0.00932^{a} ±	0.0003	0.006426^{a} ±	0.0002	74.5364^{b} ±	0.6237
8	0.1154^{a} ±	0.0014	-0.0164^{ab} ±	0.0010	0.01517^{b} ±	0.0008	-0.01915^{c} ±	0.0006	-0.00955^{a} ±	0.0004	0.006741^{a} ±	0.0004	77.3129^{a} ±	0.9146
9	0.1187^{a} ±	0.0020	-0.01371^{a} ±	0.0015	0.01282^{c} ±	0.0011	-0.01677^{a} ±	0.0008	-0.00883^{a} ±	0.0006	0.004749^{b} ±	0.0005	79.528^{a} ±	1.3323

Appendix 7. The estimate of regression coefficients describing lactation curve of protein yield by parity number, lactation year and month in which the lactation starts in 670-d extended lactation New Zealand dairy goats for the period 2013-2019.

	α0py		α1py		α2py		α3py		α4py		α5py		αTpy	
Parity Number														
1	0.09951^{c} ±	0.0009	0.01458^{a} ±	0.0007	-0.00005^{d} ±	0.0004	-0.00832^{d} ±	0.0003	0.000881^{a} ±	0.0003	0.007182^{a} ±	0.0002	66.6716^{c} ±	0.6
2	0.1232^{a} ±	0.0011	-0.00399^{b} ±	0.0008	0.004431^{c} ±	0.0005	-0.00759^{c} ±	0.0003	-0.00032^{b} ±	0.0003	0.005655^{b} ±	0.0003	82.5784^{a} ±	0.7
3	0.1237^{a} ±	0.0011	-0.01127^{c} ±	0.0008	0.007076^{b} ±	0.0005	-0.00636^{b} ±	0.0003	-0.00102^{b} ±	0.0003	0.004846^{bc} ±	0.0002	82.8863^{a} ±	0.7
4	0.1248^{a} ±	0.0011	-0.01407^{cd} ±	0.0008	0.007812^{b} ±	0.0005	-0.0056^{ab} ±	0.0004	-0.00063^{b} ±	0.0003	0.004262^{bc} ±	0.0003	83.6541^{a} ±	0.7
5	0.122^{a} ±	0.0014	-0.0147^{d} ±	0.0010	0.008292^{b} ±	0.0006	-0.0058^{ab} ±	0.0004	-0.0008^{b} ±	0.0004	0.004676^{bc} ±	0.0003	81.7763^{a} ±	0.9
6	0.1175^{b} ±	0.0020	-0.0142^{cd} ±	0.0014	0.008252^{b} ±	0.0009	-0.00506^{a} ±	0.0006	0.000427^{ab} ±	0.0006	0.004122^{c} ±	0.0005	78.7629^{b} ±	1.3
7	0.1041^{c} ±	0.0032	-0.02126^{e} ±	0.0023	0.01383^{a} ±	0.0015	-0.00433^{a} ±	0.0010	-0.00117^{b} ±	0.0009	0.00356^{c} ±	0.0007	69.7848^{c} ±	2.1
8	0.1022^{c} ±	0.0040	-0.01229^{cd} ±	0.0028	0.01007^{ab} ±	0.0018	-0.00376^{a} ±	0.0012	-0.0013^{b} ±	0.0011	0.004168^{bc} ±	0.0009	68.4833^{c} ±	2.6
Lactation Year														
2013	0.1032^{e} ±	0.0026	-0.01399^{c} ±	0.0019	0.01335^{a} ±	0.0012	-0.00694^{d} ±	0.0008	-0.00328^{d} ±	0.0007	0.006239^{a} ±	0.0006	69.1869^{e} ±	1.7
2014	0.1108^{d} ±	0.0012	-0.00421^{a} ±	0.0009	0.003401^{d} ±	0.0006	-0.00522^{bc} ±	0.0004	0.00093^{a} ±	0.0003	0.005632^{a} ±	0.0003	74.2263^{d} ±	0.8
2015	0.1143^{c} ±	0.0014	-0.01293^{c} ±	0.0010	0.007583^{b} ±	0.0006	-0.00443^{b} ±	0.0004	0.001457^{a} ±	0.0004	0.003771^{d} ±	0.0003	76.5832^{c} ±	0.9
2016	0.1112^{d} ±	0.0014	-0.00849^{b} ±	0.0010	0.008514^{b} ±	0.0006	-0.00589^{cd} ±	0.0004	-0.00053^{bc} ±	0.0004	0.004576^{c} ±	0.0003	74.5421^{d} ±	0.9
2017	0.119^{b} ±	0.0013	-0.00915^{b} ±	0.0009	0.005466^{c} ±	0.0006	-0.00608^{cd} ±	0.0004	-0.00058^{bc} ±	0.0004	0.004867^{bc} ±	0.0003	79.7214^{b} ±	0.8
2018	0.1199^{b} ±	0.0013	-0.01436^{c} ±	0.0009	0.007832^{b} ±	0.0006	-0.00346^{a} ±	0.0004	-0.00033^{b} ±	0.0003	0.003176^{d} ±	0.0003	80.3464^{b} ±	0.8
2019	0.1241^{a} ±	0.0012	-0.00443^{a} ±	0.0008	0.0061^{c} ±	0.0005	-0.00894^{e} ±	0.0004	-0.0011^{c} ±	0.0003	0.00543^{ab} ±	0.0003	83.1669^{a} ±	0.7
Lactation Month														
6	0.1115^{b} ±	0.0018	-0.0089^{ab} ±	0.0013	0.008223^{ab} ±	0.0008	-0.005^{a} ±	0.0006	-0.0003^{ab} ±	0.0005	0.004364^{a} ±	0.0004	74.7082^{b} ±	1.1
7	0.1116^{b} ±	0.0009	-0.01109^{b} ±	0.0006	0.008537^{a} ±	0.0004	-0.00583^{a} ±	0.0002	-0.00101^{b} ±	0.0002	0.004867^{a} ±	0.0002	74.8053^{b} ±	0.5
8	0.1163^{a} ±	0.0013	-0.0102^{ab} ±	0.0009	0.007474^{b} ±	0.0006	-0.00658^{b} ±	0.0004	-0.00087^{b} ±	0.0003	0.005129^{a} ±	0.0003	77.9203^{a} ±	0.8
9	0.1192^{a} ±	0.0018	-0.00841^{a} ±	0.0013	0.005622^{c} ±	0.0008	-0.006^{ab} ±	0.0005	0.00021^{a} ±	0.0005	0.004877^{a} ±	0.0004	79.865^{a} ±	1.2