Accelerated and out-of-season lamb production in New Zealand

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Gina deNicolo

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Abstract

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Abstract

The objective of this study was to evaluate ewe and lamb performance in an accelerated lamb production system, and to compare the performance and lamb output between a conventional and an accelerated lamb production system. In the "Conventional" system, ewes were bred in March to lamb in August. The "Accelerated" system was based on the "STAR" system (Lewis et al., 1996), in which there were five breeding periods within each year. In the current experiment these were 14th January, 28th March, 9th June, 21st August and 2nd November. Progesterone was used to synchronise the breeding periods and during the non-breeding season, eCG was used to induce reproductive activity. Lambing began on each of these dates and weaning was 73 days later, coinciding with the next breeding period. The experiment ran over a three-year period beginning with breeding in March 2003 and was complete with the weaning of lambs from the January 2006-bred ewes. This resulted in 15 lambing and breeding periods over the three years in the Accelerated system and three lambing and breeding periods in the Conventional system.

Average pregnancy rates were lower in the Accelerated system than in the Conventional system. Lamb growth rates were similar between the two systems, although lamb live weights at weaning were lower in the Accelerated system due to the age of the lambs at weaning (average = 69 vs 96 days). More lambs were born and weaned, resulting in more kilograms of lamb weaned in the Accelerated system relative to the Conventional system over the experimental period (26,200 vs 24,300 kg).

Labour input was 35% higher in the Accelerated system, or 13% higher per lamb weaned. Average annual ewe energy requirements were 6% higher in the Accelerated system. Ewe energy requirements per kilogram of lamb weaned was lower (6%) in the Accelerated system due to more breeding and lambing periods per ewe per year.

Laparoscopic observation of ewes' ovaries at each breeding period revealed that most ewes had active ovaries and were therefore capable of successfully producing a viable foetus. In a subsequent experiment, blood samples were collected for analysis of progesterone concentrations from ewes bred during the spring and autumn breeding periods. Observations of data indicated that a small number of ewes conceived and lost their conceptus, or had abnormal corpora lutea. Results suggested that pregnancies were failing due to a lack of an appropriate signal from the embryo to the dam/uterus.

Exposing Romney ewes to an artificial lighting regimen was unsuccessful for inducing reproductive activity during spring. In another experiment, melatonin implants administered to Romney ewes in spring and used in conjunction with eCG and progesterone, resulted in 61% more lambs born per ewe treated, compared to eCG and progesterone alone. This result indicated that melatonin implants, used with eCG and progesterone may be a suitable method for improving reproductive performance in sheep bred out of season in New Zealand.

Delaying weaning of lambs and breeding lactating ewes can be used to obtain heavier lamb weaning weights in the Accelerated system. Spring-bred ewes had lambs weaned at either 69 days post partum or 90 days post partum. Reproductive performance was similar between the two groups of ewes, and lamb live weights in the later weaned group were heavier when lambs were 90 and 120 days of age.

This research has shown that accelerated or out-of-season lamb production is an option for some New Zealand sheep farmers. However, the mechanisms associated with reproductive seasonality and methods of successfully circumventing this seasonality require further attention in order to achieve optimum reproductive performance.

Acknowledgements

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Sheep breeds

EF	East Friesian Composite (½ East Friesian, ¼ Texel, ¼ Polled Dorset)
Rom	Romney

Hormones (endogenous and artificial)

FSH	Follicle stimulating hormone
LH	Luteinizing hormone
GnRH	Gonadotrophin releasing hormone
eCG/PMSG	Equine chorionic gonadotrophin/Pregnant mares' serum gonadotrophin
CIDR	Controlled internal drug releasing devices
MAP	medroxyprogesterone
FGA	fluorogestone acetate

Reproductive jargon

Oestrus rate	Proportion of ewes displaying oestrus per ewe exposed to the ram
Pregnancy rate	Proportion of ewes pregnant per ewe exposed to the ram
Conception rate	Proportion of ewes pregnant per ewe mated
Fecundity	Number of lambs (or foetuses) per ewe pregnant
Fertility	Number of lambs (or foetuses) per ewe exposed to the ram
PPI	Post partum anoestrus interval (the period of time between parturition and resumption of ovarian activity

Chapter 1 Introduction

Farming is an important industry in New Zealand with agriculture adding $16.6 billion to New Zealand's economy (MWNZ, 2006b). Lamb meat contributes 12.7% to that export market and contributes to 55% of the international exported lamb meat trade.

Lamb production in New Zealand is limited by the seasonal pattern of pasture growth and the fact that most breeds of sheep are reproductively active only during the autumn-early winter period. While annual lamb production has steadily increased over the last fifty years, the seasonal pattern in which this lamb is produced limits the supply of young lamb for chilled trade for overseas markets. There is potential, in some parts of New Zealand, to increase the frequency with which a ewe lambs within a year providing the reproductive seasonality can be circumvented.

McCutcheon et al. (1993) introduced the concept of an accelerated lamb production system in New Zealand under pastoral conditions. While out-of-season lamb production has been investigated in New Zealand, no true accelerated system has been thoroughly investigated. The implementation of such a system as described by McCutcheon et al. (1993) offers exciting opportunities for New Zealand's sheep farming industry, but it also presents some potential difficulties, foremost of which is the seasonality associated with sheep reproduction. Similarly, breeding a proportion of a flock to lamb outside of spring is another alternative which is more commonly researched and used commercially. As with accelerated lamb production, out-of-season reproduction requires circumvention of reproductive seasonality.

The objectives of the research were to evaluate an accelerated lamb production system, to compare the productivity of an accelerated system and a conventional once-yearly system. The list below briefly describes each chapter and outlines the objectives for each of those chapters. Chapters 3, 5 to 10 are published journal articles, are in press, or have been submitted for publication. Due to the nature of the research, the order of the chapters does not necessarily correspond with chronological submission/publication of the respective journal articles.

Chapter **two**: The objective of this chapter was to outline sheep production in New Zealand, convey its importance to the New Zealand economy, and to review literature on accelerated lamb production systems, seasonality in sheep, and methods previously described in the literature to overcome reproductive seasonality.

Chapter **three**: This chapter describes and compares a "Conventional" once-yearly lamb production system with an "Accelerated" lamb production system over a three-year period. The Accelerated system was based on the "STAR" system, developed by Cornell University, New York, and reported by McCutcheon et al. (1993) and Lewis et al. (1996). The objectives here were to provide proof of concept to the sheep farming industry and to compare the performance of both ewes and lambs in the two systems.

Chapter **four**: The labour input and ewe energy requirements of the Accelerated and Conventional lamb production system are calculated and the main findings are presented.

Chapter **five**: The reproductive performance of ewes is the main focus of this chapter, but lamb performance was also monitored. The objectives in this chapter were to compare the performance of ewes and lambs within the Accelerated lamb production system over a period of three years. Problems associated with aseasonal reproduction are also discussed.

Chapter **six**: The research associated with chapters three and five lead to the questions "is impaired or reduced ovarian activity a cause of the low reproductive performance in ewes bred outside of the normal breeding season?" This therefore, was the objective of this chapter. Ovarian activity was monitored at two breeding periods within the normal breeding season, and three outside of the breeding season.

Chapter **seven**: In this Chapter blood progesterone concentrations were collected from ewes bred during the autumn and spring breeding periods. Samples were collected from Day 8 to Day 39 post oestrus, with the expectation that progesterone profiles would indicate where pregnancies were failing.

Chapter **eight**: The objective of the experiment in this chapter was to expose ewes to 24 hrs of artificial light to break photorefractoriness. It was hypothesised that exposure to artificial light would induce reproductive activity and improve pregnancy rates in sheep bred during late spring.

Chapter **nine**: This chapter was designed to circumvent the seasonality in sheep by using melatonin implants. It was postulated that the melatonin implants would improve reproductive performance in ewes bred during the spring.

Chapter **ten**: One method of increasing the weaning weight and improving the lamb output in the Accelerated system (with relatively short lambing to rebreeding intervals) is to delay weaning and breed lactating ewes. Here, it was hypothesised that breeding lactating ewes in spring would not affect aseasonal reproductive performance, but would increase the live weight of lambs at 90 and 120 days of age.

Chapter **eleven**: The final chapter summarises the findings of this research and the conclusions of chapters 3 to 10. Some speculations are suggested regarding the low aseasonal reproductive performance, further research is recommended in some of these areas and the weaknesses and limitations of this research are outlined.

Literature Review:

Accelerated and out-of-season lamb production

G. deNicolo

Chapter 2 Literature review

2.1 Introduction

Year-round lamb production offers exciting opportunities for New Zealand's export trade, it can increase capital utilisation of meat processing plants and skilled labour, and is one method of providing young lamb to consumers throughout the year. It may also offer economical benefits to farmers via production of young lamb at a time of the year when premiums may be available and increased ewe efficiency (the number of lambs born per ewe per year, or the kilograms of lambs sold per ewe per year).

Research into out-of-season lamb production has been carried out for the last 50 years (i.e. where a proportion of a flock is bred outside of the normal breeding season). Accelerated lamb production systems (i.e. lamb production systems in which ewes lamb more than once a year) have also been investigated with various husbandry systems being utilised. These systems include breeding ewes so that individual animals have the opportunity to lamb twice in one year, three times in two years, or five times in three years. Some of these production systems have been successful while others failed to be economically sustainable. There have been few such systems attempted in New Zealand, although several experiments have investigated early season, or out-of-season lamb production.

Sheep are seasonal breeders and most breeds are receptive to the ram only during the autumn-early winter period when daylight hours are decreasing. The mechanisms behind this seasonal phenomenon in sheep have been thoroughly investigated. Reproductive seasonality has implications when breeding sheep more frequently and outside of the normal breeding season, and exogenous hormones are required to induce reproductive activity, particularly during deep anoestrum in seasonal breeds, such as the Romney, Perendale, Coopworth or Suffolk.

The purpose of this literature review was to firstly, provide a background into New Zealand lamb production and its importance to the New Zealand economy, in terms of production and export volumes. Accelerated lamb production systems are explored, and advantages of the production of lamb on a year-round basis are discussed. Limitations associated with out-of-season reproduction are covered, and a section is devoted to seasonality in sheep, and the use of exogenous reproductive hormones, melatonin and artificial lighting treatments, as a means of overcoming reproductive seasonality.

There is substantial literature available on seasonality in sheep and this literature review can not cover all of this. Rather, it has been written with the intention of covering the issues that are more pertinent to out-of-season or accelerated lamb production in New Zealand.

2.2 Sheep production in New Zealand

Sheep numbers in New Zealand have fluctuated over the past four and a half decades (Figure 2.1) from 48 million in 1960 to 70 million in the 1980s, and then declining over the last two decades to 40 million. In June 2005, there were over 27.2 million ewes utilised for breeding. Despite the large decline in sheep numbers over the last twenty years, total kilograms of lamb produced (Figure 2.2) has been maintained by an increase lambing percentages and heavier lamb carcass weights (Figure 2.3).

New Zealand exports lamb products to over 100 destinations including countries in the Middle East, Europe, Africa, the Pacific, Asia and North America. Since 1981, New Zealand has consistently exported over 95% of its processed lamb. In the 2005/06 season, 25.6 million lamb carcasses produced 435,000 tonnes and 98% (426,000 tonnes, 24.8 million lambs) of that was exported (MWNZ, 2006a). New Zealand is the largest sheep meat exporter in the world, supplying 55% of the world's internationally traded lamb and earning New Zealand around $1.9 billion ($2.7 billion in total sheep products)

(MWNZ, 2003). The European Union is the biggest importer of New Zealand lamb meat with around 50% (226,700 tonnes) of New Zealand's exported lamb meat being sent there annually.

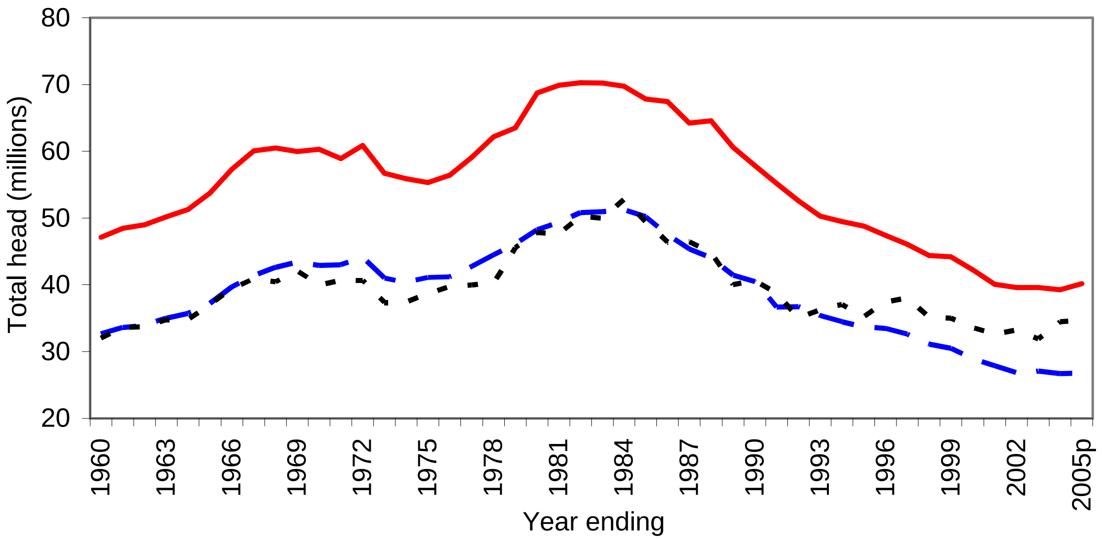

Figure 2.1 Numbers (millions) of sheep in New Zealand from 1960 to 2005. Total sheep (—), breeding ewes and hoggets (— — —) and lambs docked (-----); P = provisional. Source MWNZ (2005).

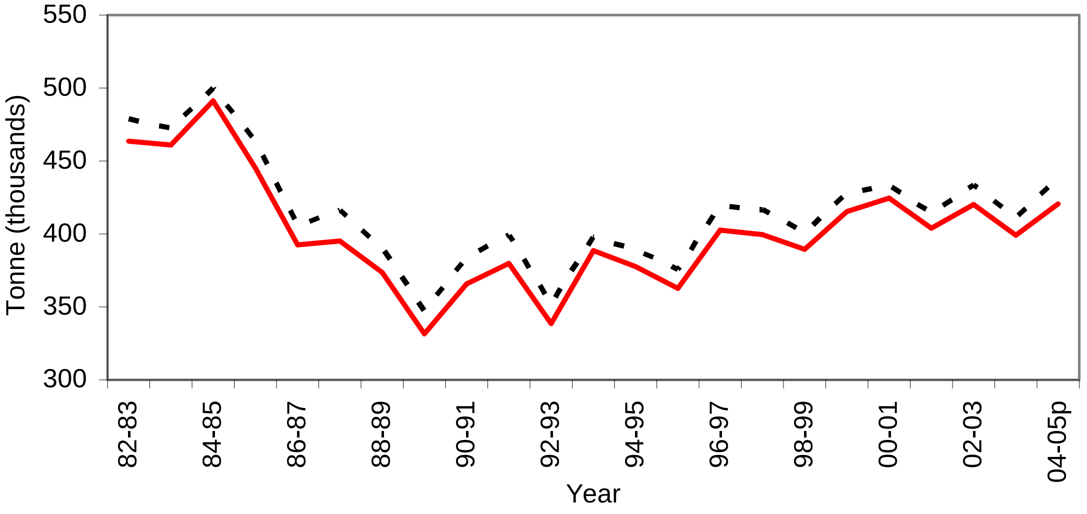

Figure 2.2 Total weight (thousand tonnes, bone-in) of New Zealand annual lamb production (- - -) and export (—) for the seasons from 1981 to 2005. Source MWNZ (2005).

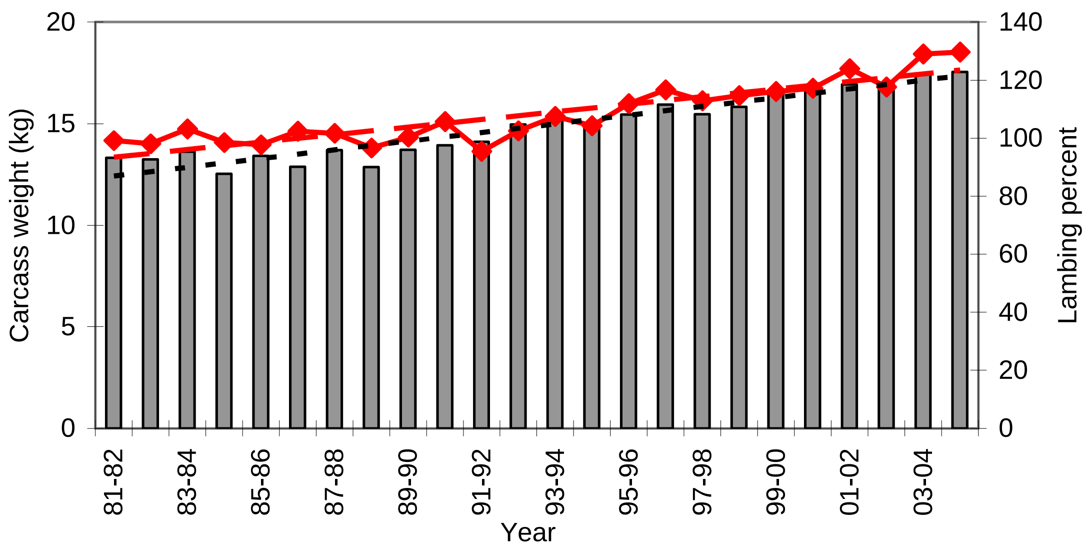

Figure 2.3 Lamb carcass weights (■) with trend line (**- - -**) and lambing percentages (—◆—) with trend line (— — —) from 1981 to 2005. Source MWNZ (2005).

Limitations with conventional lamb production

Lambing percentages and lamb mortality

As farmers target increased lambing percentages and ewe efficiency in their flocks, lambing percentages (lambs docked/ewes bred) in New Zealand have risen from 98% in 1960 to 124% in 2006 (MWNZ, 2006a). However, increased lambing percentages through larger litter sizes, are associated with increased lamb mortality. Multiple-born lambs (particularly triplet-born lambs) have lower birth weights (Dalton et al., 1980; Scales et al., 1986; Hinch et al., 1996; Jopson et al., 2000; Kenyon et al., 2002) and are at higher risk of dying from starvation and exposure (Figure 2.4), thereby contributing to higher perinatal mortality rates (Hight and Jury, 1969; Dalton et al., 1980; Hinch et al., 1983; Scales et al., 1986; Rowland et al., 1992; Morris et al., 2003; Morris and Kenyon, 2004). Mortality rates from 11% to 40% have been reported in triplet-born lambs (Dalton et al., 1980; Scales et al., 1986; Nicoll et al., 1999; Kenyon et al., 2002; Morris et al., 2007) and from 12% to 35% in twin-born lambs (Dalton et al., 1980; Litherland et al., 1999; Tarbotton and Webby, 1999; Kenyon et al., 2002; Morris et al., 2007).

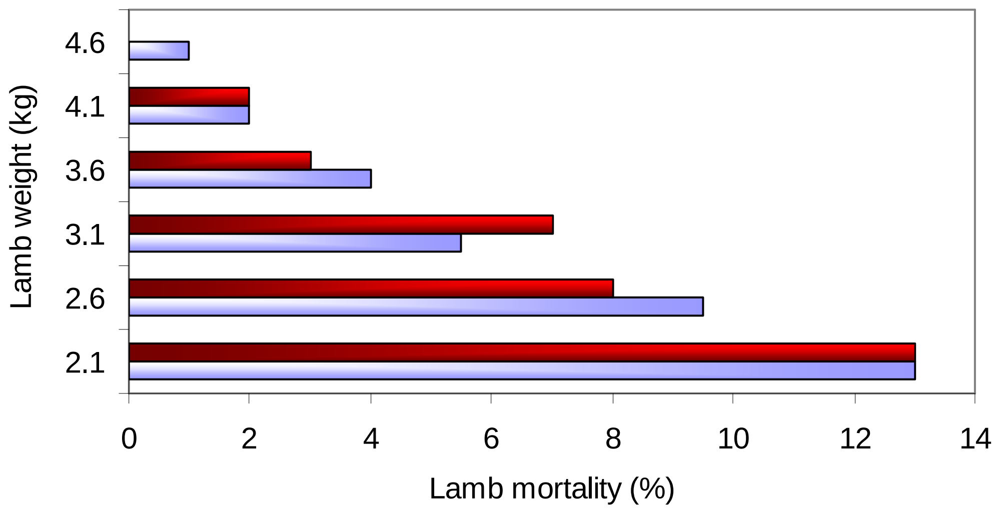

Figure 2.4 Lamb deaths from starvation/exposure classified according to birth weight; multiple-born (■) and, single-born (■) lambs (Dalton et al., 1980)**.**

One way of avoiding high perinatal lamb mortality while still achieving high ewe efficiency is by increasing the number of times a ewe lambs within a year. So, while lambing percentages at a particular lambing may be equal, or even lower, the overall lambing percentage for that year could be increased. Moreover, if the number of triplet lambs is reduced per lambing, overall lamb survival and growth rates to weaning might be increased.

Seasonality of lamb supply

Another important limitation to the conventional pattern of lamb production in New Zealand, is that it is seasonal, and is somewhat driven by pasture growth patterns. This allows New Zealand to keep the cost of lamb production low and thereby compete more effectively on the international market. This seasonal pattern of pasture growth dictates that most lambs are ready for slaughter in the summer and autumn period (Johnson, 1989; MWNZ, 2006a). The economic efficiency of processing is seriously affected by this seasonality of production (Johnson, 1989). The monthly fluctuations in lamb kill throughout the year (Figure 2.5) indicates that meat processing plants operate at or near capacity for only a few months of the year and a significant proportion of the skilled labour is only used for that part of the year.

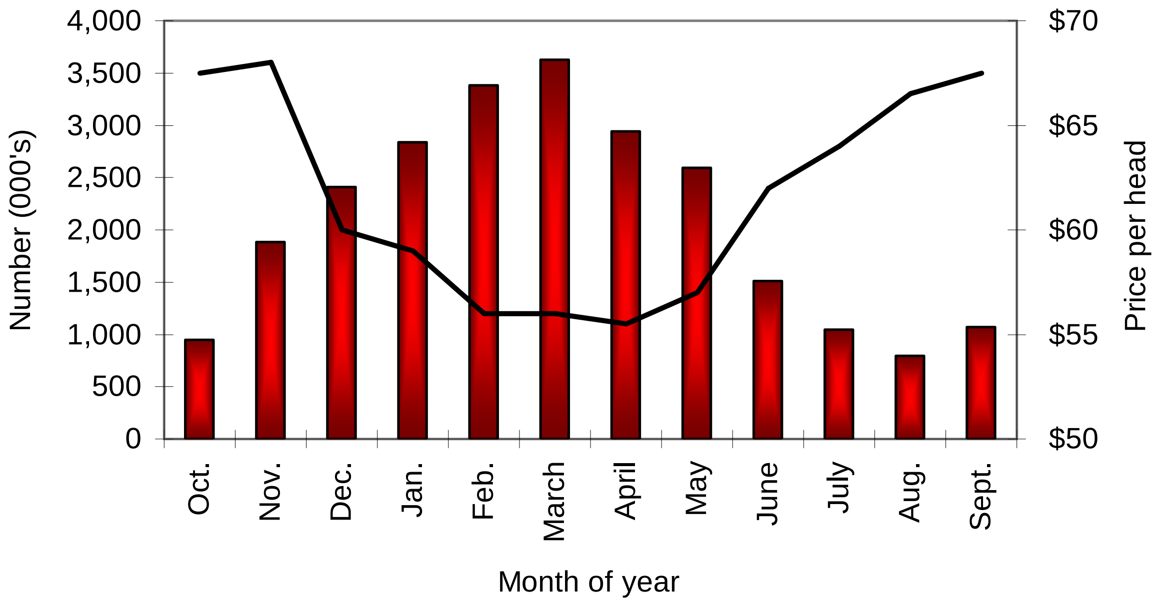

Figure 2.5 Number of lambs sent for processing each month in New Zealand for the 2004/05 season (■) (Personal Communication, Williams, August 2007) and average monthly lamb schedule from February 2004 to January 2005 ($ per head; —) (MWNZ, 2006a).

In New Zealand, some meat processing companies often do not pay significant premiums for young lamb sent for slaughter outside of the normal season. The schedule price may be higher, but that is due to the scarcity of animal available for slaughter (Figure 2.5).

In summary, farm returns could be increased by providing lambs for slaughter over the period where availability is traditionally low and schedule price is often higher. There are two methods that can spread the production of lamb over a year to ensure a steady provision of lamb for national and international supply throughout the year; breeding a proportion of the flock to lamb out of season or increasing the frequency of breeding/lambing within a year (i.e. accelerated lamb production).

2.3 Accelerated lamb production systems

Accelerated lamb production is where ewes lamb more than once a year, and these systems differ from out-of-season lamb production. The latter is usually regarded as a system in which the normal breeding season (for all or a part of a flock) is extended or altered rather than breeding more than once a year. The most common accelerated lambing system involves ewes being bred every eight months or three times in two years (Speedy and FitzSimons, 1977; Notter and Copenhaver, 1980; Dzakuma et al., 1982; Vesely and Swierstra, 1985; Fahmy, 1990; Nugent and Jenkins, 1991; Fogarty et al., 1992a; Urrutia et al., 2001). Other systems, although not as thoroughly researched, involve breeding ewes every six months, i.e. twice yearly (Land and McClelland, 1971; Whiteman et al., 1972; Walton and Robertson, 1974; Goot and Maijala, 1977) and four lambings in three years (Menegatos et al., 2006). Wang and Dickerson (1991), Lewis et al. (1996) and Smith (2006) reported a system (the “STAR” accelerated lambing system) in which ewes have the opportunity to lamb five times in three years.

Advantages of accelerated lamb production systems

The number of lambs born per year can be increased without increasing litter sizes by increasing the frequency by which ewes are bred within each year. For example, Fahmy (1990) reported 2.3 lambs born per ewe per year in an accelerated lambing system where ewes lambed every eight months. Walton and Robertson (1974) reported 3.54 lambs born per ewe per year in a system in which ewes lambed at six-monthly intervals – an increase of 53% over the conventional once-a-year lamb production. Rawlings et al. (1987) reported that an eight-monthly lambing system produced 37% more lambs per year than the conventional once-a-year lambing system. Other accelerated lambing systems have also reported the number of lambs per ewe per year to be greater than the conventional lambing system (Table 2.1). Whilst there are numerous examples of accelerated lamb production, there are seldom comparisons with conventional once-lambing systems within the same study.

Table 2.1 Number of lambs born per ewe per year in accelerated lamb production systems, country in which study was conducted and breed of sheep.

Breed by lambing interval	Lambs born/ ewe/yr	Country	Reference
Eight-monthly lambing interval [a]			
Finnish Landrace x Dorset Horn	2.13	Edinburgh, Scotland	Speedy and FitzSimons (1977)
Finish Landrace x Rambouillet	2.20 – 3.41	Virginia, USA	Notter and Copenhaver (1980)
Finnsheep, Dorset and Rambouillet crossbred ewes Hampsire, Suffolk and crossbred rams	1.92	Oklahoma, USA	Dzakuma et al. (1982)
Finish Landrace and Dorset crosses	2.51 – 2.06	Alberta, Canada	Vesely and Swierstra (1985)
Finnsheep, DLS (synthetic breed) and Finn x DLS	3.27	Quebec, Canada	Fahmy (1990)
Booroola Merino x Poll Dorset, Trangie Fertility Merino x Poll Dorset and Border Leicester x Merino	1.81 – 2.38	NSW, Australia	Fogarty et al. (1992)
Merino Rambouillet	2.74	Mexico	Urrutia et al. (2001)
Six-monthly lambing interval			
Finnish Landrace x Dorset Horn	2.90	Edinburgh, Scotland	Land and McClelland (1971)
Dorset, Rambouillet and Dorset x Rambouillet	1.86	Oklahoma, USA	Whiteman et al. (1972)
Finnish Landrace	3.54	Quebec, Canada	Walton and Robertson (1974)
Finnish Landrace	4.03	Finland, Europe	Goot and Maijala (1977)

[a] 8 monthly lambing intervals is equivalent to lambing three times in two years.

Season of lambing

While lower birth weights have been recorded for autumn-born lambs (Morris et al., 1993; Jenkinson et al., 1995; McCoard et al., 1996; Gootwine and Rozov, 2006), several authors have found no significant difference in perinatal mortality for lambs born in different seasons (Notter and Copenhaver, 1980; Notter et al., 1991; Morris et al., 1993; Dabiri et al., 1996; Fisher, 2004). In other studies (McQueen, 1986; Reid et al., 1988), higher lamb survival rates have been reported in autumn-born lambs compared to spring-born lambs despite lower birth weights in the autumn-born lambs (Reid et al., 1988).

In New Zealand, timing of once-yearly lambing varies throughout the country, but usually occurs from July (Hawkes Bay) through to November (South Island high country), during which time, the highest rainfall and lowest temperatures are recorded (Figure 2.6). Therefore, given that newborn and perinatal lambs are most at risk from exposure in wet and cold conditions (Gregory, 1995), lambing at other times of the year could be seen as advantageous, providing nutritional requirements of pregnant and lactating ewes can be met.

Some regions of New Zealand may be suitable for accelerated lamb production as they are less seasonal with pasture growth rates. New pasture species, the development of ryegrass cultivars that have increased growth rates in the winter periods and the increased use of nitrogen fertilisers have changed the pattern of pasture growth as seen in Figure 2.7, in that higher pasture growth rates are now achieved compared to those in the 1970s. The pattern of pasture growth in Dargaville indicates that it could support the production of lamb outside of the normal season as it has acceptable summer and winter pasture growth which would support spring and summer breeding (summer and autumn lambing; winter and spring lamb finishing; Figure 2.7). Higher ambient temperatures during these periods could also result in lower perinatal lamb mortality, and adequate rainfall encourages pasture growth (Figure 2.6). Hawkes Bay has low pasture growth rates in mid to late summer, and is therefore not suited to summer lambing or finishing, although summer breeding, and spring or early summer finishing would be suitable for this area. The Rangitikei region has adequate pasture growth throughout the year and thus, may support lambing and lamb finishing at any time of the year.

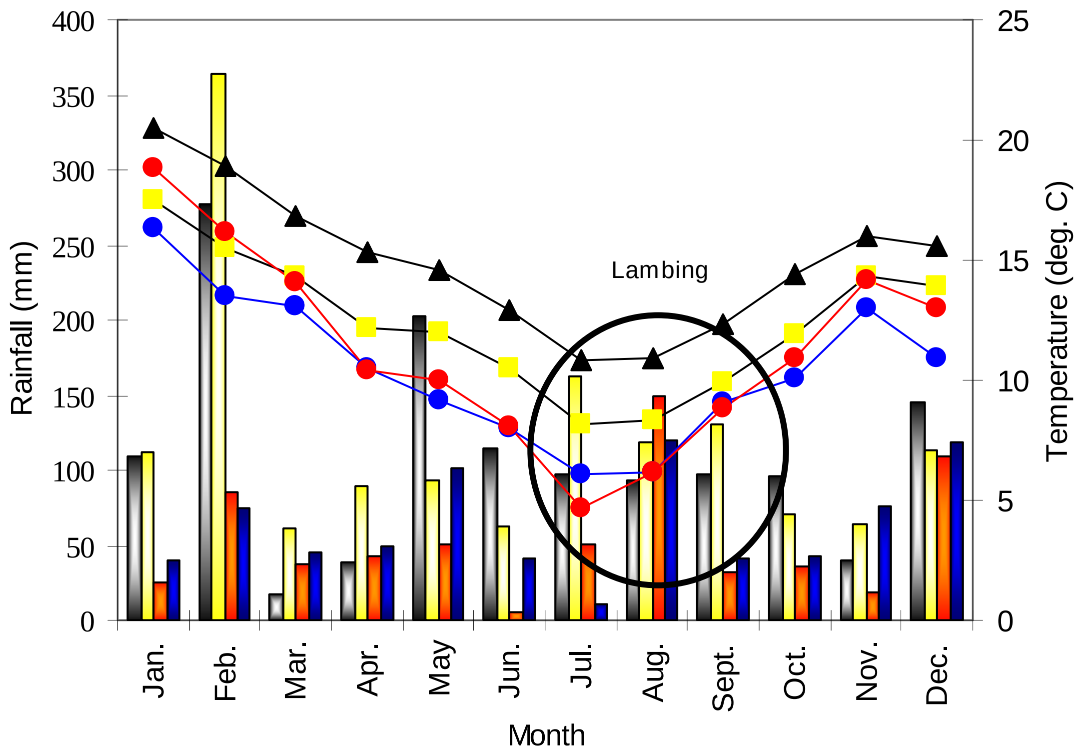

Figure 2.6 Average monthly rainfall (bars) and temperature (lines) in 2004 for New Zealand's main area (Auckland; ■, Wellington; ■, Christchurch; ■ and Dunedin; ■) in relation to time of lambing (circled).

Most areas in the South Island would not be suited to winter lamb production due to low pasture growth (Figure 2.7) and low ambient temperature (Figure 2.6). Areas such as Southland, that have high pasture growth over late spring and summer, would be more suited to lambing later in the year (i.e. winter breeding; summer lambing; autumn finishing), particularly in areas that suffer from heavy lamb losses due to low temperatures and high rainfall (and sometimes snow storms over the spring lambing period).

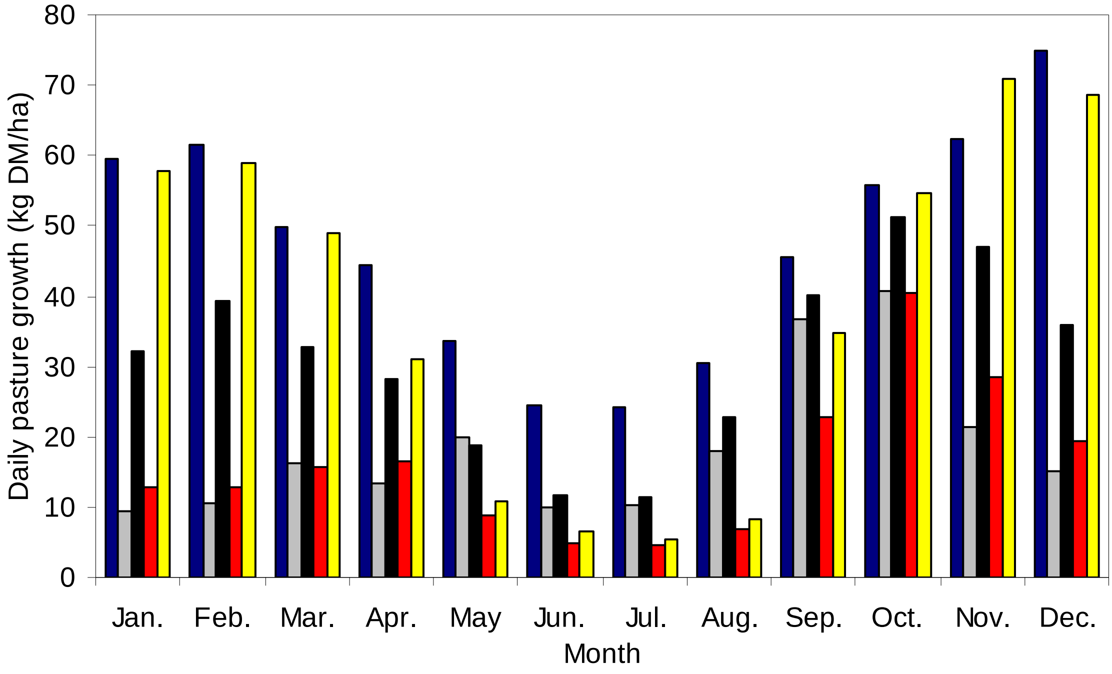

Figure 2.7 Seasonal pattern of pasture growth for different regions in New Zealand (Dargaville; ■, Hawkes Bay; ■, Rangitikei; ■, non irrigated Canterbury plains; ■, and Southland plains; ■). Source (Radcliffe, 1974; 1975; Baars, 1976; Radcliffe, 1976; Rickard and Radcliffe, 1976).

In conclusion, accelerated lamb production is more suited to some areas of New Zealand, while a shift in the lambing season for a proportion of a flock is more practical for other areas.

2.4 Limitations to accelerated lamb production systems

For an accelerated lamb production system to be successful in New Zealand, several factors need to be considered; out-of-season pregnancy rates, postpartum intervals, and labour and ewe feed/energy requirements. To this authors' knowledge, there has been no information/data published either on the labour input or on the annual ewe energy requirements in an accelerated lamb production system. Nevertheless, these components need to be evaluated for any lamb producer who is considering implementing an accelerated lamb production system. In some accelerated lamb production systems, ewes need to be re-bred soon after parturition and while still suckling lambs therefore it is important to address postpartum anoestrus intervals and lactational anoestrus.

Postpartum anoestrus interval and lactational anoestrus

The effects of lactation on reproductive success vary greatly. Reports on the return to oestrus following parturition (i.e. postpartum anoestrus interval; PPI) have also provided variable results. A ewe is unable to return to oestrus and successfully breed prior to uterine involution which has usually occurred by 24 days postpartum (Call et al., 1976). Therefore, in an accelerated lamb production system, PPI is not an issue with ewe productivity as long as ewes are bred post uterine involution.

It is difficult to separate the seasonal anoestrus from lactational anoestrus, as in seasonal breeds of sheep lactation occurs during the non-breeding season. Nevertheless, some studies have attributed reduced aseasonal reproductive performance to the lacational status of the animal (Mallampati et al., 1971; Lewis and Bolt, 1983). Other studies have reported better reproductive success in lactating ewes compared with non-lactating ewes (Hulet and Foote, 1967; Pope et al., 1989; Fogarty et al., 1992b). For example, Hulet and Foote (1967) reported that more lactating ewes returned to oestrus compared with non-lactating ewes after one treatment with progesterone. A similar pattern was reported in autumn- and spring-bred ewes without progesterone administration (Pope et al., 1989). Further, Pope et al. (1989) reported that a higher proportion of ewes that were lactating over that breeding period lambed and, during the non-breeding season, Fogarty et al. (1992b) reported increased litter size in lactating ewes relative to non-lactating ewes.

Low concentrations of luteinising hormone (LH) have been associated with reduced fertility (Pelletier and Thimonier, 1973) and are lower in lactating ewes compared with non lactating ewes (Lewis and Bolt, 1983). Since peripheral LH concentrations are important for ovulation, it is possible that the reduced LH concentrations, present in lactating ewes, prevent ovulation and delay the return to reproductive activity.

Litter size affects PPI since ewes rearing twin lambs have a longer PPI than ewes rearing singletons (Barker and Wiggins, 1964; Hulet and Stormshak, 1972). No correlation however, has been reported between milk production and PPI in lactating ewes (Fletcher, 1971b), although negative correlations between plasma prolactin concentrations and the resumption of ovarian activity have been reported (Fitzgerald and Cunningham, 1981). Rhind et al. (1980) suggested prolactin was responsible for the effect of season and lactation on ewe fertility, and Kann and Martinet (1975) concluded that surges of prolactin, specifically induced by suckling were the cause of suppressed ovarian activity during lactation. Several other studies have indicated that the physiological stimulus of a suckling lamb is responsible for prolonged PPI and reduced fertility in lactating ewes (Denamur and Martinet, 1960; Fletcher, 1971b; Restall, 1971; Kann and Martinet, 1975). It would therefore appear that if re-breeding occurs during a stage when lambs suckle more frequently for shorter periods (i.e. during early lactation) (Obregon et al., 1992; Reale and Bousses, 1995), the effect of lactation would be expected to be greater (i.e. poor reproductive performance).

Nutrition has been found to affect PPI whether the ewes were lactating or not at the time of breeding, and Hunter and van Aarde (1973) concluded that if ewes were fed adequately for their lactational status, and their nutritional requirements were met, PPI should not differ between lactating and non-lactating ewes.

These studies suggest that it is possible, if not advantageous to breed lactating ewes providing their nutritional requirements are met, uterine involution has occurred (24+ days postpartum) and they are towards the end of lactation when lambs suckle less frequently. It is therefore feasible to breed ewes whilst they are lactating in an accelerated lambing system.

Reproductive seasonality in sheep

Where possible, this review of literature regarding the seasonality in sheep is restricted to studies conducted with the ewe. Photoperiod changes are interpreted by the eye and the photoreceptor in the eye transmits a signal via the suprachiasmatic nucleus and superior cervical ganglion to the pineal gland (Hoffman and Reiter, 1965; Reiter, 1968; Stetson and Watsonwhitmyre, 1976). The pineal gland then produces a biochemical response to changes in light and dark where light inhibits and dark stimulates the synthesis of melatonin (Arendt et al., 1981).

Photoperiodic signals are converted by the pineal gland into a hormonal signal, namely melatonin (Maeda et al., 1988), and this signal, through a complex nature of interactions, regulates the reproductive season in sheep. Clear diurnal changes in melatonin concentrations have long been recognised (Rollag and Niswender, 1976; Rollag et al., 1978; Matthews et al., 1992). The primary effect of light is to inhibit the pineal gland's secretion of melatonin (Rollag et al., 1978; Arendt and Ravault, 1988), therefore, melatonin concentrations during the period of long nights (i.e. winter) remain elevated for a longer duration than when nights are short (i.e. summer).

High prolactin concentrations are generally considered to be an impediment to successful reproduction in sheep during both lactation and the anoestrus period. During the non-breeding season blood prolactin concentrations are high whereas during the breeding season, they are low (Walton et al., 1977; Thimonier et al., 1978; Walton et al., 1980; Kennaway et al., 1983; Webster and Haresign, 1983; Karsch et al., 1989; Santiago-Moreno et al., 2000). The high prolactin concentrations during the non-breeding season are alone, not responsible for anoestrum (Walton et al., 1980) and have been described as coincidental rather than causally related to photoperiod (Webster and Haresign, 1983).

Luteinising hormone is important in the control of ovulation but there appears to be no differences in LH concentrations in sheep between the breeding and non-breeding seasons (Poulton et al., 1987). There are however, seasonal differences in LH pulses (Goodman et al., 1982; Bittman et al., 1985; Robinson et al., 1985a) which are important for ovulation. During the breeding season, oestradiol has a weak negative feedback effect (Webster and Haresign, 1983) permitting the necessary LH pulse frequency for ovulation to occur. During the non-breeding season, oestradiol has a much stronger effect and is able to block tonic LH secretion (Legan et al., 1977; Thimonier et al., 1978), reducing LH pulse frequency below that necessary to sustain the follicular oestradiol secretion required to cause the preovulatory LH surge (Scaramuzzi and Baird, 1977; Goodman and Karsch, 1980; Goodman et al., 1982; McNeilly et al., 1982), thereby preventing ovulation.

A number of studies however, have indicated that progesterone is the primary steroid controlling tonic LH secretion (Hulet and Foote, 1967; Mallampati et al., 1971; Baird and Scaramuzzi, 1976; Hauger et al., 1977; Karsch et al., 1980a; Lewis and Bolt, 1983; Pope et al., 1989; Kasavubu et al., 1992) and peripheral progesterone concentrations vary between the breeding and non-breeding seasons (Rhind et al., 1978; Forcada et al., 2003; Coelho et al., 2006).

Follicle stimulating hormone (FSH) is responsible for stimulating the development of follicles and also stimulates the release of oestrogen. Blood FSH concentrations have been shown to be associated with follicular growth and regression (Bartlewski et al., 2000; Duggavathi et al., 2005). While other reproductive hormone concentrations vary between the breeding and non-breeding seasons, there appears to be little or no variation in FSH blood concentrations (Walton et al., 1977; Walton et al., 1980) and exposure to short days does not increase FSH concentrations (Walton et al., 1980).

2.5 Overcoming seasonality

Methods used to alter the breeding season or breed during the anoestrus period, rely on stimulating the hypothalamic activity using artificial photoperiod or melatonin, or depend on the use of artificial reproductive hormones to circumvent the effects of season. The most common and widely researched are those systems that use progesterone and equine chorionic gonadotrophin (eCG; also known as pregnant mares' serum gonadotrophin or PMSG). For this reason, this section of the literature review is limited to progesterone and eCG for the use of inducing reproductive activity during the non-breeding season, and, in the case of progesterone, enhancing out-of-season pregnancy rates after post-mating supplementation. Exogenous melatonin and exposure to artificial photoperiods have also been used to circumvent seasonality in sheep, and are also discussed.

Exogenous reproductive hormones

Progesterone and reproduction

To induce most breeds of sheep to reproduce outside of their natural breeding season, exogenous hormones are required. The induction of oestrus relies on previous exposure to progesterone, which, during the non-breeding season, is artificial progesterone. In the past, reproductive activity has been induced with injections of progesterone intramuscularly (Dutt, 1952; Robinson, 1954a; 1954b; 1954c; 1955; Gordon, 1958; Braden et al., 1960; Gordon, 1963; Lamond, 1964; Fletcher, 1971a; Alifakiotis, 1977; Haresign et al., 1996), subcutaneously using implants (Gordon, 1958; Cunningham et al., 1980; Kittok et al., 1983; McLeod and Haresign, 1984) and/or via oral supplements (Southcott et al., 1962; Daniel et al., 2001), albeit with varying results. These methods of progesterone administration are neither popular nor practical for New Zealand sheep farming practices. Intravaginal administration via the use of progesterone-impregnated pessaries and controlled internal drug release devices

(CIDRs) are the most common method utilised. Therefore, this literature review concentrates on sheep research using intravaginal progesterone administration.

Exogenous progesterone, administered to the ewe, mimics the release of progesterone from the corpora lutea. Exposure to progesterone is required to sensitise the hypothalamus to oestrogen and this is required for the display of oestrus (i.e. prevention of silent oestrus). After withdrawal of the progesterone source, events surrounding ovulation and oestrus occur as they would normally if the progesterone source was endogenous.

There is a substantial amount of scientific literature published where exogenous/artificial progesterone has been utilised in the reproduction of sheep, both during the breeding season and the non-breeding season. Results from the use of progesterone, either in the form of progesterone, medroxyprogesterone (MAP), fluorogestone acetate (FGA) or norgestomet, in conjunction with the use of eCG or alone, have been variable, in terms of pregnancy rates and/or conception rates. These studies are difficult to compare as different husbandry/management systems are used, and hormone regimens, season, breeds and latitude also differ.

Variability in pregnancy and/or conception rates have been reported where progesterone has been used for synchronisation of oestrus during the breeding season or for induction of cyclic activity during the non-breeding season. Further, progesterone administration has been shown to reduce the proportion of ewes pregnant or that lamb from progesterone-synchronisation during the breeding season (Rhodes and Nathanielsz, 1988; Wheaton et al., 1993; Daniel et al., 2001). When progesterone is used alone (i.e. without eCG) during the non-breeding season, it appears to work more successfully and achieve higher pregnancy rates during the transition back into the breeding season (i.e. mid to late summer; 81% (Smith et al., 1988a), 64-76% (Morris et al., 1993), 93-95% (Wheaton et al., 1992)) and not at a time when ewes are in the transitioning from oestrus to anoestrus (early spring; 12% (Smith et al., 1988a)), or in deep anoestrus (late spring to early summer; 11% (Cunningham et al., 1980), 2% (Smith et al., 1988a), 55% (Kohno et al., 2005)).

The normal luteal phase, in which peripheral progesterone concentrations are elevated is 11 days (Day 3 to Day 14 of the oestrous cycle (Geisert and Malayer, 2000)). It was once thought that the duration of progesterone administration should mimic the luteal phase of the oestrous cycle. The duration of artificially induced elevated progesterone concentrations range from five to 14 days, with little variation in results (Ungerfeld and Rubianes, 1999a; Knights et al., 2001; Ungerfeld and Rubianes, 2002; Ungerfeld et al., 2003). Longer durations tended to be more effective in these studies, but the differences were not statistically different. However, while there appears to be no industry recommendation, duration of progesterone administration used in some more recent research is 12-14 days (Hawken et al., 2005; Kohno et al., 2005; Ungerfeld et al., 2005; Zeleke et al., 2005; Gomez et al., 2006). Pharmacia & Upjohn, the manufacturers of Eazi-Breed™ CIDRs®, recommend 12-14 days during the breeding season and 7-12 days during the non-breeding season.

Progesterone, the uterine environment and post-mating supplementation

Progesterone plays a major role in controlling the uterine environment required for successful embryo development (Ashworth, 1995). The periovulatory period has been shown to be important for embryonic survival (Moore, 1985; Wilmut et al., 1985) and is thought to be responsible for the rapid preimplantation growth phase of the embryo (Bindon, 1971).

Exogenous progesterone supplementation has also been used during early gestation as an aid to improved pregnancy rates, but is only successful when restoring endogenous progesterone concentrations (i.e. it does not elevate progesterone concentrations that, with no intervention, would have been low). Some studies (Pearce et al., 1984; Davis et al., 1986; Parr et al., 1987) have found progesterone supplementation from 10-26 days post mating increased pregnancy rates, while other studies have found no effect on pregnancy rates with progesterone supplementation from 3-14 days post mating (McMillan, 1987; Kleemann et al., 1991; Davies and Beck, 1992; Iglesias et al., 1997; Kenyon et al., 2005). Since increased pregnancy rates were reported in studies were progesterone supplementation was continued for up to 26 days post mating, and no effect was reported where supplementation occurred at an earlier stage post mating, it appears that the time of supplementation could be more important than the duration (i.e. 10-26 days post mating).

Equine chorionic gonadotrophin (eCG) and reproduction

Administration of equine chorionic gonadotrophin (eCG or PMSG) causes a surge in the release of gonadotrophins (e.g. FSH and LH) which results in ovulation. The most common route of administration is intramuscular. During the breeding season, eCG is used to increase ovulation rate (Gherardi and Lindsay, 1980). During the non-breeding season, eCG is required for the follicles to develop to a stage at which they are viable and can ovulate.

During the non-breeding season, at the time when ewes are in deep anoestrus, eCG is used in conjunction with exogenous progesterone and this has resulted in higher reproductive performance than when progesterone is used alone (Dutt, 1952; Robinson, 1954a; 1954b; 1954c; Raeside and Lamond, 1956; Gordon, 1958; Cunningham et al., 1980).

Reproductive response to eCG tends to increase as the dose rate of eCG increases (Andrewes et al., 1987; Knight et al., 1989b), although Smith et al. (1988a) showed that a higher dose does not always result in higher pregnancy rates. Andrewes et al. (1987) found that a higher proportion of ewes treated in November with progesterone and 750 I.U. eCG lambed (74%) compared with ewes treated with progesterone and 250 I.U. eCG (42%). Similarly, Faure et al. (1983) reported increases in pregnancy rates after administration of 0, 60 300 I.U. eCG.

Smith et al. (1988a) reported varying responses to 400 or 800 I.U. eCG throughout the year with no clear pattern indicating whether one dose rate was consistently better: In October, December and April pregnancy rates were higher for 800 I.U. eCG than for 400 I.U., in June and August, there was little difference between the two dose rates, and in February 400 I.U. resulted in a higher pregnancy rate. Although the differences between the eCG dose rates varied, the pattern of response for each was similar to that reported by Gheradi and Lindsay (1980) in Merino ewes whereby the response mimicked the natural pattern (i.e. best results were achieved during the autumn period, and the worse during the spring period).

Melatonin

Melatonin is synthesised in the pineal gland and has been identified as being responsible for a cascade of events ending in the eruption of fertilisable eggs from the ovaries of seasonal breeders, including sheep (Follett, 1982; Matthews et al., 1993; Williams and Helliwell, 1993).

Knight (1983) fed Romney ewes in New Zealand melatonin for 25 or 45 days from early January, exposed them to rams in late January, and achieved pregnancy rates of 62 and 44%, respectively. In Australia, melatonin implants used alone (i.e. no progesterone or eCG) in January-bred Romney ewes have resulted in pregnancy rates as high as 95% (Williams et al., 1992). Since Knight (1983) and Williams et al. (1992) both used Romney ewes bred at a similar time of the year (January) at similar latitudes (37^{o}S and 38^{o}S for New Zealand and Australia, respectively), and control groups had pregnancy rates of 29 and 89%, respectively, the difference in pregnancy rates cannot be entirely explained by the use of oral vs implanted melatonin. Neither does the duration of melatonin administration account for the difference as the pregnancy rate in ewes fed melatonin for 25 days was 62% whereas corresponding group of ewes in the Williams et al. (1992) study (i.e. ewes administered melatonin implants 21 days prior to ram introduction), pregnancy rates were 98%.

Melatonin implants appear to work more efficiently in Mediterranean sheep breeds than they have done in New Zealand breeds since Abecia et al. (2007) reported significantly more lambs (0.33) per treated ewe on two of four farms where melatonin implants were used in spring. Forcada et al. (1999) also reported an increase in 0.36 lambs per treated ewe when melatonin was administered to Rasa Aragonesa ewes in spring. Melatonin increased pregnancy rates by 19% in spring-bred Rasa Aragonesa ewes (Lopez Sebastian and Inskeep, 1991). Similarly, Laliotis et al. (1997) reported increased pregnancy and conception rates when melatonin implants were used in spring-bred Chois ewes, and Abecia et al. (2007) reported that melatonin implants increased pregnancy rates in spring- and summer-bred Rasa Aragonesa ewes. Horoz et al. (2003) reported high pregnancy rates in Turkish Kivircik ewes bred in summer, although the pregnancy rates between the different groups (control; 75%, melatonin; 85% progesterone and eCG; 90%, progesterone, ecG and melatonin, 95%) were not significant.

Since the earlier experiments in New Zealand (Knight, 1983), advancements in technology and the delivery of melatonin (e.g. oral vs implants), it is feasible to suggest that the use of melatonin in aseasonal breeding programs may be more successful than it has been in the past, and should be considered as an option for circumventing seasonality in sheep.

Artificial light treatments

Scientists have used various light/dark regimes to induce sheep to reproduce during the non-breeding season. Yeates (1949) was among the first to alter the photoperiod and breeding season of ewes by exposing ewes to artificial light. The breeding season of Suffolk X Border Leicester X Cheviot ewes was reversed by reversing the photoperiod (i.e. ewes were exposed to artificially long days during winter, and short days during summer). Shortly after, Hart (1950) proved that an abrupt decrease in daylight hours and an associated increase in dark-hours had the ability to induce maiden Suffolk ewes to cycle three months earlier than ewes under ambient photoperiod. This experiment (Hart, 1950) showed that gradual decreases and/or increases in artificial light (i.e. to mimic ambient photoperiodic changes) are not necessary to evoke a reproductive response in sheep following exposure to an artificial lighting regime.

Manipulation of photoperiod controls the production of melatonin from the pineal gland, and entrains the underlying circadian rhythm generators located in the hypothalamus. Exposure of ewes to extended periods of light followed by exposure to shorter periods of light (i.e. extended periods of darkness) retrains the hypothalamus and changes the sensitivity of the hypothalamus to oestrogen, thereby inducing reproductive activity (Legan and Winans, 1981). Exposing ewes to artificial light rather than preventing exposure to light (i.e. dark) via light proof housing may be a more convenient method of manipulating photoperiod. Ducker & Bowman (1974) added artificial light to mask night hours, thereby increasing the number of hours the ewes' were exposed to light. Following an abrupt decrease in light hours (from 22 hours to 16 or 18 hours), reproductive status was successfully induced in Dorset Horn and Clun Forest ewes and eight-monthly lambing intervals were obtained.

Williams (1974) showed that the larger the decrease in daylight hours (whether gradual or abrupt), the sooner the onset of first oestrus but that this also coincided with an earlier onset of anoestrus. Exposing Border Leister ewes to 13 hrs of light and 11 hrs of darkness resulted in a reduction in the proportion of ewes displaying oestrus (100% to 38%) and lambing (90% to 11%).

2.6 Management difficulties with accelerated lambing

Certain task associated with the management of an accelerated lambing flock need to be addressed. Such tasks include when to shear ewes, when to introduce new breeding ewes to the flock, the possibility of extra labour requirements, increased vaccination use for pregnant ewes, the frequency of breeding and therefore lambing, feed utilisation and the need for winter and summer feed crops.

Shearing is important due to the risks associated with embryo/foetal losses from overnight fasting and handling of pregnant sheep. The introduction of breeding ewes should occur at a time when they are most likely to conceive whilst avoiding having a larger autumn breeding flock. Breeding ewes more frequently, and the subsequent increase in lambing frequency needs to considered in terms of increased labour, and the decreased time within each year where farmers usually have the opportunity to take holidays. The input of feed into an accelerated lambing systems needs thought with the use of crops as an option to evening out feed availability throughout the year.

However, literature available on management options and decisions is, to this author’s knowledge, non existent.

2.7 Summary

Lamb production is an important part of New Zealand’s agricultural sector and is a significant contributor to international trade. An accelerated lamb production system, incorporating aseasonal breeding programs may offer New Zealand sheep farms the opportunity to increase ewe efficiency by lambing more frequently than the conventional once-yearly lamb production system. Accelerated lamb production systems have been used internationally with varying successes. The main constraint to these systems is the poor reproductive performance (namely pregnancy and conception rates) in sheep bred during the non-breeding season.

The most widely used method for circumventing seasonality is the use of exogenous reproductive hormones, namely progesterone and eCG which, used in combination, can result in reasonable reproductive performance. Melatonin implants are becoming an internationally accepted method for aseasonal breeding although results vary (depending mainly on latitude). Artificial photoperiodic manipulation has also been used to alter the seasonality in sheep with some experiments highlighting the effect of differing light:dark regimens on seasonality exhibited by most breeds of sheep.

2.8 Scope and purpose of research

There is potential for some areas of New Zealand to produce lamb year round by utilising an accelerated lamb production system, such as the "STAR" system (Lewis et al., 1996). In this system, there are five breeding and lambing periods within each year, and ewes have the opportunity to breed and lamb five times in three years. Although out-of-season breeding programs have been trialled in New Zealand (Andrewes et al., 1987; Lowe et al., 1988; McQueen and Reid, 1988; Reid et al., 1988; Knight et al., 1989b; Knight et al., 1992; Morris et al., 1993), an accelerated lamb production system based on five breeding periods per year has, until now, has not been attempted in New Zealand.

The objective of this research was to investigate the potential of an accelerated lamb production system which has five breeding periods within one year, including three aseasonal breeding periods, and to provide "proof of concept" to New Zealand sheep farmers. More specifically, the objectives were:

1. To compare an "Accelerated" lamb production system with a "Conventional", once-yearly lambing system.

Comparisons in reproductive performance of ewes in the Accelerated lamb production system and the Conventional once-yearly lambing system were made. Lamb live weight at weaning and average daily growth rates from birth to weaning were also compared between the two systems. Animals were managed under commercial conditions to ensure conditions were close to those that the industry would expect.

Two sheep breeds were used: The Romney – as a majority of the New Zealand sheep flock is comprised of Romney sheep – and an East Friesian Composite (EF). The EF was a synthetic breed made up of ½ East Friesian, ¼ Polled Dorset and ¼ Texel and this composite was chosen for its potential attributes for fertility and milk production (East Friesian), out-of-season breeding potential (Polled Dorset) and meat production (Texel).

2. To compare the different breeding periods (14th January, 28th March, 9th June, 21st August, 2nd November) in the Accelerated lambing system.

The focus of this was to compare the reproductive performance of ewes and the growth rate of lambs at the five different breeding/lambing periods throughout the year. Aseasonal breeding periods have previously been identified as having poor reproductive performance and were therefore the focus of further experiments.

3. To identify weaknesses in the Accelerated lamb production system and design intervention experiments to overcome those areas identified.

Comparison of an accelerated and a conventional lamb production system

G. deNicolo
S.T. Morris
P.R. Kenyon
P.C.H. Morel

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Chapter 3 Comparison of an accelerated and a conventional lamb production system

Abstract

In New Zealand, a large proportion of lamb is produced during a condensed period. One method of providing a continuous supply of lamb for processing is to lamb more frequently. The objective of the current experiment was to compare ewe and lamb performance in a conventional once-yearly lamb production system (CL) with an accelerated lamb production system (AL) over a three-year period using two breeds of sheep (East Friesian Composite; EF, and Romney). Pregnancy rates were lower in the AL flock relative to the CL flock due to lower out of season reproductive performance ($P<0.001$). Litter sizes were similar at birth but were higher in the CL flock at weaning ($P<0.001$). Birth weights and, due to an older weaning age, weaning weights were heavier in the CL flock ($P<0.001$). Growth rates were similar in EF lambs but better in Romney lambs in the AL flock compared to the CL flock. More ewes were bred in the AL flock, resulting in more lambs born and weaned per ewe per year. More frequent breeding of ewes resulted in an increase of 8% in weight of lamb weaned over the three-year experimental period.

3.1 Introduction

Lamb production in New Zealand is largely driven by the seasonal pattern of pasture growth, with ewes being bred in the autumn to lamb in spring when pasture growth is increasing. This seasonal pattern of lamb production means there is poor annual utilisation of meat processing plants, with over half of spring-born lambs being processed during the January to April period (MWNZ, 2005). The current, somewhat condensed pattern of lamb production is not suited to the year-round chilled lamb trade.

One way of providing a less condensed, more even spread of lamb throughout the year, is to breed ewes more frequently than once yearly, that is, an accelerated lamb production system. In addition to providing a constant year-round supply of lamb, accelerated lamb production systems could be used to achieve a greater number of lambs per ewe per year, as an alternative to targeting high fecundity rates in the conventional once-a-year lamb production systems. Inducing ewes to lamb, on average, more than once a year is achievable, however results have been variable (Carpenter and Spitzer, 1981; Lofstedt and Eness, 1982; Horoz et al., 2003). McCutcheon et al. (1993) suggested the implementation of an accelerated lamb production system to increase the number of lambs born within a flock, but such systems have not been thoroughly tested. The "STAR system, reported by Wang et al. (1991), Lewis et al. (1996) and Smith (2006), is an accelerated lamb production system that has five breeding and lambing periods within a year, and in which individual ewes have the opportunity to breed and lamb five times in three years. Theoretical modelling on this system indicates an accelerated lamb production system has potential financial advantages for certain scenarios under pastoral conditions in New Zealand (Morel et al., 2004).

The objective of this study was to measure ewe reproductive performance and lamb output, in an accelerated lamb production system (five lambings per ewe in three years) and to compare this accelerated system with a conventional once-yearly lamb production under pastoral conditions in New Zealand.

3.2 Material and methods

Five hundred and six two-year-old and mixed-aged ewes of two breeds (Romney and East Friesian Composite (1/2 East Friesian, 1/4 Polled Dorset and 1/4 Texel; EF)) were randomly assigned to either a "Conventional" (CL) or an "Accelerated" (AL) lambing flock. The CL flock consisted of 239 ewes (121 Romney and 118 EF) and the AL flock contained 134 Romney ewes and 133 EF ewes. Thirty-four individual paddocks in a 41.4 ha block were randomly allocated into two blocks of 21.1 and 20.3 ha for the CL and AL flocks, respectively. The experimental period was from March 2003 to August 2006 when lambs from the ewes mated in January 2006 were weaned.

Ewes were shorn in December and in May, regardless of where they were in the reproductive cycle. Lambs were weaned from the ewes and were transport off the property.

Each year, forage crops were fed in summer (hybrid turnip; cv Pasja) and winter (annual ryegrass; cv Hunter) to meet feed demands throughout the year, so that on each block there were approximately 14 ha of permanent ryegrass/white clover pasture and approximately 6 ha of forage crop.

Conventional lamb production flock management

Ewe management

Ewes in the CL flock were joined with rams of their respective breeds for 46 days beginning on 28th March at a ram:ewe ratio of approximately 1:80. On 21st June each year, pregnancy status and the number of foetuses present were determined by transabdominal ultrasonography using a 3.5 Mz transducer.

Ewes were managed under commercial conditions, and ewe live weights and condition scores were recorded on the first day of the breeding period (Day P0) and two weeks prior to the first predicted day of lambing (prelamb). Parturition date was recorded for each ewe that lambed.

Lamb management

Within 24 hrs of birth, lambs were weighed, ear-tagged, and dam, litter size and sex were recorded. Lambs were weighed at approximately 35 days of age and at weaning (average age at weaning = 96, 83 and 109 days in 2003, 2004 and 2005, respectively). Weaning occurred at the discretion of the farm manager, which was usually subject to pasture availability, and therefore environmental conditions. To provide a direct comparison of daily weight gain between the CL and AL lambs and to eliminate growth rate differences, a sub sample of CL lambs (n=109) were weighed (unfasted) in 2005, 74 days after the first day of predicted lambing (average age = 66 days).

Accelerated lamb production flock management

Experimental design

The accelerated lamb production system was designed to have five breeding periods within each year, beginning 28th March, 9th June, 21st August, 2nd November and 14th January. In order to achieve this, the AL flock was initially divided into three flocks with approximately equal numbers of Romney and EF ewes. Each of the breeding periods were 73 days apart and were 21 days in duration, resulting in a total of 15 breeding periods over the duration of the experiment. Lambing was predicted to begin 146 days after the first day of the breeding period, and lambs were weaned from their dams 73 days after the first predicted day of lambing. The day of weaning coincided with the first day of the next synchronised breeding period. Therefore, each of the five lambing periods within one year, occurred 73 days after the preceding lambing period. Ewes that were identified as non pregnant were removed from the group, had CIDRs inserted on Day P-11, and at Day P0, joined the group of newly weaned ewes for re-breeding. Ewes were culled if they had three consecutive unsuccessful breeding periods.

Therefore, at the beginning of each 73 day period there was one group of ewes being re-bred (after having weaned lambs or after being diagnosed non pregnant from the previous breeding period), one group beginning to lamb and one group in mid gestation. For example, ewes bred at the 28th March breeding period began lambing 21st August. Lambs from these ewes were weaned and ewes were rebred on 2nd November. Ewes that failed to become pregnant at the March-breeding period were re-bred at the subsequent breeding period (9th June). Ewes mated in June, lambed in November, and were weaned and rebred in January. Non pregnant ewes from June were re-bred in August. This pattern continued for the duration of the experimental period (March 2003 to August 2006 after lambs were weaned from January-mated ewes).

Ewes were fed according to their physiological state (Nicol and Brookes, 2007). Feeding levels were monitored through unfasted liveweight measurements on Day P0, at pregnancy diagnosis (Day P62), two weeks prior to lambing, and at approximately 35 days post lambing. The target for ewes in the AL system was to maintain similar live weights throughout the experimental period.

Ewe management

Ewes were synchronised using progesterone primed controlled internal drug release devices (CIDRs; 0.3 g progesterone; Pharmacia & Upjohn, Auckland, New Zealand). Additionally, equine chorionic gonadotrophin (eCG; Folligon, Intervet Ltd, Auckland, New Zealand) was administered intramuscularly at CIDR withdrawal for the January (400 IU), August (800 IU) and November (800 IU) breeding periods. These differing dose rates were chosen as the most appropriate method to induce reproductive cyclicity in ewes during the respective anoestrus periods (Smith et al., 1988a; Knight et al., 1989b). The ram:ewe ratio was approximately 1:10 and the rams remained with the ewes for the 21-day breeding period (Day P0-21). On Day P7 CIDRs were reinserted and removed on Day P14.

On Day P62, pregnancy status and the number of foetuses present were determined by transabdominal ultrasonography using a 3.5 Mz transducer. Date of parturition was recorded for each ewe that lambed.

Lamb management

Litter size, lamb sex and dam were recorded for each lamb within 24 hr of birth. Lamb live weight was recorded within 24 hr of birth, at approximately 35 days of age and at weaning (73 days after the first predicted day of lambing).

Statistical analysis

All statistical analysis was done using SAS software (V8, SAS Institute Inc, Cary, NC, 2001). A general linear model (PROC GLM) was used to analyse ewe live weights. The statistical model included lamb production system, year of breeding, breed and ewe age (2-year old vs mixed age). System, breed and year interactions were also tested but were non significant and therefore removed. The model was then re-run without non significant fixed effects and interactions.

Univariate analysis was used to compare the number of pregnant and non pregnant ewes (pregnancy rate). Pregnancy rate was defined as the number of pregnant ewes per ewe exposed to the ram. Pregnancy data were treated as binomial traits, were logit transformed and analysed using a logistical regression model (GENMOD). Values were back-transformed into percentages for presentation. The model for pregnancy rates included lamb production system, year of breeding and breed as fixed effects. Ewe age and ewe live weight were included in the original model but had no significant effect, so were removed. Breed by system by year interaction was also tested but found to be not significant and was removed before the model was re-run.

Litter size is defined as the number of lambs in a litter for each ewe that lambed at each lambing period. Litter size at birth and at weaning were analysed as categorical variables with lamb production system, year and breed as fixed effects. Interactions were also tested and removed where there were no significant effects, and the model was then re-run.

The number of lambs born (NLB) and weaned (NLW) per ewe per year, were analysed using the same model. The NLB and NLW are defined as the number of lambs born to each ewe that lambed per year (as opposed to each lambing period). This differs from litter size as ewes in the AL system lambed more than once a year therefore gave birth to and weaned more than one litter within a year.

Lamb live weight at birth and weaning, and average daily weight gain (ADG) were analysed using a general linear model (PROC GLM). The statistical model included lamb production system, year, ewe breed and age (2-tooth vs mixed age), lamb sex, and litter size at birth as fixed effects. Ewe age was not significant in the model so was removed and the statistical model was rerun. Interactions were tested, removed if not significant, and the model re-run with only significant effects.

A general linear model (PROC GLM) was used to compare the growth of CL lambs with the growth rate of AL lambs for a similar period. The statistical model included system, breed, lamb sex and litter size at birth as fixed effects. Birth weight was also tested but had no effect. Ewe age was tested but removed from the statistical model as it had no effect. Interactions were tested and removed where they were not significant. The statistical model was then re-run without ewe age or any interactions.

Lamb mortality was assessed using a univariate analysis which included production system, breed, year and litter size at birth (1, 2 or $\geq$ 3 lambs) in the statistical model. Year of breeding was not significant and there was a year by production system interaction. Other non significant interactions were removed and the model was re-run.

Lamb mortality was defined as any lamb recorded as having died or any lamb with birth records but no weaning live weight record.

3.3 Results

Ewe live weights

The 3-year average breeding and prelamb live weights were heavier for both EF and Romney ewes in the AL system than in the CL system (Table 3.1; P<0.05). In both flocks, average live weights over the three years were heavier in the EF ewes compared with the Romney ewes (P<0.001), with the exception of the breeding live weight in the AL flock.

Table 3.1 Ewe live weights (kg) on the first day of the breeding period (Day P0) and at approximately two weeks prior to the first predicted day of lambing (prelamb) for East Friesian composite and Romney ewes in the accelerated and conventional lamb production systems. Values are least squares means ± standard error.

Lambing system	East Friesian Composite		Romney	
	Day P0	Prelamb	Day P0	Prelamb
Accelerated lamb production system				
Year 1	60.9 ± 0.63 [a]	63.7 ± 0.70 [a]	60.7 ± 0.61 [a]	61.9 ± 0.75 [a]
Year 2	61.9 ± 0.60 [b]	65.7 ± 0.73 [b]	61.0 ± 0.61 [a]	64.1 ± 0.75 [b]
Year 3	62.9 ± 0.61 [c]	71.0 ± 0.72 [c]	63.2 ± 0.56 [b]	67.1 ± 0.69 [c]
3-year average	61.9 ± 0.35 [z]	66.8 ± 0.44 [z 2]	61.6 ± 0.34 [z]	64.4 ± 0.45 [z 1]
Conventional lamb production system				
Year 1	58.2 ± 0.89 [a]	66.5 ± 0.81	51.6 ± 0.87 [a]	55.9 ± 0.86 [a]
Year 2	61.9 ± 0.87 [b]	65.7 ± 0.80	60.5 ± 0.86 [b]	62.0 ± 0.80 [b]
Year 3	58.7 ± 0.92 [a]	65.2 ± 0.88	52.1 ± 0.85 [a]	60.3 ± 0.69 [b]
3-year average	59.6 ± 0.52 [y 2]	65.8 ± 0.49 [y 2]	54.7 ± 0.50 [y 1]	59.4 ± 0.48 [y 1]

[a b] indicates differences within columns and lambing system (P<0.05)

[1 2] indicates breed differences within row and Day P0 or prelamb live weight (P<0.05)

[y z] indicates differences between lambing systems within Day P0 or prelamb live weight (3-year average; P<0.05)

Ewe reproductive performance

Three-year average pregnancy rates in the CL flock were higher than in the AL flock for both EF and Romney breeds (Table 3.2; P<0.001). Pregnancy rates in the Romney and EF ewes in the CL flock did not differ when averaged over the three years, while in the AL flock, EF ewes had higher pregnancy rates (P<0.001).

Number of lambs born and weaned

The number of lambs born (NLB) and weaned (NLW), per ewe lambing per year was higher in the AL flock compared with the CL flock (P<0.001; Table 3.5 and Table 3.6). This was consistent across all three years and for both breeds. Both NLB (P<0.001) and NLW (P<0.05) over the three years were lower for Romney ewes than for EF ewes in the AL flock. These parameters were similar between Romney and EF ewes in the CL flock.

Table 3.2 Pregnancy rates (ewes pregnant/ewes exposed to the ram) for East Friesian composite and Romney ewes in the accelerated and conventional lamb production systems. Values are logit ± standard errors, with back transformations (%) in parentheses.

Lambing system	East Friesian Composite	Romney
Accelerated lamb production system		
Year 1	1.13 ± 0.15 (75.5) [b 2]	0.45 ± 0.13 (61.1) [1]
Year 2	0.36 ± 0.13 (58.9) [a]	0.19 ± 0.13 (54.7)
Year 3	0.94 ± 0.14 (71.9) [b 2]	0.30 ± 0.12 (57.3) [1]
3-year average	0.81 ± 0.08 (69.2) [y 2]	0.31 ± 0.07 (57.7) [y 1]
Conventional lamb production system		
Year 1	3.11 ± 0.46 (95.7) [b]	3.13 ± 0.46 (95.8)
Year 2	4.07 ± 0.71 (98.3) [b]	4.75 ± 1.00 (99.1)
Year 3	2.28 ± 0.33 (90.7) [a]	2.97 ± 0.36 (95.1)
3-year average	3.15 ± 0.30 (95.9) [z]	3.62 ± 0.39 (97.4) [z]

[a b] indicates significant differences within columns and lambing system (P<0.05)

[1 2] indicates significant breed differences within row (P<0.05)

[y z] indicates significant differences between lambing systems within breed (3-year average; P<0.05)

The three-year average for litter size at birth, per ewe lambed for each lambing period, did not differ between systems within breed (Table 3.3). Within each system however, EF ewes had larger litter sizes at birth than Romney ewes (P<0.001). Litter size at weaning did not differ between ewe breeds within each system, but litter size at weaning was larger (P<0.001) in the CL flock compared to the AL flock.

Table 3.3 Litter size at birth and weaning for East Friesian composite and Romney ewes in the accelerated and conventional lamb production systems. Values are least squares means ± standard error.

	East Friesian Composite		Romney	
Lambing system	Birth	Weaning	Birth	Weaning
Accelerated lamb production system				
Year 1	1.55 ± 0.05	1.29 ± 0.06 [a b]	1.39 ± 0.06 [a]	1.14 ± 0.06
Year 2	1.65 ± 0.06	1.36 ± 0.06 [b]	1.52 ± 0.05 [a b]	1.28 ± 0.06
Year 3	1.66 ± 0.05	1.19 ± 0.06 [a]	1.55 ± 0.05 [b]	1.18 ± 0.06
3-year average	1.62 ± 0.03 [2]	1.28 ± 0.04 [y]	1.49 ± 0.03 [1]	1.20 ± 0.04 [y]
Conventional lamb production system				
Year 1	1.56 ± 0.06 [a]	1.16 ± 0.06 [a]	1.47 ± 0.07 [a]	1.13 ± 0.07 [a]
Year 2	1.80 ± 0.06 [b]	1.77 ± 0.07 [c]	1.72 ± 0.06 [b]	1.70 ± 0.07 [c]
Year 3	1.67 ± 0.07 [a b]	1.40 ± 0.07 [b]	1.52 ± 0.05 [a]	1.35 ± 0.06 [b]
3-year average	1.68 ± 0.04 [2]	1.44 ± 0.04 [z]	1.57 ± 0.04 [1]	1.40 ± 0.04 [z]

[a b] indicates differences within columns and lambing system (P<0.05)

[1 2] indicates breed differences within row, birth and weaning (P<0.05)

[y z] indicates significant differences between lambing systems within breed (3-year average; P<0.05)

Lamb live weights and daily growth

Over the three years, the average lamb birth weight within breed was higher in the CL system compared with the AL system (P<0.001; Table 3.4). Live weight at weaning was also higher in the CL system relative to the AL system (P<0.001), but CL lambs were older at weaning than AL lambs. Within system, weaning weights were significantly heavier in EF lambs compared with Romney lambs (P<0.05). Average daily growth rate did not differ significantly between EF ewes in the CL and AL system. Romney lambs in the AL system grew faster than Romney lambs in the CL system (P<0.05). Within system, EF lambs had higher ADGs than Romney lambs (P<0.001).

Live weights of a sub group of CL lambs were recorded in 2005 only. These provided a direct comparison between the systems, but that comparison could only be made with spring-born AL lambs. Nevertheless, between birth and Day 74 after the first predicted day of lambing, CL lambs had slower growth rates than lambs born in the AL system (247 ± 6.5 vs 274 ± 6.9 g/d; P<0.001). For this sub group, triplet-born lambs grew slower over this same period, relative to their twin- and singleton counterparts (230 ± 14.1, 254 ± 5.2 and 297 ± 8.0 g/d, respectively; P<0.001). Romney lambs had lower growth rates than EF lambs for this period also (247 ± 5.9 vs 274 ± 7.4 g/d, respectively; P<0.01).

Lamb mortality

The 3-year average lamb mortality between birth and weaning was similar in the AL system (34.1%) and CL systems (30.3%). There was no system by litter size interaction, but mortality of litter sizes of three or more was 73.2% and higher than other litter sizes (P<0.001). Twin and singleton mortality rates were 18.5 and 21.3%, respectively and did not differ. Mortality rates in lambs born to EF ewes was higher than in lambs born to Romney ewes (37.8% vs 27.3%; P<0.01). In the CL flock, lamb mortality was higher in Year 2 (45.9%) compared with Year 1 and 3 (29.1 and 20.3%, respectively; P<0.05). Year 3 (47.5%) in the AL flock had higher lamb mortality rates than Years 1 and 2 (31.2 and 26.2%, respectively; P<0.05). Lamb mortality was higher in the CL flock than in the AL flock in Year 2 (P<0.01), and in Year 3 this pattern was reversed (P<0.001).

Table 3.4 Birth weights (kg), weaning weights (kg) and average daily liveweight gains (ADG; grams/day) for East Friesian Composite and Romney lambs in the accelerated and conventional lamb production systems. Values are least squares means ± standard error. Average weaning age in Accelerated and Conventional lamb production systems were 69 and 96 days, respectively.

Lambing system	East Friesian Composite			Romney		
	Birth weight	Weaning weight	ADG	Birth weight	Weaning weight	ADG
Accelerated lamb production system						
Year 1	4.50 ± 0.06 ^{b}	21.57 ± 0.29 $^{b\,2}$	244 ± 3.47 ^{a}	4.35 ± 0.07 $^{a\,b}$	20.68 ± 0.34 $^{b\,1}$	236 ± 3.96
Year 2	4.30 ± 0.06 ^{a}	22.05 ± 0.32 $^{b\,2}$	256 ± 3.74 $^{b\,2}$	4.23 ± 0.07 ^{a}	20.78 ± 0.34 $^{b\,1}$	240 ± 3.96 ^{1}
Year 3	4.44 ± 0.06 $^{a\,b}$	19.12 ± 0.32 ^{a}	213 ± 3.88 ^{a}	4.45 ± 0.06 ^{b}	18.73 ± 0.39 ^{a}	212 ± 3.87 ^{a}
3-year average	4.41 ± 0.04 ^{y}	20.91 ± 0.19 $^{2\,y}$	238 ± 2.24 ^{2}	4.34 ± 0.04 ^{y}	20.06 ± 0.20 $^{1\,y}$	229 ± 2.39 $^{1\,z}$
Conventional lamb production system						
Year 1	5.17 ± 0.08 $^{b\,2}$	31.07 ± 0.39 $^{c\,2}$	265 ± 4.63 $^{b\,2}$	4.91 (± 0.08 $^{b\,1}$	26.69 ± 0.39 $^{b\,1}$	227 ± 4.54 $^{b\,1}$
Year 2	4.16 ± 0.07 ^{a}	24.19 ± 0.39 $^{a\,2}$	236 ± 4.64 $^{a\,2}$	4.70 ± 0.07 ^{a}	22.03 ± 0.36 $^{a\,1}$	215 ± 4.40 $^{a\,1}$
Year 3	4.74 ± 0.08 $^{a\,1}$	29.01 ± 0.39 $^{b\,2}$	216 ± 4.59 $^{a\,2}$	5.01 ± 0.06 $^{b\,2}$	26.07 ± 0.32 $^{b\,1}$	195 ± 3.72 $^{a\,1}$
3-year average	4.84 ± 0.05 ^{z}	28.09 ± 0.24 $^{2\,z}$	239 ± 2.83 ^{2}	4.88 ± 0.04 ^{z}	24.93 ± 0.22 $^{1\,z}$	212 ± 2.65 $^{1\,y}$

$^{a\,b}$ indicates differences within columns and lambing system (P<0.05)

$^{1\,2}$ indicates breed differences within row, birth and weaning weights, and ADG (P<0.05)

$^{y\,z}$ indicates significant differences between lambing systems within breed (3-year average; P<0.05)

Table 3.5 Number of lambs born (NLB) and weaned (NLW) per ewe lambed per year for East Friesian composite and Romney ewes in the accelerated and conventional lamb production system. Values are least squares means ± standard error.

Lamb system	East Friesian Composite		Romney	
	NLB	NLW	NLB	NLW
Accelerated lamb production system				
Year 1	2.39 ± 0.09	2.01 ± 0.08 ^{b}	2.05 ± 0.09	1.71 ± 0.09
Year 2	2.24 ± 0.09	1.87 ± 0.09 $^{a\,b}$	2.08 ± 0.09	1.76 ± 0.09
Year 3	2.33 ± 0.09	1.65 ± 0.08 ^{a}	2.02 ± 0.09	1.59 ± 0.08
3-year average	2.32 ± 0.05 $^{z\,2}$	1.84 ± 0.05 $^{z\,2}$	2.05 ± 0.05 $^{z\,1}$	1.68 ± 0.05 $^{z\,1}$
Conventional lamb production system				
Year 1	1.56 ± 0.08 ^{a}	1.25 ± 0.08 ^{a}	1.47 ± 0.09 ^{a}	1.38 ± 0.09 ^{a}
Year 2	1.80 ± 0.09 ^{b}	1.79 ± 0.08 ^{c}	1.72 ± 0.08 ^{b}	1.69 ± 0.08 ^{b}
Year 3	1.62 ± 0.09 $^{a\,b}$	1.43 ± 0.08 ^{b}	1.57 ± 0.08 ^{a}	1.42 ± 0.07 ^{a}
3-year average	1.66 ± 0.05 ^{y}	1.49 ± 0.05 ^{y}	1.59 ± 0.05 ^{y}	1.50 ± 0.05 ^{y}

$^{a\,b}$ indicates differences within columns and lambing system (P<0.05)

$^{1\,2}$ indicates breed differences within row, birth and weaning columns (P<0.05)

$^{y\,z}$ indicates significant differences between lambing systems within breed (3-year average; P<0.05)

Overall system performance

Over the three years, the CL system produced 24,316 kg of lambs weaned (1151 kg/ha), while the AL system produced 26,205 kg (1292 kg/ha; Table 3.6). The EF flock in the AL system produced nearly 26% more lamb (on a kg basis) than the CL system, while the Romney AL flock produced around 8% less lamb than the CL system.

Of the 267 original AL flock (133 EF; 134 Romney), 186 ewes (90 EF, 96 Romney) had the opportunity to lamb 5 times as a result of being bred at least 5 times over the three year period. Twenty-four percent of Romney ewes, and 34.4% of EF ewes lambed five times, and 49.0% of Romney ewes and 43.3% of EF ewes lambed four times.

Table 3.6 Number of East Friesian Composite (EF) and Romney ewes bred and lambed, number of EF and Romney lambs born and weaned, and kilograms of lambs sold for each year for the conventional and accelerated lamb production systems.

Lambing system	Conventional		Accelerated	
Breed	EF	Romney	EF	Romney
Yr 1 Total number of ewes bred	117	119	260	271
Total number of ewes lambed [a]	112	109	188	168
Number lambs born [b]	162	150	290	231
Lambs weaned/ewe lambed/year	1.25	1.38	2.01	1.71
No lambs weaned [c]	130	138	241	192
Kg lamb weaned [d]	4,130	3,767	5,256	4,080
Kg lamb weaned/ ha	391	357	518	402
Yr 2 Total number of ewes bred	143	134	282	285
Total number of ewes lambed [a]	139	134	167	153
Number lambs born [b]	209	202	266	218
Lambs weaned/ewe lambed/year	1.79	1.69	1.87	1.76
No lambs weaned [c]	152	171	221	157
Kg lamb weaned [d]	3,492	3,667	4,817	3,959
Kg lamb weaned/ ha	331	348	475	390
Yr 3 Total number of ewes bred	105	163	278	321
Total number of ewes lambed [a]	98	159	187	181
Number lambs born [b]	148	230	295	249
Lambs weaned/ewe lambed/year	1.43	1.42	1.65	1.59
No lambs weaned [c]	131	207	217	199
Kg lamb weaned [d]	3,777	5,483	4,246	3,847
Kg lamb weaned/ ha	360	522	418	379
Total kg lamb weaned for 3 years	11,399	12,917	14,319	11,886
	24,316		26,205	
Kg lamb weaned/ha for 3 years	1151		1292	

[a] Based on the number of ewes present at pre-lamb weighing

[b] Based on the number of lambs with birth weight recorded

[c] Based on the number of lambs with weaning live weight recorded

[d] Based on raw weaning weights multiplied by the number of lambs weaned per block

3.4 Discussion

The primary objectives of the current experiment were to compare an accelerated lamb production system (AL) previously reported by Lewis et al. (1996), adapted to a pastoral based system, with a conventional once-a-year lamb production system (CL).

Ewe live weight has not previously been reported in accelerated lambing systems (e.g.Lahlou-Kassi et al. (1989) and Lewis et al. (1996)). In the current trial, ewes were managed under commercial conditions to match their physiological nutritional requirements in both systems. Live weight data from the AL system, indicated no negative consequences of the AL system on ewe live weight.

Low pregnancy rates in the ewes bred outside of the normal breeding season (January, August and November (deNicolo et al., 2007a; Chapter 5)) reduced the overall pregnancy rates in the AL flock. These were not particularly different to other out-of-season breeding studies using similar exogenous reproductive hormones (Andrewes et al., 1987; Smith et al., 1988a; Knight et al., 1989b; Ungerfeld and Rubianes, 2002). Due to more frequent lambing, there were more lambs born and weaned per ewe in the AL system, compared with the CL system, despite the low out-of-season pregnancy rates. The number of lambs born per EF ewe per year, in the AL flock for the current experiment, was similar that obtained in other accelerated lambing systems (Notter and Copenhaver, 1980; Vesely and Swierstra, 1985; Fogarty et al., 1992a).

The CL system produced significantly heavier lambs at weaning compared with the AL system which can be explained by the age of the lambs at weaning. Average daily growth rates between birth and weaning, indicated that there was little difference within breed and between systems, although at the one time when a direction comparison could be made, ADG was 11% higher in the AL lambs compared with the CL lambs. DeNicolo et al. (2006; Chapter 10) reported that breeding during late lactation does not affect pregnancy or conception rates in Romney ewes, nor does it have any affect on the subsequent progeny. This indicates that weaning can be delayed to improve lamb weaning live weights without affecting ewe reproductive performance.

As litter size increased, birth weight and growth rates decreased, while mortality increased which agrees with other studies (Hinch et al., 1983; Litherland et al., 1999; Kenyon et al., 2002; Morris et al., 2003; Morris and Kenyon, 2004). Regardless, the high mortality rates observed in the triplet lambs in the current trial (76%) were higher than previously reported (Dalton et al., 1980; Hinch et al., 1983; Nicoll et al., 1999; Kenyon et al., 2002; Morris et al., 2003; Thomson et al., 2004).

In terms of kg of total lamb weaned, the AL system generated 8% more weight of lamb weaned than the CL system (or 12% more on a per ha basis). Over the three-year experimental period, the EF AL flock produced 26% more kg of lamb than the EF CL flock, whereas the CL Romney ewes produced 8% less lamb than the AL Romney ewes. This suggests that the New Zealand Romney breed is less suitable for accelerated lamb production systems due to lower pregnancy rates, a lower number of lambs born and weaned per ewe, and lower lamb weaning weights.

Although a greater output was achieved in the AL system, costs such as feed, labour and exogenous reproductive hormones need to be considered. Increased handling of animals, and increased frequency of lambing, would be expected to increase labour costs. There were no reproductive hormones used in the CL system, therefore, the costs of breeding were higher in the AL system. Feed flow through both systems is expected to be different with a more sustained, less fluctuating pattern of demand in the AL flock compared to the CL flock (Morel et al., 2004), although this area requires further investigation.

3.5 Conclusion

Breeding ewes on a more frequent basis in the current experiment resulted in a greater number of ewes being joined, and more lambs born and weaned per year compared with a conventional once-yearly lambing system. These increases compensated for the lower pregnancy rates and the lower weaning weights in the AL flock. The EF ewes in the AL flock produced 26% more kilogram of weaned lamb than EF ewes in the CL flock. The extra costs in this system should be considered before an accelerated lamb production program be implemented. If out-of-season pregnancy rates could be improved, accelerated lamb production may have a place in the sheep industry in certain parts of New Zealand.

Two issues not investigated in this chapter were the requirement of labour and the food or energy requirements of ewes in the two systems. This is an important consideration as one would expect that a ewe being bred and lambing more frequently than in the Conventional lamb production system would require more energy to maintain live weight, and sustain multiple pregnancies and lactations. Further, as lambing occurs five times in one calendar year, and artificial reproductive hormones are administered, labour or time requirement should also be investigated, on a flock basis and a per ha basis. As there are more lambs born and weaned in the Accelerated lamb production system, the increase in the number of lambs weaned could offset the assumed increase operating costs in terms of labour requirements and time input.

The objective of the next chapter was to assess both the energy requirement of ewes, calculate the pasture requirements based on that and compare between the two systems, and also to determine the labour requirements for the two systems and make a comparison.

The accelerated lamb production system is further investigated in Chapter 5 with particular emphasis on ewe reproductive performance at the different breeding periods. Lamb birth weight, growth rates and weaning weights are also examined for the different lambing periods throughout the year.

Ewe energy requirements, and labour input – a system comparison

G. deNicolo
S.T. Morris
P.R. Kenyon
P.C.H. Morel

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Chapter 4 Ewe energy requirements, and labour input - a system comparison

4.1 Introduction

The reproductive performance of ewes, and the live weights and growth rates of their lambs in two different lamb production systems were examined in Chapter 3. These lamb production systems were a Conventional once-yearly lambing system and an Accelerated lamb production system, in which there were five breeding and lambing periods within a year, and where individual ewes had the opportunity to lamb five times in three years. However, labour input for the main stock-handling and animal management tasks, and ewe energy requirements were not assessed.

The labour input required in terms of stock-handling and management in an Accelerated lamb production system, along with ewe energy requirements have received little attention, despite a significant number of these systems having been studied world wide (e.g. Speedy and FitzSimons, 1977; Notter and Copenhaver, 1980; Dzakuma et al., 1982; Vesely and Swierstra, 1985; Fahmy, 1990; Fogarty et al., 1992a). There were two objectives of the current chapter: Firstly, to calculate ewe annual energy requirements in the Conventional once-yearly and Accelerated lamb production systems studied in Chapter 3. The second objective was to assess and compare the time requirement to perform the main husbandry and management tasks required to operate these two systems.

4.2 Methods

Annual ewe energy requirements

The method used to calculate annual ewe energy requirements were based on the equations of Nicol and Brookes (2007) using the factorial approach where energy requirements for each stage of production were estimated separately, then summed. Individual annual ewe energy requirement within each lamb production system were calculated using data gathered in Chapter 5 along with the following assumptions:

i. Litter size at birth: Accelerated; 1.56, Conventional; 1.63 (Table 3.3)
ii. Litter size at weaning: Accelerated; 1.24, Conventional; 1.42 (Table 3.3)
iii. Lamb birth weight: Accelerated; 4.38 kg, Conventional; 4.85 kg (Table 3.4)
iv. Lamb weaning weight: Accelerated; 20.5 kg, Conventional; 26.5 kg (Table 3.4)
v. Assumed ewe liveweight change over one year: Accelerated; 5 kg, Conventional; 6 kg
vi. Maintenance requirements were for a 60 kg ewe grazing rolling hill country.

Values from Chapter 3 are the average for both breeds and is the average of all three years (e.g. litter size at birth; EF = 1.62; Romney = 1.49; average = 1.56). For the Accelerated system, the valued used is the average of all 15 breeding periods.

To a compare the annual energy requirement of a ewe in both systems, the average requirements of a ewe bred in either January/August, March/November or June were calculated. The values for this were based the average energy requirements of a January/August, March/November and June-bred ewe using the average values quoted above (Appendix D). Further, using these calculations and values, annual energy requirements for various scenarios, considered to be feasible measures for improving the Accelerated system, were also calculated.

Labour input

The labour input, in terms of time taken to perform the main animal husbandry and management tasks were calculated for the year from 1st January 2005 to 31st December 2005. Calculations were determined on a per task basis and were calculated using estimations of time taken to perform each task per ewe or lamb given by the farm manager. The time per animal for each task was then multiplied by the number of animals present for that task. For example, it was estimated that crutching ewes took 2.5 minutes per ewe through a sheep-handling cradle, drenching took one minute per ewe, and shearing took two minutes per ewe. Calculations for most animal husbandry/management tasks were the same for both systems, except for the checking of ewes and lambs at lambing time (including recording lambing data; tagging lambs, and recording sex, dam, birth rank and birth weights). The exception to this was when no lambing data were recorded for each ewe lambing: On this occasion, the farm manager was asked how much time each day would be required to check ewes and lambs during the lambing period for a flock of 250 ewes, and a flock of 70 ewes (average flock size for lambing in the Accelerated system). Ewe and lamb checks were carried out for 50 days once yearly in the Conventional system, and for 10 days on five separate occasions in the Accelerated system.

4.3 Main findings

Annual ewe energy requirements

To enable a direct comparison between the two lamb production systems, calculations and assumptions regarding the live weight of a ewe were the same between the two systems with the exception of the live weight change. By using this method, a direct comparison of the energy requirements for the different production levels (i.e. number of lambs born and weaned per lambing and per year, and lamb live weights at birth and weaning) could be made. Using an average of the January/August, March/November and June bred ewes (Appendix D), the difference in energy requirement between a 60 kg ewe grazing on rolling hill country in the Accelerated and Conventional lamb production systems is small - 380 MJME per year or 6% in favour of the Conventional lamb production system (Table 4.1).

Table 4.1 Values used for calculation of annual energy requirements for one 60 kg ewe grazing rolling hill country in the Conventional and the Accelerated lamb production systems. Values are three year averages (from Chapter 3).

	Conventional	Accelerated
Ewe LWt (kg)	60	60
Ewe LWt change (kg)	6	5
Lambs born / ewe lambing	1.63	1.56
Lamb birth Wt (kg)	4.85	4.38
Lambs weaned/ewe lambing	1.42	1.24
Lamb weaning Wt (kg)	26.5	20.5
ME requirements (MJME)		
Maintenance [1]	10 x 365 3650	10 x 365 3650
Weight change [2]	25 MJME x 6 kg 150	25 MJME x 5 kg 125
Pregnancy [3]	245 MJME x 1.63 lambs 399	221 MJME x 1.56 lambs x av. gest. [4] 517
Lactation [2]	45MJME x 26.5 kg x 1.42 lambs 1693	45MJME x 20.5 kg x 1.42 lambs x av. lactations [4] 1907
Total ME requirement	5892	5256

[1] See Appendix A

[2] See Appendix B

[3] See Appendix C

[4] Averages from Appendix D

Energy requirements differ over a year in the Accelerated lamb production system, depending on when a ewe is bred (Appendix D). A ewe bred in January (and re-bred in August; 2 gestations, 1 lactation) requires 5628 MJME per year, and this is 5% lower than in the Conventional lamb production system (6143 MJME per year; Table 4.1). March-bred ewes have 1½ gestations and two lactation periods within one calendar year therefore their energy requirements are higher than a ewe in the Conventional system (6594 vs 5892 MJME per year; 12%). Similarly, a ewe bred in June has 1½ gestations and two lactations.

Various scenarios for improving the Accelerated system were put forward and those scenarios are shown in the shaded areas in Table 4.2. These improvements were considered feasible and were small; 4.5 or 6.5kg increase in lamb weaning weight, 0.4 increase in litter size at birth and the associated increase in litter size at weaning, a 10% decrease in lamb mortality. The energy requirements per kilogram of lamb weaned per year were also calculated. For each of these scenarios, energy requirements per kilogram of lamb weaned was lower in the Accelerated system compared to the Conventional system (due to the increase in the number of breeding and lambing periods within one year). For example, if lamb weaning weight were to be increased to 25 kg, ewes would require 10% more energy per year compared to a ewe in the Conventional system, but would require 20% less per kilogram of lamb weaned. Increasing lamb weaning weight to 27 kg would require 24% less energy per kilogram of lamb weaned. Energy requirements for a ewe with increased litter size and lamb weaning weight, and a decrease in mortality, would be 16% more per ewe per year in the Accelerated compared to the Conventional system, but would be 27% less per kilogram of lamb weaned.

Table 4.2 Annual energy requirements (MJME) for a 60 kg ewe grazing rolling hill country in the Conventional and Accelerated lamb production system, and different scenarios for improvement of the Accelerated system. Shaded areas are the proposed improvement.

	Conventional	Accelerated						
	No change	No change	Increased weaning weight		Increased litter size	Decreased mortality	Increased litter size and decreased mortality	Increase litter size and weaning weight, and decreased mortality
NLB	1.63	1.56	1.56	1.56	1.6	1.56	1.6	1.6
NLW	1.42	1.24	1.24	1.24	1.28	1.4	1.44	1.44
Birth weight	4.85	4.38	4.38	4.38	4.38	4.38	4.38	4.38
Weaning weight	26.5	20.5	25	26.5	20.5	20.5	20.5	25
Annual MJME for:								
Maintanence	3650	3650	3650	3650	3650	3650	3650	3650
Weight change	150	125	125	125	125	125	125	125
Pregnancy	399	590	354	354	363	354	363	363
Lactation	1693	1907	2325	2465	1968	2153	2214	2700
TOTAL MJME req.	5892	6272	6454	6594	6106	6282	6352	6838
Lambings per year	1	1.67	1.67	1.67	1.67	1.67	1.67	1.67
Total kg lambs weaned	37.6	42.4	51.7	54.8	43.7	47.8	49.2	60.0
MJME/kg lamb weaned	157	148	125	120	140	131	129	114
Difference in relation to Conventional (%)								
Annual MJME requirement		6.4	9.5	11.9	3.6	6.6	7.8	16.1
MJME/kg lamb weaned		-5.5	-20.2	-23.1	-10.8	-16.1	-17.5	-27.2

Appendix E shows the feed flow through both the CL and the AL systems, along with the estimated feed demand for each flock for the year running 1 April 2005 to 31 March 2006. The pattern of demands in the AL flock shows a flatter, more consistent trend than that for the CL flock, which peaks at lambing time. Within the AL flock, of the three groups of ewes in their different production cycle, there is one mob in late gestation, lambing or lactating, on mob being bred or in early gestation, and another mob in mid gestation. Having three mobs at different stages of their production cycle flattens out the feed demand. After lambs are weaned in the CL system, there is a decline in feed demand as ewes are returned to maintenance feeding and lambs are weaned off the farm. Throughout the year, the AL flock have higher feed demand with the exception of lambing and flushing in autumn. There are however, still fluctuations in pasture cover in both systems. Spring surplus was conserved for supplements, at the discretion of the farm managers.

Labour input

There were differences between the Accelerated and Conventional lamb production systems for the time required to perform two tasks: Events surrounding each breeding period (40.1 vs 15.3 hrs for the Accelerated and Conventional systems, respectively) and events surrounding lambing (73.7 vs 62.9 hrs; Table 4.3).

The management or husbandry tasks that were specific to the Accelerated lamb production system (such as the use of reproductive hormones) resulted in higher labour input for each breeding period. These increased time requirements were further compounded by the fact that more ewes were bred each year in the Accelerated lamb production system (570) compared to the Conventional system (281), therefore tasks related to breeding in the Accelerated system (namely recording crayon mating marks, pregnancy diagnosis, animal handling (i.e. drafting into respective breeds for breeding, removal of cull ewes, ram harness fitting and crayon changing etc) had higher time requirements relative to the Conventional system.

Table 4.3 Time requirements in hours for tasks involved in running a conventional lamb production system and an accelerated lamb production system run on 20 hectares.

Task	Conventional	Accelerated
Shearing		
Ewes	16.7	17.0
Rams	1.0	1.0
Ewe crutching	21.3	23
Drenching		
Ewes	8.5	5.0
Lambs	4.5	6.0
Stock shifting	24.0	72.0
Ram testing	0.5	2.5
Insertion and removal of CIDRs		11.4
Breeding	2.0	7.3
Crayon tupp reading	8.4 (0) [1]	11.4 (0) [1]
Pregnancy diagnosis	4.9	10.0
Pre-lamb vaccination	3.2	3.7
Lambing	42.8 (37.5) [2]	47.2 (21.0) [2]
Docking	11.6	15.2
Weaning	8.5	11.3
Total hours	158.0 (144.3) [1 2]	243.9 (206.3) [1 2]
No. lambs weaned	338	451
Time spent per lamb weaned (hours)	0.47 (0.43) [1 2]	0.54 (0.46) [1 2]

[1] With no crayon mating marks recorded, pregnancy information solely based on pregnancy diagnosis, and no conception information required.

[2] No lambing data (lamb tag numbers, birth weight, litter size, dam and lamb sex). Conventional system = 45 min/day x 50 days; Accelerated system = 25 min/day x (5 lambing periods per year x 10 days).

At lambing (in both systems), lambs were tagged and birth weights, litter size, sex and dam identity recorded. Ewes in the Accelerated lambing flock were lambed in smaller groups and were quieter due to more handling throughout the year from a higher lambing frequency and more yarding. Therefore, the time taken to catch lambs, identify dams and ensure all new born lambs in the paddock had been recorded was less, thereby shortening time spent per ewe lambing. Time requirements at lambing per ewe lambing were greater in the Conventional system compared to the Accelerated system (8 vs 10 min per ewe lambed). However, as more ewes lambed in the Accelerated system, the total time requirement over the year for lambing was higher in the Accelerated system compared with the Conventional system (47.2 vs 42.8 hrs per year). The total time required for all events surrounding lambing (including docking and weaning) was higher in the Accelerated system compared to the Conventional system (73.7 vs 62.9 hrs). If no lambing data were recorded, over one year, more time was spent checking ewes and lambs at lambing time in the Conventional system than in the Accelerated system due to larger flock size (37.5 vs 21.0 hrs).

In the Accelerated system ewes were managed in three separate groups according to their physiological state (breeding/early gestation, mid/late gestation, lactating/lambing). This management resulted in a three-fold difference between the two systems in the time spent moving groups of ewes.

Time taken for shearing and crutching ewes was similar between the systems and any difference was due to the number of ewes present in each system at the time of shearing or crutching.

More time was spent drenching ewes in the Conventional system than in the Accelerated system. This calculation was based on Conventional ewes being drenched prior to the breeding period and at docking (as per farm management practice). Ewes in the Accelerated system were only drenched at docking when ewes had faecal egg counts (FEC) higher than 500 eggs/gram or three out of 10 ewes had FEC >1000 eggs/gram. Lambs were drenched at weaning in both systems and as there were more lambs weaned in the Accelerated system, slightly more time was spent drenching lambs during the year (6.0 vs 4.5 hrs).

The total time required to run the systems on their respective blocks for the year from 1st January to 31st December 2005 was 244 and 158 hours for the Accelerated lamb production system and the Conventional lamb production system, respectively. If no crayon mating marks were recorded during the breeding periods and no data recorded during the lambing periods (lamb tag numbers, birth weight, litter size, dam and lamb sex), total time requirements in the Accelerated flock were still greater (206 vs 144 hrs per year).

4.4 Conclusion

In the Accelerated lamb production system, a 60 kg ewe grazing rolling hill country requires 6% more energy than a 60 kg ewe in the Conventional system. A January/August-bred ewe in the Accelerated system requires 5% less energy than a ewe in the Conventional system, while a March/November- or June-bred ewe bred requires 12% more energy. An increase of 4.5 kg in lamb weaning live weight in the Accelerated system would require 10% more energy than a ewe in the Conventional system, but 20% less per kilogram of lamb weaned. Scenarios suggested for improving the Accelerated system resulted in a 12-16% increase in annual ewe energy requirements, but 20-27% less energy per kilogram of lamb weaned.

The total labour input required to perform the main animal husbandry and management tasks in the Accelerated system was 35% more than in the Conventional system (86 hours per year). However, when this labour input was divided by the number of lambs weaned, the difference was 13% higher per lamb weaned for the year running 1st January to 31st December 2005 in the Accelerated system.

Appendix A

Calculations for basal metabolic rate of a ewe including the metabolic cost of grazing, movement and activity (Nicol and Brookes, 2007).

<u>MJME required for basal metabolic rate</u>	
Basal MR=	species * sex*0.28*exp(-0.03*age)*(LWt^0.75)/Km
Where:	
LWt = liveweight (kg)	60
Species = 1.0 for sheep	1
Sex = 1 for females	1
Km = M/D*0.02 + 0.5, where M/D = MJME/kg DM (assumption MJME/kg DM = 10)	0.7
Age	4
Days	365
MJME per day =	**7.65**
<u>MJME required for grazing activity</u>	
ME graze =	LWT*[Species*DM intake * (0.9-dig))]/Km
Where:	
LWt = liveweight (kg)	60
Species = 0.2 for sheep	0.02
Dig = DM digestibility, calculated as (ME/DM)/15.088	0.662778367
Km = M/D*0.02 + 0.5, where M/D = MJME/kg DM (assumption MJME/kg DM = 10)	1.0
MJME per day =	**0.28**
<u>MJME required for movement</u>	
ME move =	0.0026*LWt*S*(TSR/SD)/(0.057*PM+0.16)
Where:	
LWt = liveweight (kg)	60
S = slope (1.0, 1.5 or 2.0 for flat land, easy hill and hard hill country, respectively)	1.5
TSR/SD = relative stocking rate, 1 for sheep	1
PM = pasture mass in tonnes DM/ha	1400
MJME per day =	**0.003**
<u>MJME required for activity</u>	
MJME activity =	LWT*((0.0026*Hkm)+(0.028*Vkm))/Km
Where:	
Hkm = horizontal km walked (assumed)	4
Vkm = vertical km climbed (assumed)	0.5
Km = M/D*0.02 + 0.5, where M/D = MJME/kg	0.7

DM (assumption MJME/kg DM = 10) (assumed)	
MJME activity =	**2.09**

TOTALS per day

Basal MR=	7.65
ME graze =	0.28
ME move =	0.003
MJME activity =	2.09
Total ME requirements	**10.0 MJME per day**

Appendix B

Further assumptions used in calculations to determine values used in Table 1 and Table 2 for energy requirements for live weight change and lactation.

MJME requirements for live weight change (Nicol and Brookes, 2007; p154)

55 MJME / kg for gain – 30 MJME / kg loss = net requirement of 25 MJME /kg live weight change

MJME requirement for lactation (Nicol and Brookes, 2007; Table 3 p155)

(45 MJME / kg lamb weaned) x lamb weaning weight x (*x* number of lambs weaned)

Appendix C

MJME requirements for pregnancy (Nicol and Brookes, 2007; Equation 6; p169)

MJME requirements for pregnancy for one lamb =

(BWt/4)*((exp(7.649-11.465*exp(-0.00643*days)))*0.0737*exp(-0.00643*days))/Kp

Where BWt = lamb birth weight (Accelerated; 4.38 kg, Conventional 4.85 kg)

Days = days post conception

Kp = 0.133

		Conventional ewe		Accelerated ewe	
		MJME		MJME	
	Days since conception	per day	per week	per day	Weekly total
End of wk 1	7	0.023	0.164	0.021	0.148
End of wk 2	14	0.036	0.254	0.033	0.229
End of wk 3	21	0.055	0.385	0.050	0.348
End of wk 4	28	0.082	0.572	0.074	0.516
End of wk 5	35	0.119	0.833	0.108	0.753
End of wk 6	42	0.170	1.192	0.154	1.076
End of wk 7	49	0.239	1.675	0.216	1.513
End of wk 8	56	0.331	2.314	0.299	2.090
End of wk 9	63	0.449	3.145	0.406	2.841
End of wk 10	70	0.601	4.210	0.543	3.802
End of wk 11	77	0.793	5.552	0.716	5.014
End of wk 12	84	1.031	7.219	0.931	6.519
End of wk 13	91	1.323	9.260	1.195	8.363
End of wk 14	98	1.675	11.726	1.513	10.590
End of wk 15	105	2.095	14.665	1.892	13.244
End of wk 16	112	2.589	18.126	2.339	16.370
End of wk 17	119	3.165	22.152	2.858	20.005
End of wk 18	126	3.826	26.781	3.455	24.186
End of wk 19	133	4.578	32.044	4.134	28.939
End of wk 20	140	5.424	37.965	4.898	34.286
End of wk 21	147	6.365	44.557	5.748	40.239
TOTAL MJME required for pregnancy			245		221

Appendix D

Values used for calculation of annual energy requirements for one 60 kg ewe grazing rolling hill country in the Conventional and the Accelerated lamb production systems (Nicol and Brookes, 2007). Values are three year averages (from Chapter 3; Table 3.3 and 3.4).

	Jan./Aug. bred [a]	Mar./Nov. bred [b]	Jun. bred [c]
Ewe LWt (kg)	60	60	60
Ewe LWt change (kg)	5	5	5
Lambs born / ewe lambing	1.56	1.56	1.56
Lamb birth Wt (kg)	4.38	4.38	4.38
Lambs weaned/ewe lambing	1.24	1.24	1.24
Lamb weaning Wt (kg)	20.5	20.5	20.5
ME requirements			
Maintenance [1]	10 x 365 3650	10 x 365 3650	10 x 365 3650
Weight change [2]	25 MJME x 5 kg 125	25 MJME x 5 kg 125	25 MJME x 5 kg 125
Pregnancy [3]	221 x 1.56 x 2 gest. 690	221 x 1.56 x 1½ gest. 517	221 x 1.56 x 1½ gest. 517
Lactation [2]	45 MJME x 20.5 kg x 1.24 lambs x 1 lactation 1144	45 MJME x 20.5 kg x 1.24 lambs x 2 lactations 2288	45 MJME x 20.5 kg x 1.24 lambs x 2 lactations 2288
Total ME requirement	5609	680	6580
Delayed weaning [4]	5860	7082	7082

[a] Based on ewe that was bred in January 14th, lambed June 9th, weaned lambs August 21st, and re-bred August 21st to lamb January 14th (= 2 x gestations)

[b] Based on ewe that was bred in November 2nd, lambed March 28th, weaned lambs was re-bred June 9th, and lambed November 2nd (=1½ x gestations and 2 x lactations)

[c] Based on ewe that lambed March 28th, weaned lambs and was re-bred June 9th, and lambed November 2nd (=1½ x gestations and 2 x lactation)

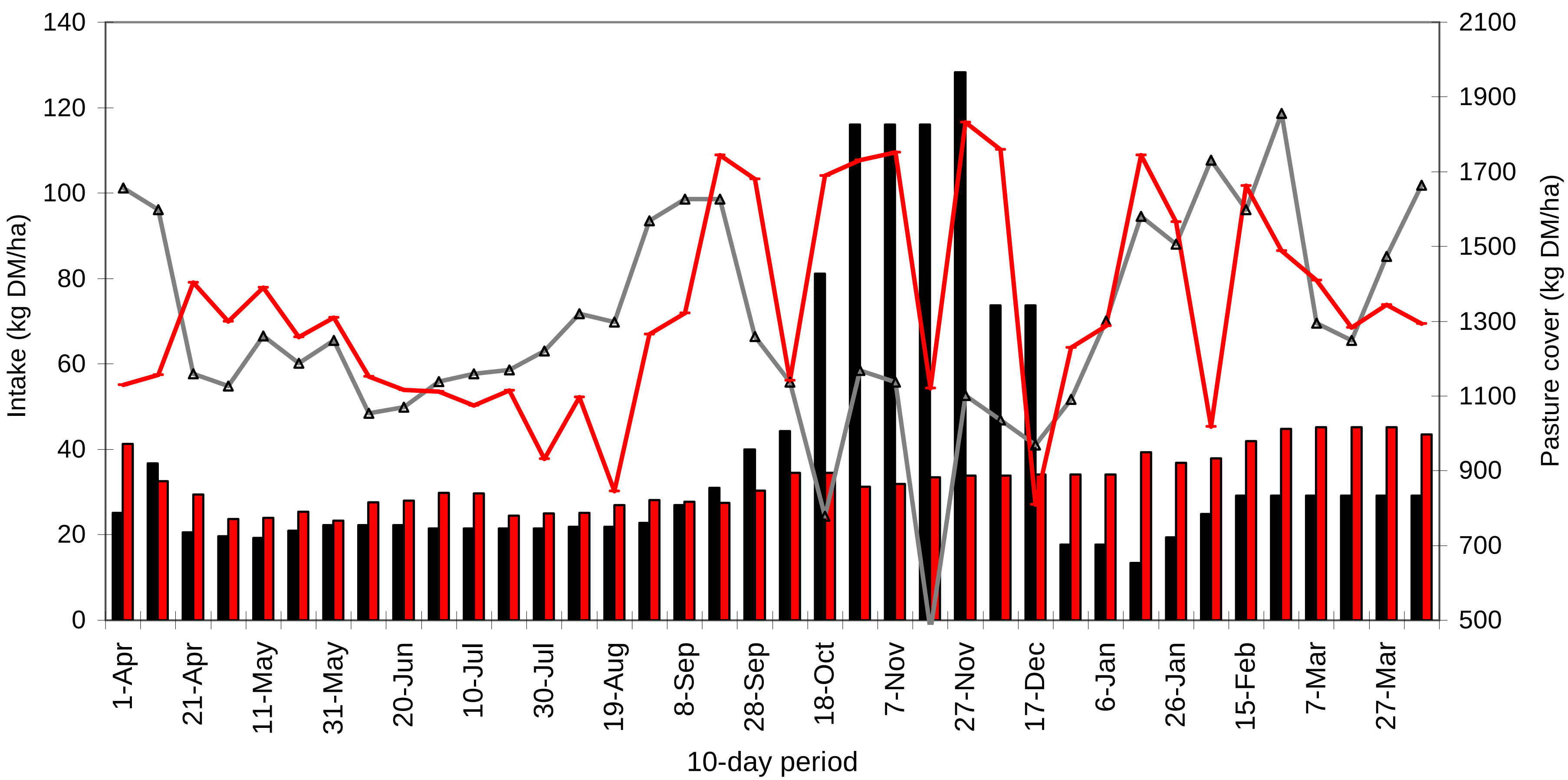
[1] See Appendix A

[2] See Appendix B

[3] See Appendix C

[4] Based on an average lamb weaning weight of 25 kg after delaying weaning

Appendix E



Pasture cover (kg DM/ha; lines) and estimated feed intake (kg DM/ha; bars) for the conventional (black) and the accelerated (red) lamb production systems from 1st April to 27th March.

Ewe reproduction and lamb performance at five different breeding periods within a year

G. deNicolo
S.T. Morris
P.R. Kenyon
P.C.H. Morel

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Chapter 5 Ewe reproduction and lamb performance at five different breeding periods within a year

Abstract

In this experiment ewe reproduction and lamb performance in two breeds (East Friesian Composite (EF) and Romney) was assessed at five different breeding and lambing periods within a year, including three aseasonal breeding periods. The experiment was designed so that weaning coincided with the first day of each synchronised breeding period. In addition to intravaginal progesterone, eCG was used for aseasonal breeding periods (January, August, November). Pregnancy rates in March (EF; 94%, Romney; 91%) and June (EF; 91%, Romney; 91%) were higher than August (EF; 54%, Romney; 45%), November (EF; 49%, Romney; 41%) and January (EF; 68%, Romney; 39%; $P<0.001$). Number of lambs born and weaned was highest for August-bred EF and March-bred Romney ewes and varied within and between years. November-born lambs were heaviest at birth and had the lowest mortality and March-born lambs were the lightest at birth ($P<0.05$). Lambs born to EF ewes were heavier than Romney lambs ($P<0.05$). August-born lambs were heaviest at weaning and grew faster from birth to weaning than lambs born in other lambing periods. This experiment demonstrated that for either an accelerated or an out-of-season lamb production system to be successful, low out-of-season pregnancy rates need to be addressed.

5.1 Introduction

In New Zealand, lamb production is governed by the seasonal pattern of pasture growth and the reproductive seasonality of sheep. Breeding sheep and producing lambs that are consistently available at any stage during the year offers New Zealand lamb meat exporters the opportunity to provide a continuous supply of young lamb throughout the year. This can be achieved by breeding and lambing a proportion of a flock out of season (McQueen and Reid, 1988; Smith et al., 1988b; Knight et al., 1989a; Morris et al., 1993) or by an accelerated lamb production system whereby ewes are bred and lamb more frequently than once a year (Goot and Maijala, 1977; Speedy and FitzSimons, 1977; Fahmy, 1990; Fogarty et al., 1992a; Lewis et al., 1996; Urrutia et al., 2001).

Low aseasonal reproductive performance in accelerated or out-of-season lamb production systems have previously been shown to limit the success of these systems. Reproductive performance, specifically pregnancy rates, have been reported to be low during the non-breeding season, regardless of whether or not exogenous reproductive hormone regimes have been incorporated (Carpenter and Spitzer, 1981; Smith et al., 1988a; Knight et al., 1989b; Morris et al., 1993; Ungerfeld and Rubianes, 1999b; 2002; deNicolo et al., 2008; Chapter 6).

Although seasonal differences in lamb birth weights have previously been reported where lambs born in spring were heavier at birth than lambs born in autumn (McCoard et al., 1996; Gootwine and Rozov, 2006) or winter (Morris et al., 1993; Jenkinson et al., 1995), no difference in lamb mortality has been reported (Notter and Copenhaver, 1980; Morris et al., 1993; Dabiri et al., 1996; Fisher, 2004). Several studies have however, reported lower growth rates in autumn-born lambs compared to their spring-born counterparts (Gould and Whiteman, 1971; McQueen, 1986; Cruickshank and Smith, 1989), although Notter et al. (1991) found no difference in pre-weaning growth rates of autumn- or spring-born lambs when creep feeding was available. Sheep farming in New Zealand is pastoral based and the feeding of high energy or protein supplements to lambs is not feasible due to the costs. Moreover, the different lambing seasons in accelerated or out-of-season lamb production systems may lead to differences in lamb growth rates. It is therefore, also important to consider pre-weaning growth of lambs during different periods of the year.

Ewe reproductive performance, and lamb growth are important to the performance and viability of accelerated or out-of-season lamb production systems. Theoretical modelling on an accelerated lamb production system based on the “STAR” system has indicated there are potential economic advantages (Morel et al., 2004). Hence, the objective of the current experiment was to monitor ewe reproductive performance and lamb performance in ewes bred and lambed at five different periods within a year.

5.2 Material and methods

Experimental design

The experiment was conducted approximately 5km south-east of Palmerston North (40^{o} south, 175^{o} east; summer solstice: 21st December, winter solstice: 21st June). The first breeding period was 28th March 2003 and the trial was completed when lambs were weaned (21st August) from the group of ewes bred in January 2006.

Two hundred and sixty seven, 2-year-old and mixed-aged East Friesian composite (1/2 East Friesian, 1/4 Polled Dorset and 1/4 Texel; EF; n=116) and Romney (n=121) ewes were divided into three groups (detailed later) and were managed on a 20.3 ha area. Ewes were managed under commercial farming conditions and were shorn in May and December.

The trial design was based on the “STAR” system developed at Cornell University, New York. (Lewis et al., 1996). There were five breeding periods (14th January, 28th March, 9th June, 21st August, 2nd November), where ewes were synchronised using progesterone primed controlled internal drug release devices

(CIDRs; 0.3 g progesterone; Pharmacia & Upjohn, Auckland, New Zealand) which were inserted eleven days prior to ram introduction. In addition, equine chorionic gonadotrophin (eCG; Folligon, Intervet Ltd, Auckland, New Zealand) was administered on the first synchronised day of breeding (Day P0) for the January (400 IU), August (800 IU) and November (800 IU) breeding periods. January was considered the transition back into to the breeding season so a lower dose of eCG was used compared to August and November (Smith et al., 1988a; Wheaton et al., 1992; Morris et al., 1993). These oestrus induction regimens were chosen as they were deemed to be the most effective methods for inducing aseasonal reproductive activity during their respective breeding periods in New Zealand (Smith et al., 1988a; Knight et al., 1989b; Morris et al., 2004; deNicolo et al., 2008; Chapter 6).

Mixed-aged rams were introduced to groups of ewes of their respective breed on Day P0 (approximate ram-ewe ratio of 1:10), and rams remained with the ewes for 21 days (Day P0 to Day P21). Seven days after the first day of the synchronised breeding period (Day P7), reused CIDRs were reinserted to give non pregnant ewes a chance to be rebred. These CIDRs were then removed on Day P14. On Day P62, pregnancy status was determined by transabdominal ultrasonography using a 3.5 MHz sector transducer applied over the caudodorsal flank fold. Any ewes identified as non-pregnant were introduced into the subsequent group for the next breeding period eleven days later.

The first group of ewes (n=88) was joined with rams on 28th March. Lambs were weaned 73 days after the first day of lambing which was predicted to be 146 days after the first day of synchronised mating. Ewes were then rebred on the day of weaning, eleven days after having CIDRs inserted. The second mob of ewes was introduced to the ram on 9th June, followed by the third mob on 21st August. Breeding, lambing, weaning and rebreeding management was the same for all the groups. Based on the first day of the synchronised breeding period, this management resulted in a breeding to rebreeding interval of 219 days. If ewes from the March breeding period were pregnant, they lambed in August and were rebred in November. Pregnant ewes from the June breeding period lambed in November, and were rebred in January, thus giving five breeding and lambing periods within one year, or fifteen breeding periods over the three-year experimental period.

Animals were grazed on ryegrass/white clover pasture on 14 ha and/or annual forage crops on the remaining 6 ha. Annual forage crops were planted in spring (brassica; *cv* Hunter pasja) and autumn (annual ryegrass; *cv* Concord Italian ryegrass) to meet feed demands through summer and winter. Supplementary feed (hay and/or balage) was harvested on the farm or bought in and, at the discretion of the farm manager, offered to ewes at times of feed deficit.

Shearing of all ewes, regardless of there production cycle, took place in December and in May. Approximately two weeks prior to lambing (pre-lamb), pregnant ewes were vaccinated with 5 in 1 claustridial vaccine (Schering Plough Animal Health, Wellington, New Zealand). Faecal eggs counts were done periodically for ewes (breeding, pregnancy diagnosis, pre-lamb, ~ 35 days post lambing and weaning) and for lambs (~ 35 days post lambing and weaning) to monitor worm counts. Ewes were drenched at trigger levels (2 x >1000 epg per 10 ewes or average FEC of >500 epg). At weaning, lambs were drenched then transported off the farm.

Statistical analysis

Pregnancy data were treated as binomial traits, were logit transformed and analysed using a logistical regression model using SAS software (V8, SAS Institute Inc, Cary, NC, 2001; GENMOD). Values were back-transformed into percentages for presentation. The statistical model included breeding period, ewe breed and year as fixed effects. Interactions were also tested, and were removed from the statistical model if they were not significant. Pregnancy rate was defined as the number of pregnant ewes per ewe exposed to the ram.

The number of lambs born (NLB) and weaned (NLW) per ewe lambed per year were analysed as categorical variables (GENMOD) with breeding period, ewe breed and year as fixed effects. Interactions were also tested, and were removed from the statistical model if they were not significant.

A general linear model (PROC GLM) was used to analyse lamb birth weights and average daily weight gain from birth to weaning (ADG). Lamb data was analysed with lambing period, lamb breed, sex, litter size and year fitted in the model as fixed effects. Breed, lambing period and year interactions were also tested. Where they were not significant, interactions were removed and the model was re-run without interactions. Lamb data is presented as month of lambing which was six months or two breeding periods after the ewes were bred.

Lamb mortality between birth and weaning was analysed as a binomial trait (GENMOD) and the statistical model included lamb breed, litter size at birth (birth rank), lambing period and year as fixed effects. Birth rank was categorised (1, 2, ≥3), and a lambing period by breed interaction was tested, but was not significant so was removed. No year by lambing period by breed interaction was tested.

5.3 Results

Ewe reproductive performance

Pregnancy rates for both EF and Romney ewes were higher in March and June (Table 5.1; $P<0.001$) and lower in August and November ($P<0.001$). In the EF ewes, pregnancy rates in January were higher than in August and November, and lower than March and June ($P<0.001$). In November and January, pregnancy rates were higher in EF ewes compared with Romney ewes (Table 5.1; $P<0.01$) but in March, June and August, pregnancy rates were similar between the two breeds.

There were significant breeding period by year by breed interactions for the number of lambs born per ewe lambed (NLB; $P<0.05$). The NLB varied throughout the year and between years (Table 5.2). This variation was not significant for the EF ewes in Year one or two, nor was it significant for the Romney ewes in Year one. In Year three, the August-bred EF ewes had the highest NLB while March-bred ewes had the lowest (P<0.05). In Year two, March-bred Romney ewes had the highest NLB while August-bred ewes had the lowest (P<0.05). June-bred Romney ewes in Year three had the highest NLB and January-bred ewes had the lowest (P<0.05). Breed differences were seen in August-bred ewes in Year two and in June- and January-bred ewes in Year three. In all three cases, EF ewes had higher NLB than Romney ewes (P<0.05).

Table 5.1 Pregnancy rates (ewes pregnant/ewes exposed to the ram) for five different breeding periods over three years for East Friesian composite and Romney ewes. Values are logit least means squares ± standard errors. Back transformations are presented as percentages.

	East Friesian Composite		Romney	
Breeding period	LSM ± se	%	LSM ± se	%
March	2.76 ± 0.41 ^{c}	94.0	2.36 ± 0.27 ^{b}	91.4
June	2.35 ± 0.42 ^{c}	91.3	2.34 ± 0.41 ^{b}	91.2
August	0.14 ± 0.18 ^{a}	53.5	-0.20 ± 0.21 ^{a}	45.1
November	-0.05 ± 0.16 $^{a\,2}$	48.7	-0.64 ± 0.16 $^{a\,1}$	40.9
January	0.77 ± 0.16 $^{b\,2}$	68.4	-0.43 ± 0.14 $^{a\,1}$	39.3

$^{a\,b}$ Indicates significant differences within columns (P<0.05)

$^{1\,2}$ Indicates significant differences within row (P<0.05)

There were significant breeding period by breed by year interactions for the number of lambs weaned per ewe lambed (NLW). In Romney ewes in Year one and in EF ewes in Year three there were no significant differences between breeding periods (P>0.05, Table 5.2), but for the remaining years within each breed, there were variations in the highest and lowest NLW at the different breeding periods. The highest NLW in EF ewes was from August-bred ewes in Year one and from June-bred ewes in Year two, whereas in Romney ewes, the highest NLW was in March in Year two and in June in

Year three. In all three years in January-bred ewes there was a breed difference where EF ewes weaned more lambs than Romney ewes (P<0.05).

Table 5.2 Number of lambs born (NLB) and weaned (NLW) per ewe lambed for five different breeding periods over three years for East Friesian composite and Romney ewes. Values are presented as least squares means ± standard error.

Year	East Friesian Composite		Romney	
Breeding period*	NLB	NLW	NLB	NLW
Year one				
March	1.53 ± 0.11	1.30 ± 0.11 $^{a\,b}$	1.50 ± 0.11	1.09 ± 0.11
June	1.47 ± 0.11	1.35 ± 0.11 $^{a\,b}$	1.36 ± 0.10	1.28 ± 0.10
August	1.75 ± 0.16	1.59 ± 0.16 ^{b}	1.43 ± 0.20	1.17 ± 0.20
November	1.63 ± 0.12	1.20 ± 0.12 ^{a}	1.44 ± 0.15	1.17 ± 0.14
January	1.63 ± 0.11	1.34 ± 0.11 $^{a\,b}$	1.45 ± 0.13	1.23 ± 0.13
Year two				
March	1.63 ± 0.11	1.27 ± 0.11 ^{a}	1.69 ± 0.10 ^{b}	1.52 ± 0.10 ^{b}
June	1.81 ± 0.14	1.61 ± 0.14 ^{b}	1.46 ± 0.14 $^{a\,b}$	1.30 ± 0.14 $^{a\,b}$
August	1.81 ± 0.16 ^{2}	1.32 ± 0.16 $^{a\,b}$	1.30 ± 0.17 $^{a\,1}$	1.05 ± 0.17 ^{a}
November	1.58 ± 0.15	1.44 ± 0.15 $^{a\,b}$	1.63 ± 0.15 $^{a\,b}$	1.37 ± 0.15 $^{a\,b}$
January	1.63 ± 0.11	1.37 ± 0.11 $^{a\,b\,2}$	1.40 ± 0.13 $^{a\,b}$	1.03 ± 0.13 $^{a\,1}$
Year three				
March	1.33 ± 0.13 ^{a}	1.07 ± 0.13	1.52 ± 0.10 $^{a\,b}$	1.25 ± 0.10 $^{a\,b}$
June	1.38 ± 0.15 $^{a\,b\,2}$	1.29 ± 0.15	1.77 ± 0.14 $^{b\,1}$	1.45 ± 0.14 ^{b}
August	2.04 ± 0.11 ^{d}	1.34 ± 0.11	1.76 ± 0.18 $^{a\,b}$	1.19 ± 0.17 $^{a\,b}$
November	1.71 ± 0.12 $^{b\,c}$	1.07 ± 0.13	1.69 ± 0.15 $^{a\,b}$	1.19 ± 0.15 $^{a\,b}$
January	1.73 ± 0.10 $^{c\,2}$	1.25 ± 0.10	1.36 ± 0.11 $^{a\,1}$	0.99 ± 0.11 ^{a}

* Month of ewe breeding

$^{a\,b}$ Indicates significant differences within columns (P<0.05)

$^{1\,2}$ Indicates significant differences within row (P<0.05)

Lamb birth weights

There were no month by breed or year interactions in lamb birth weights. Lambs born in November were the heaviest at birth, followed by August- and January-born lambs (P<0.001; Table 5.3). January-born lambs also had similar birth weights to

March- and June-born lambs. Lambs born to EF ewes were heavier compared to Romney lambs (P<0.05), and lambs born in Year one were similar to the other years, but lambs born in Year two and three differed (P<0.05).

Table 5.3 Effect of lamb breed, year and lambing period on lamb birth weights and mortality from birth to weaning (average age = 69 days). Values are presented as least squares means ± standard error. Lamb mortality values are logit transformed least squares means ± standard error, and are also presented as back-transformed percentages.

Variable	Birth weight	Mortality	
		(LSM ± SE)	(%)
Breed			
East Friesian Composite	4.41 ± 0.04 [b]	1.39 ± 0.10	32.8
Romney	4.29 ± 0.04 [a]	1.43 ± 0.12	31.5
Year			
One	4.38 ± 0.05 [a b]	1.49 ± 0.13 [a]	29.6
Two	4.25 ± 0.05 [a]	1.67 ± 0.14 [a]	24.5
Three	4.43 ± 0.05 [b]	1.08 ± 0.11 [b]	44.7
Lambing period [1]			
August (March)	4.43 ± 0.05 [c]	1.22 ± 0.14 [b]	38.9
November (June)	4.68 ± 0.06 [d]	1.82 ± 0.20 [a]	20.8
January (August)	4.27 ± 0.07 [a b c]	1.45 ± 0.19 [a b]	30.8
March (November)	4.10 ± 0.06 [a]	1.31 ± 0.17 [b]	35.8
June (January)	4.28 ± 0.05 [b]	1.26 ± 0.14 [b]	37.5

[a b c d] Indicates significant differences within variable (P<0.05)

[*] Interactions were significant and are presented in Table 4

[1] Month of ewe breeding in parentheses

Lamb weaning live weights

There were significant (P<0.001) interactions between year, ewe breed and lambing period for live weights at weaning, although there were no consistent patterns within each year for either the heaviest or the lightest lambs at weaning (Table 5.4). November-born EF and Romney lambs were heaviest at weaning in Year one, and lightest in Year two (P<0.05). In Year two June-born EF and January-born Romney lambs were heaviest and January-born EF and Romney lambs were lightest in Year one (P<0.05). In Year three, lamb of both breeds were heaviest when born in August and lightest when born in January (P<0.05). Weaning weights in EF lambs were higher than Romney lambs for August- and January-born lambs in Year one, August- and November-born lambs in Year two and in August-, November- and June-born lambs in Year three (P<0.05).

Table 5.4 Weaning weight (kg) and daily weight gain between birth and weaning (ADG; grams/day) for five different lambing periods over three years for East Friesian composite and Romney ewes. Values are presented as least squares means ± standard error.

Year	East Friesian Composite		Romney	
Lambing period*	Weaning weight	ADG	Weaning weight	ADG
Year one				
August	22.50 ± 0.55 [b c 2]	266 ± 6.97 [b 2]	19.40 ± 0.59 [b 1]	231 ± 7.27 [b 1]
November	24.03 ± 0.57 [c]	264 ± 7.06 [b]	24.21 ± 0.53 [c]	277 ± 6.53 [c]
January	19.92 ± 0.74 [a 2]	213 ± 9.22 [a 2]	16.82 ± 1.09 [a 1]	174 ± 11.51 [a 1]
March	19.94 ± 0.60 [a]	215 ± 7.41 [a]	19.00 ± 0.76 [a b]	209 ± 9.44 [b]
June	21.18 ± 0.51 [a b]	244 ± 6.39 [b 2]	19.96 ± 0.66 [b]	225 ± 8.14 [b 1]
Year two				
August	23.21 ± 0.59 [c 2]	283 ± 7.37 [c 2]	21.40 ± 0.48 [b 1]	253 ± 5.94 [c 1]
November	20.65 ± 0.61 [a 2]	248 ± 7.63 [a b 2]	18.59 ± 0.72 [a 1]	219 ± 8.88 [a 1]
January	21.99 ± 0.74 [a b c]	243 ± 9.15 [a b]	22.41 ± 0.90 [b]	251 ± 11.16 [b c]
March	20.96 ± 0.73 [a b]	234 ± 9.09 [a]	20.34 ± 0.76 [a b]	229 ± 9.49 [a b]
June	23.08 ± 0.55 [b c]	263 ± 6.88 [b]	21.53 ± 0.74 [b]	242 ± 9.24 [a b c]
Year three				
August	24.14 ± 0.73 [d 2]	299 ± 9.27 [d 2]	21.57 ± 0.50 [c 1]	265 ± 6.26 [c]
November	21.29 ± 0.77 [c 2]	231 ± 9.61 [c]	18.89 ± 0.69 [b 1]	207 ± 8.28 [b]
January	15.41 ± 0.59 [a]	157 ± 7.66 [a]	15.49 ± 0.92 [a]	160 ± 11.40 [a]
March	20.40 ± 0.70 [c]	223 ± 8.70 [c]	18.42 ± 0.75 [b]	206 ± 9.32 [b]
June	17.93 ± 0.59 [b 2]	197 ± 6.67 [b 2]	16.30 ± 0.63 [a 1]	167 ± 7.88 [a]

* Month of lambing

[a b] Indicates significant differences between period of lambing, within column and within year (P<0.05)

[1 2] Indicates significant differences between breed, within row (P<0.05)

Lamb growth rates from birth to weaning

Lamb daily growth rates for year by lambing period within breed interactions are presented in Table 5.4. August-born EF lambs had the highest daily weight gains for all three years and the lowest growth rates were in January-born lambs in Years one and three, and in March-born lambs in Year two (P<0.05). For Romney lambs in Year one, November-born lambs had the fastest growth rate and January-born lambs had the lowest (P<0.05). In Years two and three August-born Romney lambs had the fastest growth rates and November- and January-born Romney lambs had the slowest growth rates for Years two and three, respectively (P<0.05). Romney lambs tended to grow slower than EF lambs, with significant differences in January- and June-born lambs (Year one), and August- and November-born lambs (Year two).

Lamb mortality

Lamb mortality was lower in November-born lambs compared with lambs born at all other times (Table 5.3; P<0.05). Although statistically, this difference was not different, the biological differences was significant. Mortality in January-, March, June- and August-born lambs were also not statistically different from each other. Year three had more lamb deaths than Years one and two (P<0.05). Across all three years, lambs belonging to litter sizes of three or more had high lamb mortality (74.0%) compared to single- (16.4%) and twin-born lambs (23.5%; P<0.001).

5.4 Discussion

The objective of the current experiment was to monitor ewe reproductive performance at five different breeding periods over three years. The use of eCG in the current experiment is confounded with breeding period as the dose rate varied (0-800 IU) throughout the year, but the objective of the experiment was not to compare or test the effects of eCG, but rather, to compare the different breeding periods in this experiment. Previous studies in New Zealand were used to develop the induction regimes used (Smith et al., 1988a; Knight et al., 1989b; Morris et al., 2004).

The ability of ewes to successfully reproduce out of season is pivotal to the viability of an accelerated or out-of-season lamb production system. The current experiment indicated that aseasonal reproductive performance is low (August; 45-54%, November; 41-49%, January; 39-68%). These results are similar to the findings of other studies were aseasonal breeding has occurred: Smith et al. (1988a) achieved conception rates of 30-52% August-, October and December-bred ewes, Knight et al. (1989b) and deNicolo et al. (2006; Chapter 10) reported pregnancy rates from 47-55% and 33-36%, respectively, in December-bred ewes, and Morris et al. (1993) reported pregnancy rates of 64-76% in January-bred ewes.

Alternative means of circumventing seasonality and achieving higher pregnancy rates in aseasonal breeding periods, therefore, needs to be addressed. Melatonin implants are a possibility and although previous results have been disappointing, methods of administration and improvements in the development of the implants may provide an improved product for use New Zealand. Earlier work in New Zealand using melatonin fed to ewes for 25 days from early January resulted in pregnancy rates of 62% (Knight, 1983). Melatonin implants have shown promise in Mediterranean breeds of sheep (83% (Forcada et al., 1999)) and in Australia with Merino, Border Leicester x Merino and Romney ewes (93-97% (Williams et al., 1992)). Recently, deNicolo et al. (2007c, see Chapter 9) reported a 15% increase in pregnancy rates and a 61% increase in the number of lamb born per 100 ewes treated when using melatonin implants in conjunction with eCG and progesterone during spring (October). Melatonin implants could be used in New Zealand in conjunction with progesterone and eCG, although this combination may be expensive.

Another option is to use artificial photoperiod to entrain the underlying circadian rhythm associated with seasonality to retrain the hypothalamus and induce photorefractoriness, which can lead to reproductive activity (Legan and Karsch, 1980; Jackson et al., 1988). However, due to housing difficulties (including the control of humidity and temperature in summer), an increase in the handling requirements of the sheep, the extensive nature of sheep farming in New Zealand, and the poor response recently shown (deNicolo et al., 2007b; Chapter 8), this option is not a practical method for circumventing seasonality in sheep.

The Romney flock used in the current experiment indicated that they were not suited to a lamb production system in which aseasonal breeding period(s) were incorporated. This finding is in accordance with deNicolo et al. (2008; Chapter 6) who reported that Romney ewes performed poorer in August, November and January compared to EF ewes. Furthermore, it appears that the Romney breed is affected by seasonality to a greater extent that other breeds (Moore et al., 1988; Smith et al., 1989; Knight et al., 1992; Morris et al., 1993). Experimentation with other less seasonal breeds of sheep may result in an improvement in aseasonal reproductive performance (e.g. Finnish Landrace (Fahmy, 1990), Border Leicester (Hall and Killeen, 1989), Dorset/Poll Dorset (Knight et al., 1989a)). However, changing to a less seasonal breed may require the use of terminal sires to ensure lamb live weights at weaning and carcass weights are suitable for the market. A further problem is the availability of sufficient numbers of such breeds of sheep in New Zealand.

Perhaps a more practical option under New Zealand conditions in this accelerated lamb production system is to change the design from five breeding periods within a year, to three or four, thereby avoiding the period of deep anoestrus and lowest reproductive performance (i.e. spring). In the current trial, August and November were the worst months for pregnancy rates, therefore these months should be avoided. Breeding in early autumn and winter when reproductive performance is expected to be high, and also incorporating one or two breeding periods which coincide with the transition into shallow anoestrus and the transition out of anoestrus may prove to be more successful (i.e. late July/early August or January, respectively).

Recently, deNicolo et al. (2008; Chapter 6) have shown that ewes are ovulating outside of the traditional autumn breeding period after hormonal oestrus induction, although they are failing to conceive. Therefore, further research in this area is required to determine means of ensuring ewes conceive and the embryo survives and results in a viable foetus and a live lamb.

McQueen (1986) and Reid et al. (1988) reported higher lamb survival rates in autumn-born lambs compared to their spring-born counterparts, although this was not the case in the current experiment: Mortality was highest in early spring-, autumn- and winter-born lambs (August, March and June), whereas late spring (November) appeared to be the best time for lamb survival. However, as expected, lamb losses between birth and weaning increase as litter size increased. This is of little surprise as the association between litter size, lamb birth weight and perinatal lamb mortality has been widely reported (Dalton et al., 1980; Scales et al., 1986; Maria and Ascaso, 1999; Jopson et al., 2000; Morris and Kenyon, 2004).

August-born (early spring) lambs had the heaviest weaning weights and the highest daily weight gains compared with other lambing periods. Forbes et al. (1979) demonstrated that exposure of lambs to longer day light hours (16 hrs light), albeit artificial, resulted in higher growth rates compared to lambs exposed to shorter periods of light (8 hrs light). This is apparently not the case with exposure to ambient photoperiod and/or pastoral-based diets since January-born lambs tended to have the lowest daily live weight gains – the lambing period where day light hours were the longest. Nevertheless, growth rates in autumn-born lambs have previously been reported to be lower than spring-born lambs (Gould and Whiteman, 1971; McQueen, 1986; Cruickshank and Smith, 1989; Morris et al., 1993) which appears to be in line with the current experiment. This may be partly due to lower milk yields since Peterson et al. (2005) reported the lowest milk yields in March-lambing ewes and the highest in June-lambing ewes, although lamb growth rates in the current trial did not coincide with that pattern of milk production. Autumn and summer pasture have lower quality than spring pasture (Machado et al., 2005), however, this should not have been an issue with the current experiment as forage crops were grown for autumn/winter and summer.

In the current experiment, lambs were weaned 73 days after the predicted first day of lambing, so they were therefore younger than lambs weaned in conventional once-yearly lamb production systems. Increasing lamb weaning weight (particularly those born outside of the normal spring lambing period) may be a practical method for improving the lamb output of accelerated and out-of-season lamb production systems. Delaying weaning and breeding ewes while they are still suckling lambs has previously been shown to be an effective means of increasing lamb weaning weight without affecting reproductive performance in spring-bred ewes (deNicolo et al., 2006; Chapter 10).

5.5 Conclusion

The objective of this experiment was to monitor ewe reproductive performance and lamb performance in a lamb production system where breeding and lambing occurred at five different periods within one year. The major weakness identified was the low aseasonal reproductive performance which supports previous studies incorporating aseasonal breeding periods, and potential solutions were identified. These results suggest that unless aseasonal reproductive performance can be improved, it is unlikely that the breeding periods of August and November, and to a lesser extent January, will be utilised in an accelerated or out-of-season lamb production system. The age of lambs at weaning also needs to be addressed as the weaning of young lambs meant live weights at weaning were not sufficient for store lamb trade during some lambing periods. If these weaknesses can be addressed, increasing the frequency of breeding and lambing may have a place in the sheep industry in some parts of New Zealand.

In this chapter, it was shown that pregnancy rates during the aseasonal breeding periods were low, particularly August and November and to a less extent, January. Observations in this chapter indicated that a majority of the ewes presented for breeding had crayon mating marks, yet were identified as being non pregnant 62 days after the start of the synchronised breeding period. The next chapter examines the theory that inactive ovarian activity contributes to this low aseasonal reproductive performance.

Induced seasonal reproductive performance of two breeds of sheep

G. deNicolo
S.T. Morris
P.R. Kenyon
P.C.H. Morel
T.J. Parkinson

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Chapter 6 Induced seasonal reproductive performance in two breeds of sheep

Abstract

The objective of the present experiment was to determine whether failure to become pregnant through out-of-season reproductive management regimes is attributable to a failure to stimulate normal corpora lutea production. Romney ewes and East Friesian Composite (EF) ewes were mated in summer, autumn, winter, and early and late spring after administration of intravaginal progesterone inserts (plus eCG in spring and summer in a factorial (2 breeds x 5 mating periods) experimental design. Oestrus rate was determined from mating data, and the number of corpora lutea were determined by laparoscopy 9 days after ram introduction. Conception rate, pregnancy rate and litter size were determined by transabdominal ultrasonography 62 days after ram introduction.

Proportions of ewes displaying oestrus did not differ significantly (75-100%) between seasons or breeds, except for the Romney ewes in summer (67%; $P<0.05$). Number of corpora lutea on Day 9 for EF ewes was lowest in autumn (1.5) and winter (1.5), and highest in late spring (2.1; $P<0.05$). In contrast, Romney ewes had the lowest corpora lutea count in summer (1.3), and the highest in autumn (1.8) and winter (1.6; $P<0.05$). Only in summer was there a difference between breeds (EF 1.8; Romney 1.3; $P<0.01$). The proportion of ewes that failed to conceive despite having one or more corpora lutea present was highest in late spring (EF 41%, Romney 43%), and lowest in autumn (EF 9%, Romney 4%) and winter (EF 14%, Romney 4%; $P<0.05$) matings. Conception and pregnancy rates followed similar patterns with values for autumn (EF 91%, 91%; Romney 96%, 96%) and June (EF 86%, 82%; Romney 91%, 83%) being significantly ($P<0.05$) higher than in early (EF 50%, 40%; Romney 54%, 50%) and late spring (EF 44%, 36%; Romney 42%, 36%). Pregnancy rate in summer was higher for EF ewes (60%) than for Romney ewes (39%) but conception rates were not statistically different (EF 68%; Romney 60%). Numbers of foetuses identified at scanning was highest in autumn (1.5) and lowest in late spring (0.5 $P<0.001$): Litter size in pregnant EF ewes was highest in early spring and lowest in winter (1.8 vs 1.2; $P<0.01$), but for

pregnant Romney ewes was highest in winter and lowest in early spring (1.9 vs 1.3; $P<0.001$).

It was concluded that seasonal differences in the ability of ewes to conceive are not the consequence of failure to display oestrus or to ovulate, but probably are a result of failure of fertilisation or the establishment of pregnancy.

6.1 Introduction

Year-round lambing systems depend on the ability of ewes to breed outside of the normal breeding season. Although much is known about the physiological principles that underlie the regulation of transitions between the breeding and non-breeding season, attempts to breed sheep out of season have generally resulted in low and variable overall pregnancy rates, with poor consistency between different studies and between different breeds/husbandry systems. This is so whether out-of-season breeding has been induced with (3-67%; Dawe et al., 1969; Carpenter and Spitzer, 1981; Smith et al., 1988a; Knight et al., 1989b; Ungerfeld and Rubianes, 1999b; Knights et al., 2003; Morris et al., 2004) or without (0-28%; Goot and Maijala, 1977; Lewis et al., 1996) the use of exogenous hormones. Conversely, despite such poor results in terms of pregnancy rates, the ability of out-of-season breeding regimens to induce behavioural oestrus is generally good. In the studies of Dawe et al. (1969), Smith et al. (1988a), Knight et al. (1989b), and Ungerfeld and Rubianes (1999b) oestrus was displayed by up to 95% of ewes. Whilst some data exist on the extent to which out-of-season breeding regimens induce normal follicular and luteal activity (e.g Hunter et al., 1986; Hunter and Southee, 1987; Smith et al., 1988b; Southee et al., 1988), the contribution that failure to induce such activity makes to the eventual pregnancy outcomes either in whole-flock management regimens, or when out-of-season management protocols are employed at different stages of the non-breeding season, has received relatively little attention.

In a recent experiment (Morris et al., 2004) in which reproductive activity was induced at five different seasons through the year, it was found that only 46-61% of those ewes which had been induced to breed out of season were subsequently identified as pregnant. Unpublished data from the same study indicated that, even though the pregnancy rate was low, 82-99% of those ewes displayed oestrus when they were exposed to rams (as indicated by crayon mating marks). However, it was not established whether the low out-of-season pregnancy rates reported in that study, as in many other similar studies, were due to inadequate follicular development, a reduced ability of the ewe to ovulate, failure of conception or implantation, or embryonic/early foetal mortality.

The objective of the present study was to examine the ovarian activity of two breeds of ewes (Romney and East Friesian Composite), to determine whether failure to induce corpora lutea was responsible for the discrepancy between high numbers of ewes displaying oestrus and low out-of-season pregnancy rates, especially in animals that were induced to breed during deep anoestrus.

6.2 Material and methods

A study was undertaken to examine the reproductive performance of ewes at five different breeding dates (early spring: mid-August, late spring: early-November, summer: mid-January, autumn: late-March and winter: early-June) over a 12 month period, using a total of 103 New Zealand Romney type ewes and 110 East Friesian Composite ewes (EF; 50% East Friesian, 25% Poll Dorset, 25% Texel) that were managed in a year-round lamb production system. The first breeding season was early spring. The experimental design was a factorial arrangement of two breeds by five mating periods by 22 to 61 replicates (ewes).

The study was carried out in New Zealand, approximately 5km south-east of Palmerston North (40^{o} south, 175^{o} east; summer solstice: 21 December, winter solstice: 21 June).

Feed demands were met using a hybrid turnip crop (cv Pasja) during the summer and winter active annual ryegrass (cv Hunter) during the winter. In summer, ewes were run on 6 ha of hybrid turnip crops and 14 ha of permanent pasture. During the winter, animals were run on 14 ha permanent pasture and 6 ha annual ryegrass.

Numbers of ewes of each breed type used at each breeding period and ewe:ram ratio are given in Table 6.1. Eleven days prior to each joining period (Day -11) all ewes had progesterone primed intravaginal devices (0.3 g progesterone; CIDRs; Pharmacia Ltd, Auckland, New Zealand) inserted. On the day of ram introduction (Day 0), ewes were weighed and condition scored (scale 1-5; Jefferies, 1961) and CIDRs were removed. In ewes that were to be joined in early spring, late spring and summer, equine chorionic gonadotrophin (eCG; Folligon, Intervet Ltd, Auckland, New Zealand) was given at doses of 800, 800 or 400 IU, respectively) by intramuscular injection. Ewes bred in autumn and winter received no eCG. Ewes were separated into their respective breed types and joined with five rams of their breed type on Day 0. Prior to introduction, rams were subjected to a breeding soundness examination (including measurement of scrotal circumference). Each ram was fitted with a crayon mating harness and run with the ewes for 9 days. Crayon mating marks were recorded on P8, as an indicator of oestrus display and mating activity.

Table 6.1 Number of mixed-aged East Friesian Composite and Romney type ewes, and the ewe:ram ratio* used for each breeding period.

Season of mating	East Friesian Composite		Romney	
	Ewes	Ewe:ram ratio	Ewes	Ewe:ram ratio
Summer	57	13.8	57	13.8
Autumn	38	19.0	51	24.7
Winter	22	10.8	24	9.4
Early spring	40	10.4	30	8.8
Late spring	61	14.2	61	14.2

* The ewe:ram ratio included non-trial ewes that were managed with each mob during each breeding period, but that did not undergo laparoscopy and were not included in this research.

On Day 9, laparoscopic examination of both ovaries was performed on all ewes and the number of corpora lutea on each ovary were recorded. Follicular activity was also subjectively scored, on the basis of numbers and sizes of antral follicles present on the surface of the ovary. Prior to examination, ewes were sedated with acetyl promazine (10 mg: Acezine 10%, Ethical Agents Ltd., Auckland, New Zealand) and lignocaine hydrochloride (20mg/ml, Nopaine: Phoenix Pharmaceutical Distributors Ltd., Auckland, New Zealand) was used at the site of entry of the laparoscope.

On Day 62, pregnancy status was determined by transabdominal ultrasonography using a 3.5 MHz sector transducer applied over the caudodorsal flank fold. Ewes that had conceived at the first and second breeding cycles were identified by this procedure. Since the laparoscopic observations had been made for the first cycle only, only pregnancy outcomes for the first cycle were used in subsequent data analysis.

Following pregnancy diagnosis, ewes were classified into one of five classifications based on the presence or absence of mating marks and corpora lutea, and pregnancy status in relation to the first synchronised oestrus cycle:

i. non-responsive (ewes that did not display oestrus (as indicated by lack of crayon harness marks) and had no corpora lutea at laparoscopy),
ii. silent oestrus (ewes that did not display oestrus but had corpora lutea observed at laparoscopy),
iii. pseudo-oestrus (ewes that displayed oestrus but had no corpora lutea observed at laparoscopy and were not pregnant),
iv. non-pregnant (ewes that displayed oestrus, had corpora lutea observed at laparoscopy and were not pregnant)
v. pregnant (ewes that displayed oestrus, had corpora lutea observed at laparoscopy and were pregnant).

Some ewes contributed to more that one set of data thereby giving 223 and 214 records for Romney and EF types, respectively. The contribution of more than one data set by some ewes occurred for two reasons. Firstly, ewes that were mated and conceived in early spring or late spring, lambed in summer or autumn, respectively, and were re-mated in autumn or winter (post weaning). Therefore, any ewes successfully conceiving to the early and late spring breeding periods contributed to two sets of data.

Secondly, any ewes that did not conceive in a particular breeding period were rebred at the subsequent breeding period. Ewes weaning a lamb prior to re-mating were considered to be in a lactating state at mating despite the lamb being weaned on the day of mating. Ewes that did not conceive to the previous mating were considered to be in a non-lactational state at mating.

Season and lactational status (lactating versus non-lactating) were used in all statistical models as fixed effects. Live weight on the first day of the synchronised breeding period (Day 0) was used as a covariate in all statistical models, but was removed where it had no statistically significant effect.

Univariate analyses compared the number of ewes displaying and not displaying oestrus (oestrus rates), and the number of ewes pregnant and not pregnant (conception rate and pregnancy rate) for breed type within each season. Oestrus rate was defined as the number of ewes marked by the ram per ewe exposed to the ram. Conception rate was defined as the number of ewes pregnant per ewe marked by the ram, and pregnancy rate was defined as the number of pregnant ewes per ewe exposed to the ram. Oestrus, pregnancy and conception data were treated as binomial traits and were logit transformed. These traits were analysed using a logistical regression model in SAS (V8, SAS Institute Inc, Cary, NC, 2001; GENMOD) and values were back-transformed into percentages for presentation. The proportion of ewes with at lease on corpus luteum present in the mated, non-pregnant ewes were similarly analysed as binomial traits. Due to a low number of non-pregnant ewes in autumn and winter, breed types were combined for statistical analysis.

The proportion of ewes within four of the five classifications (no oestrus, pseudo oestrus, non pregnant or pregnant) were analysed as binomial traits. To obtained breed differences, a breed by month interaction was tested. Some classifications had a low number of observations (0-2) so where there was no overall breed difference, the two breeds were analysed separately to test of a seasonal effect. In the case of the occurrences of silent, pseudo and no oestrus, seasons with zero observations were removed to test for significant differences between the remaining seasons. Live weight at breeding was tested, but had no significant effect on these variables, so was dropped from the statistical model. In the case of the occurrence of silent oestrus, the low number of observations meant a sensitive statistical analysis could not be performed. A simple statistical model for the occurrence of silent oestrus used breed, lactational status or season as main effects. Within breed, overall lactational status or season were also tested.

The number of corpora lutea present at laparoscopy and litter size per ewe scanned and per pregnant ewe were analysed using non parametric analysis (GENMOD) with respect to breed and season of breeding. Data for follicular activity on Day P9 were not subjected to further analysis, as, whilst indicative of ovarian activity, there was no reason to suppose that it was related to event around the induced oestrus/ovulation. .

6.3 Results

Oestrus rates (number of ewes marked by the ram per ewe exposed to the ram) in EF ewes ranged from 75% in early spring to 100% in autumn. In the Romney type, oestrus rate in summer was the lowest (67%) and in autumn, it was the highest (100%). Thirty-two percent of Romney type ewes exposed to the ram in summer failed to display oestrus. In autumn oestrus rate was 100% in Romney type ewes, with values of 89, 85 and 92% for winter, late spring and early spring, respectively. Oestrus rates recorded in summer for EF ewes were higher than those recorded for Romney type ewes ($P<0.01$). There were no other significant breed differences within other seasons ($P>0.05$).

There were no significant differences in conception rates (number of ewes pregnant per ewe mated) between lactating and non-lactating ewes, but there was a breed by lactational status interaction where conception rates in lactating Romney type ewes (75.0 %) were higher than in non-lactating Romney type ewes (58.8%; P<0.05). Conception rates in the EF ewes were lowest in early and late spring (50 and 44%, respectively) and highest in autumn and winter (90.9 and 85.7%, respectively; P<0.05; Figure 6.1). In the Romney type ewes, conception rates were higher in autumn and winter (96.1 and 90.9%, respectively) compared to summer, and early and late spring (59.5, 53.6 and 41.5%, respectively, P<0.05). There were no significant differences in conception rates between breeds within each season.

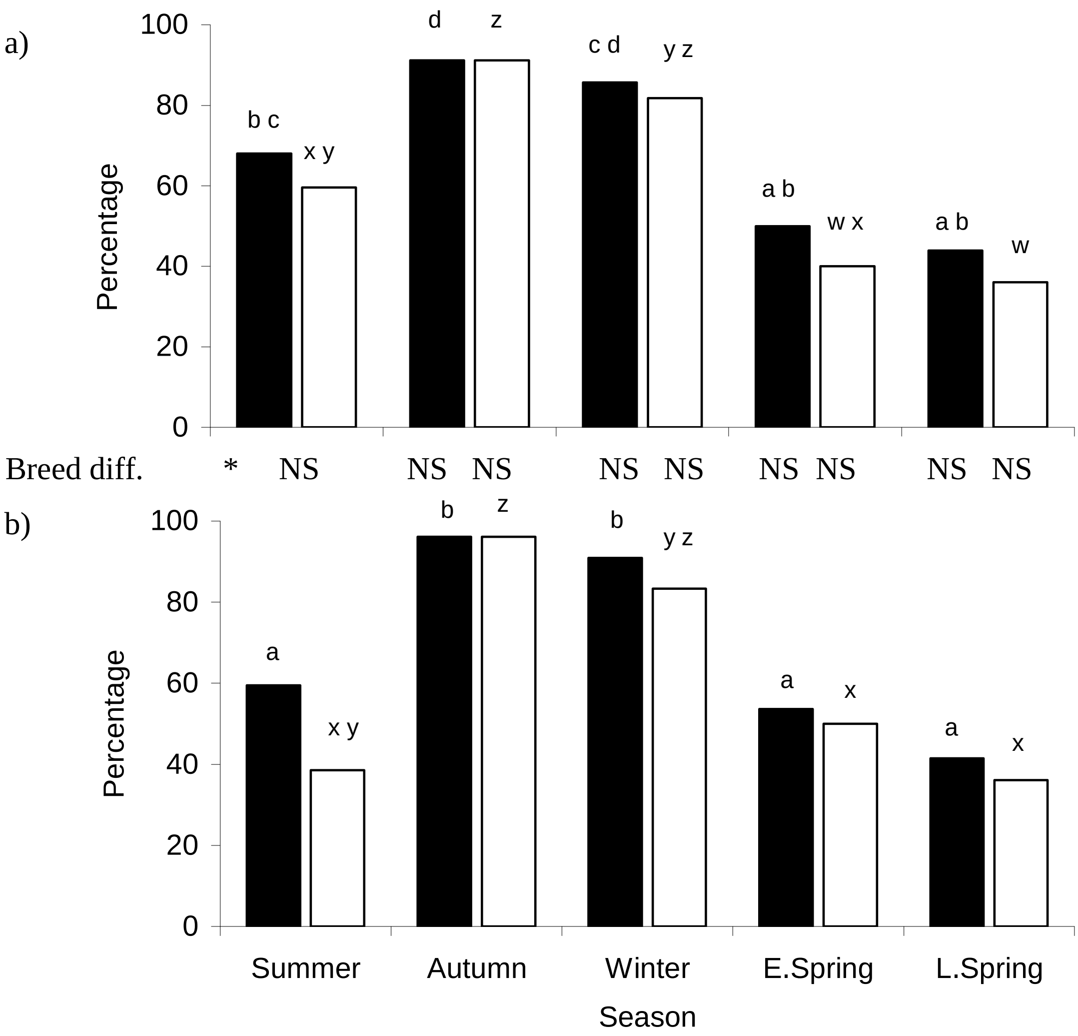

Figure 6.1 Conception rates (ewes pregnant per ewe mated; ■) and pregnancy rates (ewes pregnant per ewe exposed to ram; □) in a) East Friesian Composite and b) Romney type mixed aged ewes bred at different seasons within one year. Different letters indicate significant differences (P<0.05) between season within ewe type and variate (abcd; conception rate, wxyz; pregnancy rate). Breed difference is shown between top and bottom figures (P<0.05).

There was no effect of lactation on pregnancy rates over all seasons and there was no significant breed difference across all seasons. Pregnancy rates in EF ewes were higher in summer (59.6%), autumn (91.2%) and winter (81.8%; P<0.05; Figure 6.1), compared with early and late spring (40.0 and 36.1%, respectively). The highest pregnancy rates in the Romney type were recorded in autumn and winter (96.1 and 83.3%, respectively), with summer (38.6%), early (50.0%) and late spring (36.1%) being significantly lower. The proportion of ewes that were not marked by the ram and that did not have any corpora lutea present at P9 (no oestrus) differed between summer (16.7%) and early spring (4.3%; P<0.05). There were no ewes of either breed in autumn, and no Romney type ewes in early spring in this category. A higher proportion of non-lactating ewes had no oestrus (11.6%) compared with ewes that had just weaned a lamb (5.3%; P<0.05). Over all seasons, the occurrence of no oestrus was lower in EF ewes (5.1%) compared to Romney type ewes (10.3%; P<0.05). When breeds were analysed separately, there were no significant differences between seasons for EF ewes (range 0-7.5%). Romney type ewes differed significantly between summer (29.8%) and late spring (6.6%; P<0.01).

The proportion of ewes classified as non pregnant (i.e. displayed oestrus, had at least on corpus luteum present at laparoscopy but was not pregnant at P62) did not differ significantly within each breed. There was a breed by lactational status interaction where the number of non-pregnant ewes was higher in non-lactating EF (30.9%) compared with non-lactating Romney type ewes (17.4%; P<0.05). The lowest proportion of non pregnant EF ewes was recorded in autumn (8.8%) and winter (13.6%) and was highest in early (32.5%) and late spring (41.0%; P<0.05; Figure 6.2). In autumn and winter, the Romney type had the lowest proportion of non pregnant ewes (3.9 and 4.2%, respectively), and in summer (24.6%), and early (33.3%) and late spring (42.6%; P<0.05) the proportions of non pregnant ewes were highest (P<0.05).

The occurrence of pseudo oestrus did not differ significantly between season overall (range 0 to 8.6%), of within either breed (range EF; 0 to 7.5%, Romney; 0 to

10.0%). Also, the proportion of ewes judged to have had a silent oestrus did not differ statistically between seasons, overall or for either breed type (range 0 to 13.3%).

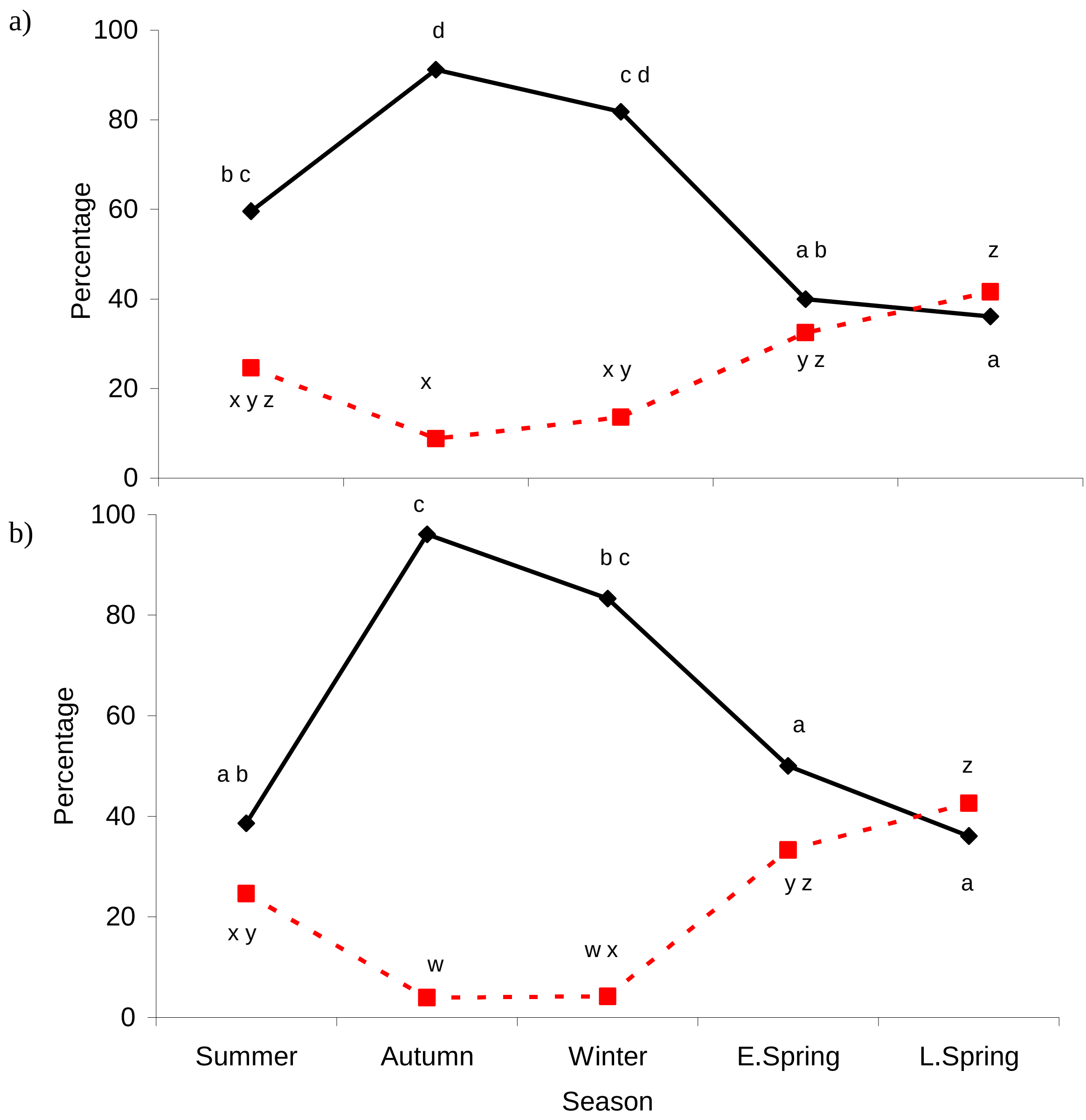

Figure 6.2 The proportion of a) East Friesian Composite and b) Romney type mixed aged ewes with successful (—◆—) or unsuccessful pregnancies (displayed oestrus with corpora lutea present; ---■---) at different seasons within one year. Different letters indicate significant differences within variates (abcd; successful pregnancy, wxyz; pregnancy failure) between season ($P<0.05$). Differences between breeds were not significantly different ($P>0.05$).

There was no significant breed difference in the occurrence of silent oestrus, nor was there any significant difference between lactating and non-lactating ewes. No ewes were classified as having had a silent oestrus in autumn, and there were no statistically significant differences between seasons (range 0-10%). Within each breed there were no significant differences between seasons (range EF; 0-12.5%, Romney 0-6.6%).

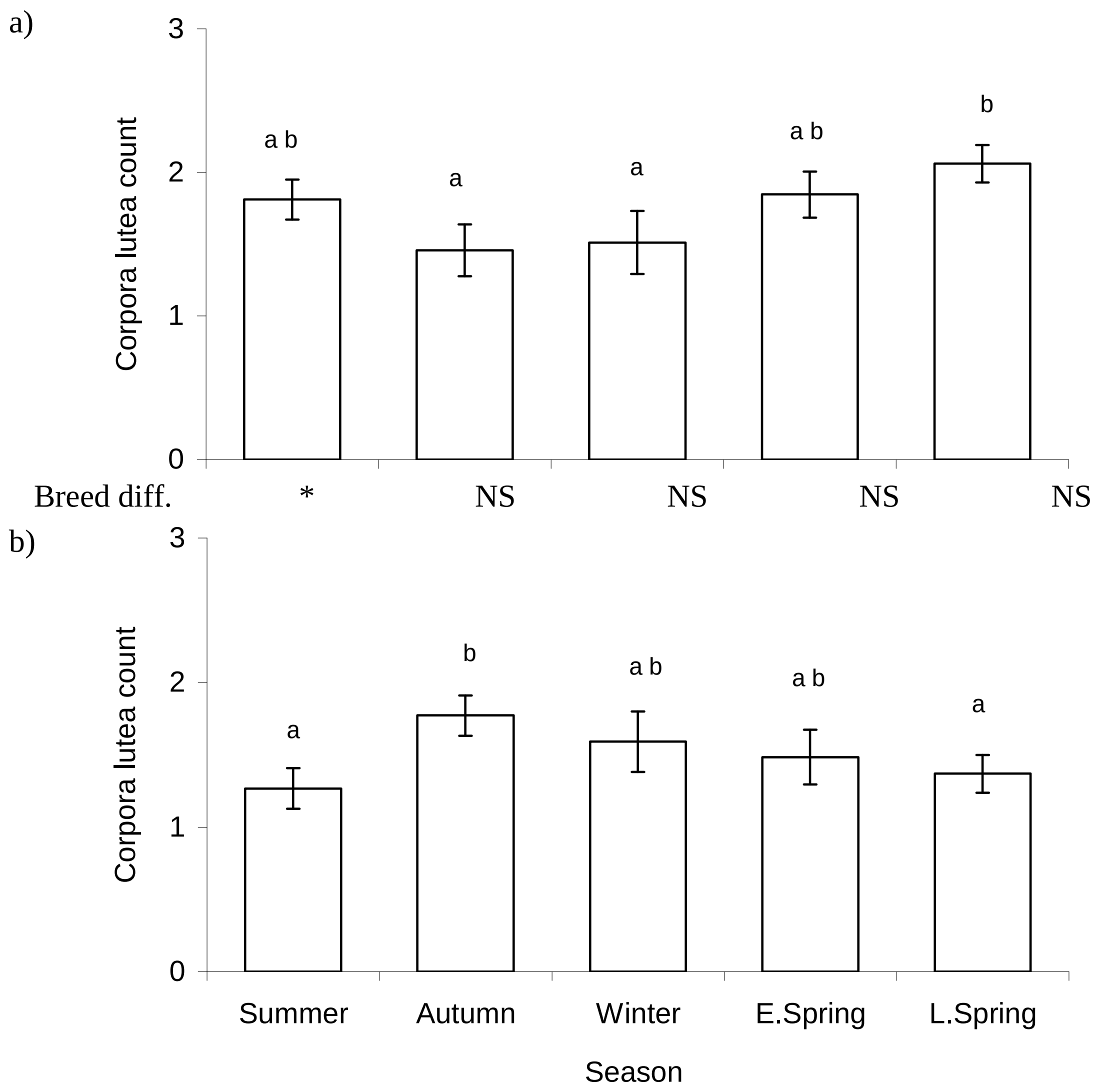

Figure 6.3 Average number of corpora lutea in all ewes exposed to the ram for a) East Friesian Composite and b) Romney type mixed aged ewes at different seasons within one year. Different letters indicate significant differences ($P<0.05$) between season within ewe type. Breed differences are shown between figures ($P<0.05$).

Due to low numbers of mated, non-pregnant ewes with and without corpora lutea in autumn (n=5 and 0, respectively) and winter (n=4 and 1, respectively), the two breed types were analysed together for all months. In autumn, all ewes in this subgroup had at least one corpus luteum at P9. The proportion of mated, non-pregnant ewes with corporal lutea present at other times of the year ranged from 82% in summer to 93% in winter, but these were not statistically different.

The average number of corpora lutea observed at laparoscopy for all EF ewes was lowest in autumn and winter, and highest in late spring ($P<0.05$; Figure 6.4). Romney type ewes had the lowest corpora lutea count in summer, and the highest in autumn and winter ($P<0.05$). East Friesian composite ewes had more corpora lutea in summer compared with Romney type ewes (1.8 vs 1.3; $P<0.01$).

The number of foetuses per ewe scanned was highest in autumn and lowest in late spring for EF ewes (1.5 and 0.5, respectively; $P<0.001$). This variable was also highest in Romney type ewes for autumn and winter (1.7 and 1.5, respectively), and lowest for summer, and early and late spring (0.6, 0.6 and 0.5, respectively; $P<0.05$). In winter, Romney type ewes had more foetuses per ewe scanned than EF ewes (1.5 vs 1.0; $P<0.05$).

Average litter size (number of foetuses per pregnant ewe) was highest for early spring-bred EF ewes (1.8), and was statistically different from winter-bred EF ewes (1.2) but not EF ewes bred in summer, autumn or late spring ($P<0.01$). Within the Romney type ewes, litter size was lowest in early-spring bred ewes (1.3). This was significantly different from litter sizes in autumn- and winter-bred Romney type ewes (1.8 and 1.9, respectively; $P<0.001$). Breed differences were observed in winter where EF ewes had smaller litter size than Romney type ewes (1.2 vs 1.9; $P<0.01$) but in early spring, EF ewes had higher litter size than the Romney type (1.8 vs 1.3; $P<0.05$).

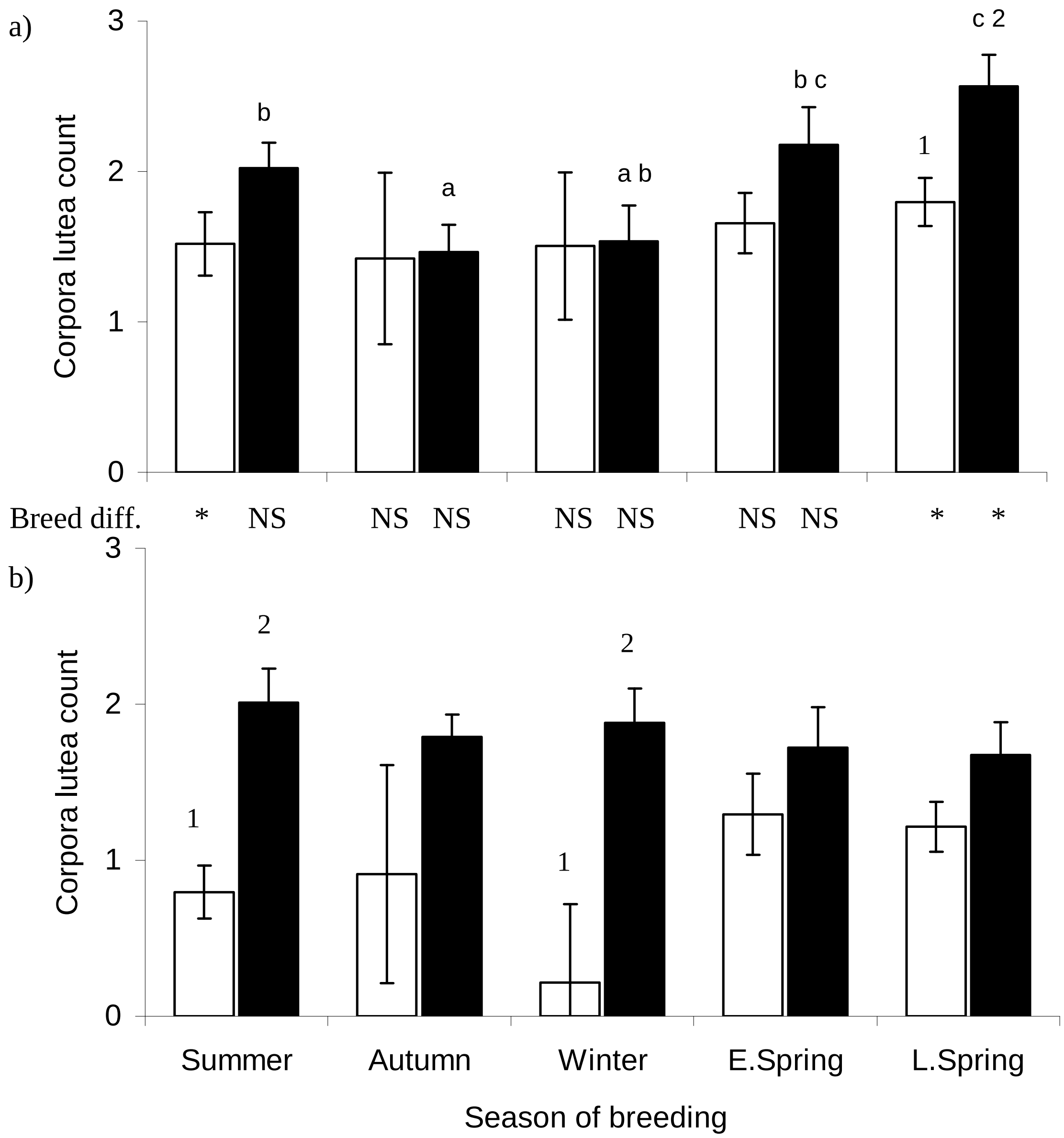

Figure 6.4 Average number of corpora lutea in non pregnant (□) and pregnant (■) a) East Friesian Composite and b) Romney type mixed aged ewes for different seasons within one year. Different letters (abc) indicate significant differences (P<0.05) between season within breed type and within pregnant ewes. Different numbers (1, 2) indicates significant differences (P<0.05) between pregnant and non pregnant ewes within breed type and month of breeding. Bars without numbers or letters are not statistically different. Breed differences are shown between figures (P<0.05).

6.4 Discussion

The use of laparoscopic examination of the ovaries of ewes bred at different stages of the annual breeding cycle has made it possible to determine the extent to which failure to induce ovulation (i.e. inasmuch as animals lack corpora lutea) has limited pregnancy rates during the non-breeding season. Moreover, it has allowed differentiation between animals that displayed oestrus, but did not ovulate and those which both ovulated and displayed oestrus but subsequently failed to conceive.

Although there have been several previous investigations of the responses of ewes to out-of-season breeding regimes, few are directly comparable with the present study. The finding of the present study that pregnancy and conception rates were lower in ewes that were stimulated to breed in early and late spring (32-60%) than in the autumn and winter (96-98%) were commensurate with (Knight et al., 1989b; Ungerfeld and Rubianes, 1999b; 2002), or higher than (Fukui et al., 1985; Smith et al., 1988a) other studies in which similar stimulation regimens (i.e. progesterone and eCG) were used. These, and other studies (e.g. Robinson et al., 1975; Wheaton et al., 1992) have also shown that pregnancy rates out-of-season are lower than in the breeding season.

Without the administration of exogenous hormones, it is difficult to induce ewes to ovulate during the summer (Hall and Killeen, 1989). The present trial has shown that ewes can respond to reproductive stimulation regimes in one of four main ways. Firstly, they may ovulate and conceive; albeit at a lower rate than in the breeding season (Robinson et al., 1975; Wheaton et al., 1992). Secondly, they may ovulate but fail to display oestrus. Thirdly, they may display oestrus, inasmuch as they permit, mating, but do not ovulate and form a corpus luteum. There were relatively few ewes in that category, but, the fourth category, namely ewes that displayed oestrus, ovulated, but failed conceive, accounted for most of the animals that failed to become pregnant. Conversely, the lower pregnancy rates in the non-breeding season could not be attributed to the proportion of ewes that had pseudo oestrus or silent oestrus, as these did not vary throughout the year.

Low pregnancy rates in the non-breeding season were therefore not generally due to low proportions of ewes displaying oestrus after the synchronisation/stimulation regimen, with oestrus rates recorded in the current trial being similar to those from other trials (Fukui et al., 1985; Smith et al., 1988a; Knight et al., 1989b).

It was not expected that most of the ewes that failed to conceive after stimulation to breed in the non-breeding season would have active ovaries (i.e. corpora lutea present on Day P9), although Smith et al. (1988a) did show a pattern at a single time point in the summer that was not dissimilar to the result of the present study. For the EF breed, even in summer, virtually all ewes had corpora lutea present, regardless of whether they conceived. Indeed, the only circumstance in the present experiment in which corpora lutea were not present in a high proportion of ewes was in the Romney type in summer. Nonetheless, even in ewes that were marked by the ram (i.e. displayed oestrus), successful pregnancies were still poor out of season (38-68%).

Two of the main factors that might have contributed to such a pattern of conception rates are ovulation rate and the normality of subsequent luteal activity. The evidence of the present study was that ovulation rate was not adversely affected by the treatment regimens, since number of corpora lutea were not significantly different across the year in ewes that conceived. Furthermore in EF ewes, there was little difference in the number of corporal lutea present between pregnant and non-pregnant animals. This may not have been the case in the Romney ewes, since there were low numbers of corpora lutea in ewes that failed to conceive in winter. Hence, in ewes that successfully conceived, the litter size varied little throughout the year (~1.5 lambs per pregnant ewe in both breeds), again suggesting that ovulation was not the limiting factor to ewes' ability to conceive.

There are other possible reasons for reduced out of season reproductive performance. There is good evidence for abnormal corpora lutea function after out-of-season induction regimens (Hunter et al., 1986; White et al., 1987; Southee et al., 1988), although the impact that this has on conception patterns at a flock level has not been studied. Similarly, there is evidence for changes in cervical mucous (Smith and Allison, 1971; Rexroad and Barb, 1977), reduced sperm numbers and viability (Hawk and Conley, 1972), negative effects on cleavage divisions (Quinlivan, 1970), and fertilisation of aged ovum, all of which could result in conception failure or early embryonic mortality (Hunter et al., 1998; Wortzman and Evans, 2005).

On the other hand, it was notable that, in summer, a relatively large proportion of Romney ewes did not display oestrus. It may simply be a case that during the early spring, late spring and summer, ewes were in deep anoestrus whereby reproductive performance is reduced, even with the use of progesterone and eCG.

Oussaid et al. (1993) described two types of anoestrus; slight anoestrus, occurring at the beginning of the anoestrus period, characterised by the presence of normal follicles; and deep anoestrus, occurring 80 days into the anoestrous period and characterised by a marked reduction in the number of antral follicles present. Ovulation during slight anoestrus could be induced by injections of luteinising hormone (LH) alone, whereas ovulation during deep anoestrus required the administration of LH and follicle stimulating hormone.

Romney ewes, having a relatively deep anoestrus, probably require a greater degree of stimulation to induce oestrus than do the more aseasonal EF; so, perhaps this is merely a reflection of a requirement for different doses of eCG needed at this time of year in the two breeds. Reduced reproductive performance has previously been reported during spring and summer with a variety of hormonal regimes (Smith et al., 1988a; Knight et al., 1989b; Ungerfeld and Rubianes, 2002; Knights et al., 2003), and indeed was the case in the current trial. There is some other evidence to support this notion: Faure et al. (1983) reported that low doses of eCG (0, 60 or 150 IU) have been reported to be less effective than higher doses at stimulating oestrus in ewes during the non-breeding season (Faure et al., 1983), whilst in another study (Smith et al., 1988a), synchronised ewes not receiving eCG had lower oestrus rates than ewes that had received eCG (400 or 800 IU).

In terms of the objective of this study to determine if reduced ovarian activity is responsible for low pregnancy rates achieved with out-of-season breeding of Romney and East Friesian Composite ewes, it was evident that the pregnancy rates obtained in the current study were low in the non-breeding season. Nonetheless, such poor pregnancy rates could not be explained with reference ovulation failure, as a majority of ewes had at least one corpus luteum present on their ovaries at nine days after the start of the synchronised mating period. The predominant change between the seasonal and non-seasonal breeding periods is in the proportion of ewes that failed to conceive after an ovulation that, at least in terms of gross observation of the corpora lutea, appeared to have been normal.

6.5 Conclusion

Out-of-season reproduction is an important component of a profitable accelerated lamb production system. Therefore the increase in the proportion of non pregnant ewes appears to be a hindrance in the adoption of accelerated or out-of-season lamb production system. This may be purely due to the ewes being in deep anoestrus in early spring, late spring and summer. Although the EF ewes tended to have better reproductive performance in summer compared to the Romney ewes, conception rates remained only moderate (68%). It was concluded that seasonal differences in the ability of ewes to conceive are not the consequence of failure to display oestrus or to ovulate, but probably are a result of failure of fertilisation or the establishment of pregnancy.

The next step in this doctoral research programme was to attempt to identify a specific time point at which pregnancy was failing. In the next chapter, serum progesterone concentrations during early pregnancy were monitored in sheep bred during the normal breeding season and at a breeding period outside the normal season. This experiment was conducted in an effort elucidate one particular stage at which conception, implantation or retention the embryo/foetus was failing.

Serum progesterone concentrations during early pregnancy in spring- and autumn-bred ewes

G. deNicolo
T.J. Parkinson
S.T. Morris
P.R. Kenyon
P.C.H. Morel

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Chapter 7 Serum progesterone concentrations during early pregnancy in spring- and autumn-bred ewes

Abstract

Blood samples were collected from ewes from Day 8-39 post tupping in spring- and autumn-bred ewes. Serum progesterone concentrations were analysed in an attempt to ascertain whether ewes were ovulating and failing to maintain pregnancy, conception was failing. Following pregnancy diagnosis 62 days after ram introduction, ewes were categorised; no display of oestrus, mated but non-pregnant, or pregnant. Progesterone profiles showed typical characteristics for their respective season of breeding. A majority of spring-bred ewes that failed to display oestrus had silent ovulations (86%) and 66% of those ewes had abnormally short-lived corpora lutea. Circulating progesterone concentrations during dioestrus in animals that had ovulated and displayed oestrus were unaffected by season. Similarly, progesterone concentrations did not differ between pregnant and mated, non pregnant ewes. The results indicated that while early luteylosis, low progesterone secretion from corpora lutea and embryo mortality did occur, these were in only a small proportion of the ewes. Further, adequately elevated progesterone concentrations indicated that a majority of mated non-pregnant ewes were capable of successfully producing a viable embryo/foetus. These results indicate a failure of maternal recognition of pregnancy, and it is recommended that events surrounding this stage of pregnancy be examined more closely in relation to the non-breeding season.

7.1 Introduction

Research over the last sixty years has failed to increase pregnancy rates in out-of-season breeding programmes to the levels observed in the normal breeding season (Yeates, 1949; Andrewes et al., 1987; Smith et al., 1988a; Knights et al., 2003; Ungerfeld et al., 2003; Morris et al., 2004). While exogenous hormones have increased pregnancy rates compared to breeding out of season without hormones, results have been poor and variable (Dawe et al., 1969; Carpenter and Spitzer, 1981; Smith et al., 1988a; Knight et al., 1989b; Knights et al., 2003).

Morris et al. (2004) bred ewes out-of-season (January, August, and November) in New Zealand but achieved poor pregnancy rates (36-55%) even with the use of progesterone primed controlled internal drug releasers (CIDRs) and equine chorionic gonadotrophin (eCG). Conversely, March and June breeding (normal breeding season in New Zealand; 40^{o} south, 175^{o} east) have resulted in comparatively higher pregnancy rates (78-94%). Interestingly, a high proportion of ewes that underwent hormonal stimulation out of season displayed oestrus and were mated (72-89%), but were diagnosed as non-pregnant.

DeNicolo et al. (2008; Chapter 6) examined the ovaries of ewes which underwent oestrus induction and synchronisation. In August, November and January at least 80% of treated ewes had active ovaries, as indicated by the presence of corpora lutea. Despite this, only 31-61% of those ewes were identified as being pregnant. It is not known whether these ewes failed to conceive, implantation failed, or implantation was followed by embryonic/foetal loss.

In the pregnant ewe, blood progesterone concentrations remain elevated until parturition and can therefore be used as an identifier of pregnancy status (Susmel and Piasentier, 1992; Boscos et al., 2003; Ehrentreich-Forster et al., 2003). In the non-pregnant ewe, luteolysis occurs on Days 12-14, with progesterone concentrations becoming basal approximately one day later. Most embryonic losses occur prior to implantation (which starts on Day 22-24 of gestation (Pineda, 2003)) and most other pregnancy losses occur relatively early in gestation (fertilisation to Day 30 (Edey, 1969; Wilmut et al., 1986; Zheng et al., 1998; Pineda, 2003)). As progesterone concentrations rapidly decline after the loss of the embryo, measurement of progesterone concentrations ecan be used to determine when losses occur. Since abnormal corpora lutea either secrete low progesterone concentrations, or normal values for a shortened period, blood progesterone concentrations can also be used to examine luteal function (Hunter, 1991; Lassoued et al., 1997).

The objective of this experiment was to measure blood progesterone concentrations during early gestation to determine if the apparent reproductive failure in ewes bred out of season is due to a failure to conceive or embryonic loss.

7.2 Materials and methods

The experiment was undertaken, under commercial pastoral sheep-farming conditions, at Massey University, Palmerston North, New Zealand (40^{o} south, 175^{o} east), and included a group of ewes bred during the non-breeding season (spring, August, n=103) and a group bred during the normal breeding season (autumn, March, n=130). In New Zealand, summer and winter solstices occur on 21st December and 21st June, respectively.

Spring and autumn-bred ewes were synchronised using intravaginal progesterone-releasing devices (CIDRs; 0.3 g progesterone; Pharmacia & Upjohn, Auckland, New Zealand) beginning 11 days prior to the introduction of rams. On the day of ram introduction CIDRs were removed. Ewes that were to be bred in spring (August), had 800 IU of eCG (Folligon, Intervet Ltd, Auckland, New Zealand) administered by intramuscular injection. No eCG was used for ewes that were to be bred in March (mid-Autumn). Two breeds of ewes – East Friesian Composite (EF; ½ East Friesian, ¼

Polled Dorset, ¼ Texel) and Romney - were managed as separate groups during the breeding period, but not during synchronisation. Five entire rams of each breed, fitted with crayon mating harnesses were joined with the two groups of ewes. Oestrus was determined by the presence of crayon marks on the ewes' rumps. These crayon marks were recorded daily for three days beginning on the day following ram introduction. The first day on which a crayon mark was recorded was defined as Day 0.

On Days 8, 10, 12, 14, 16, 18, 20, 22, 24, 29, 34 and 39 approximately 8 mls of blood was collected by jugular venupuncture into evacuated glass tubes containing lithium heparin anticoagulant (lithium heparin anticoagulant: vacutainers; Becton Dickinson, Preanalytical Systems, Franklin Lake, USA) from subsamples of ewes of each breed in autumn and spring (see below; n=90). Ewes that did not display oestrus within 3 days of ram introduction had a blood sample collected, beginning 11 days after ram introduction.

Blood samples were immediately placed on ice until centrifuged at 1000 g for 10 minutes to separate plasma. Plasma was then collected and stored at -20^{o}C until analysis. Plasma progesterone concentrations were measured in duplicate by enzyme-linked immunosorbant assay (ELISA; validated by Sauer et al. (1986) and Groves et al. (1990); Ridgeway Science, UK). Using duplicate 10 μl aliquots, the assay sensitivity was 0.5 ng/ml, with inter- and intra-assay coefficients of variation of 16.0% and 5.9% , respectively.

Ewe live weight was recorded on the first day of the synchronised breeding period and on the day of pregnancy diagnosis. Two months after ram introduction, pregnancy status was determined by transabdominal ultrasonography using a 3.5 MHz sector transducer applied over the caudodorsal flank fold. Ewes were classified into one of three categories based on the presence of crayon mating marks (indicating oestrus) and pregnancy status:

1. No oestrus (ewes that did not display oestrus),
2. Mated non-pregnant (ewes that displayed oestrus and were identified as non-pregnant),
3. Pregnant.

For both spring- and autumn-bred ewes, progesterone concentrations were measured in samples collected from all ewes not displaying oestrus, all mated non-pregnant ewes and ten pregnant ewes.

Plasma progesterone concentrations were subjected to analysis of variance, using a general linear model in SAS (V8, SAS Institute Inc, Cary, NC, 2001). Ewe category (no oestrus, mated non-pregnant, pregnant), season (autumn vs spring) were fitted as fixed effects within time after oestrus (day), and a ewe group by month interaction was fitted. Breed was tested in the model but was not significant, so was removed from the statistical model. The effects of live weight recorded at CIDR removal was initially added as a covariate, but, as it was not significant in the model (P>0.05), it was deleted.

7.3 Results

There were no differences in the proportion of ewes that did not display oestrus between the autumn- and spring-bred ewes (Table 7.1). The proportion of ewes that displayed oestrus and were non-pregnant, and the proportion of ewes that were pregnant were different between the autumn- and spring -bred ewes such that there were less mated non-pregnant and more pregnant ewes in the autumn breeding period (P<0.001).

A total of five spring-mated ewes had elevated progesterone concentrations beyond Day 16, but were then diagnosed non-pregnant. It was assumed that these ewes had experienced embryonic loss. A further five ewes failed to display elevated progesterone concentrations (<1.0 ng/ml), or had a short luteal phase (i.e. premature drop in progesterone concentrations) following oestrus induction. In the spring-bred ewes that did not display oestrus, nine had a complete data set. Six of these ewes were considered to have abnormal corpora lutea based on low progesterone concentrations between Days 8 and 14, two were thought to have premature luteolysis and only one had a normal progesterone profile (Figure 7.1). In the autumn-bred ewes, two failed to display elevated progesterone concentrations and two had short luteal phases. One ewe had no increase in progesterone concentration until Day 29. Progesterone profiles for the autumn-bred ewes that did not display oestrus indicate that six had short luteal phases, but as the ewes did not have crayon mating marks, it can not be stated conclusively that these ewes ovulated at the same time as those ewes with crayon mating marks. There were no individual ewes in the autumn-bred group that had low progesterone concentrations and failed to display oestrus.

Table 7.1 Numbers of ewes and proportions that did not display oestrus (no oestrus), displayed oestrus but were non-pregnant (mated non-pregnant) and were pregnant (pregnant) for March and August breeding periods. Numbers of animals from which samples for progesterone assay were collected are shown in parenthesis. Proportions are presented in least squares means with values back transformed into percentages presented in parentheses.

	March		August		Difference
	n	Proportion	n	Proportion	
No oestrus	9 (7)	-2.65 ± 0.37 (6.6%)	11 (10)	-2.20 ± 0.36 (9.9%)	NS
Mated non-pregnant	29 (11)	-1.36 ± 0.23 (20.5%)	42 (40)	-0.35 ± 0.20 (41.4%)	0.001
Pregnant	92 (11)	0.98 ± 0.21 (72.7%)	50 (11)	-0.15 ± 0.21 (46.4%)	0.0001

During the first oestrus cycle (i.e. Day 8-12), there were no differences in mean progesterone concentrations between pregnant and mated, non-pregnant ewes in either the March or August breeding periods (Figure 7.2).

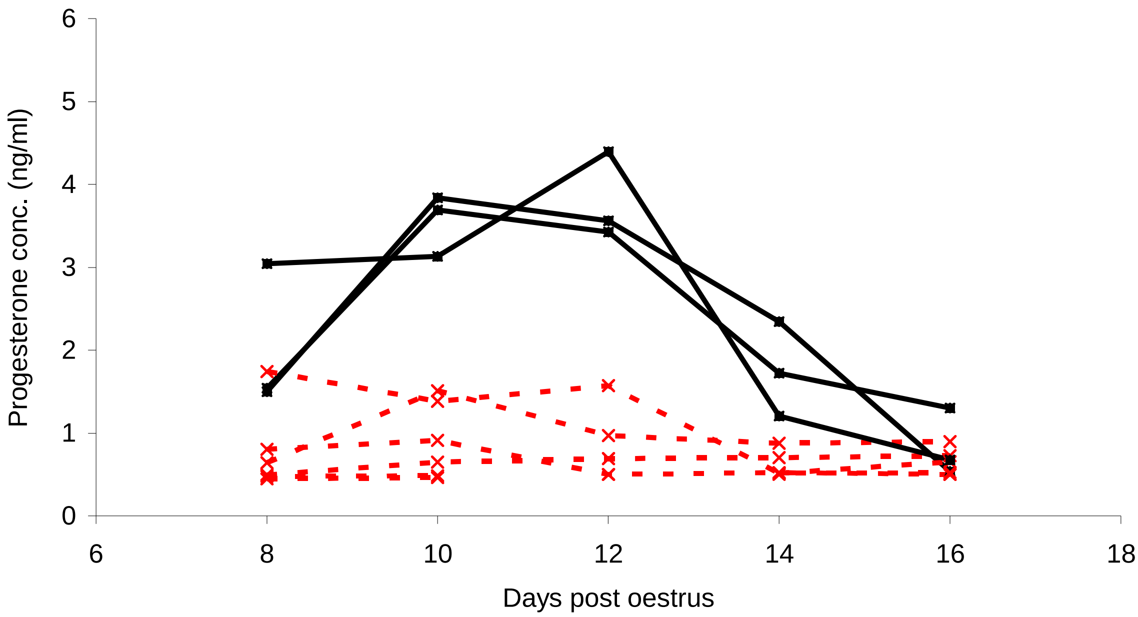

Figure 7.1 Progesterone concentrations (ng/ml) for individual ewes that did not display oestrus after progesterone + eCG treatment in spring (August) with normal (solid line; n=3) or abnormal (dashed line; n=6) corpora lutea.

In the autumn-bred ewes that did not display oestrus, mean progesterone concentrations were elevated until Day 14 and again on Day 20 (Figure 7.3). In the spring-bred ewes, progesterone concentrations fell on Day 14, reached basal concentration on Day 16 and did not rise again during the experimental period. During the follicular phase (Days 16-18), progesterone concentrations were basal in spring-bred ewes that failed to display oestrus and in mated ewes that were identified as non-pregnant.

Mean plasma progesterone concentrations declined ($P<0.001$) between Days 14 and 16 post-oestrus (indicating the onset of luteolysis; Figure 7.3) in ewes bred in autumn or spring that were mated but then identified non-pregnant. For spring-bred ewes, progesterone concentrations remained at basal values for the remainder of the experimental period. In non-pregnant ewes in the autumn-bred group, progesterone concentrations were elevated again on Day 20 following the first display of oestrus. Following the first luteal phase, progesterone concentrations in the mated non-pregnant autumn-bred ewes, were lower (P<0.01) than in pregnant ewes until the peak of the second luteal phase (Day 29; P<0.05; Figure 7.3).

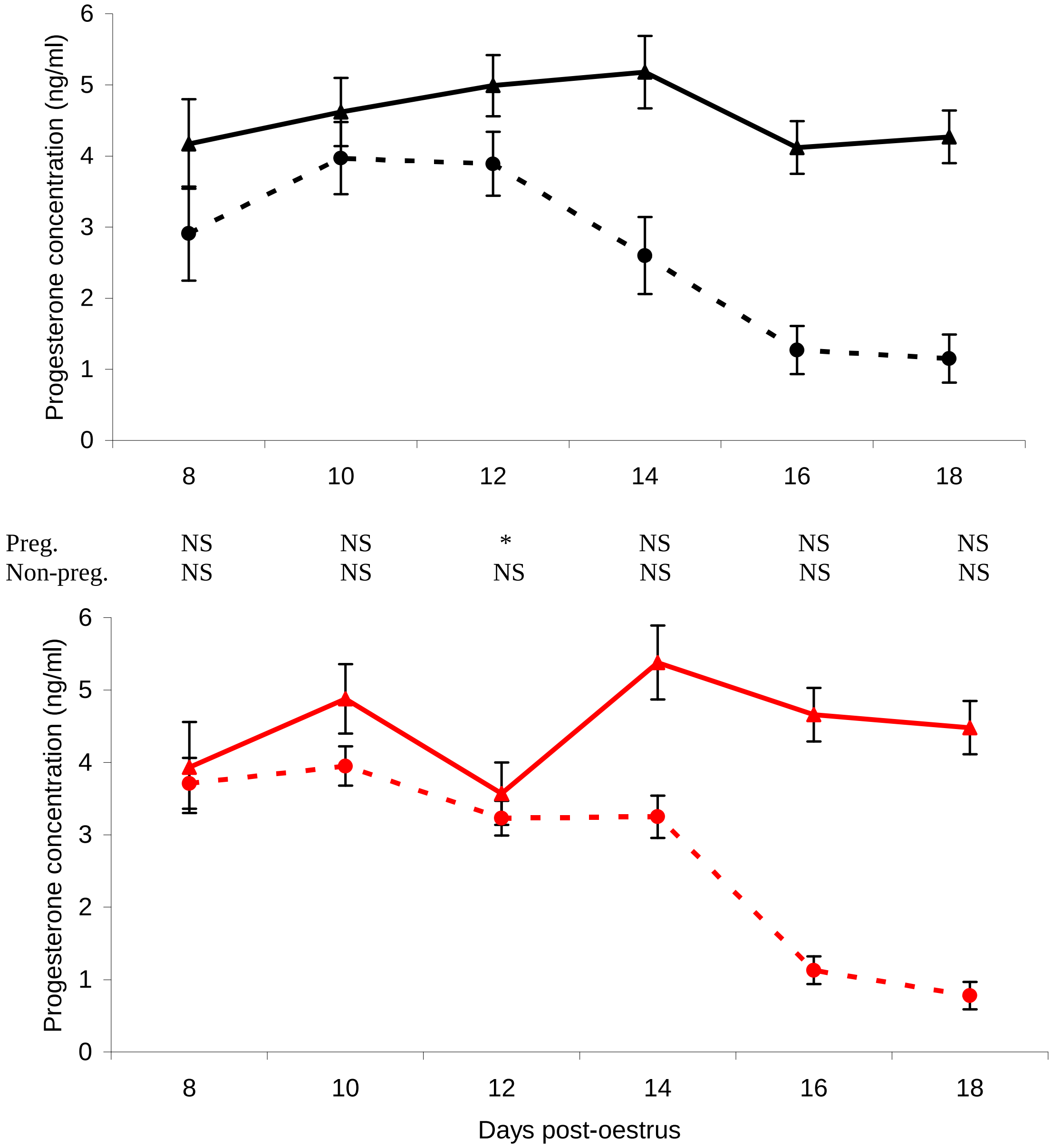

Figure 7.2 Mean progesterone concentrations (ng/ml) for March- (top) and August-bred (bottom) pregnant (solid line) and non-pregnant (dashed line) mixed aged ewes from Day 8 to 18 post-oestrus. Differences between March- and August-mated ewes are displayed between graphs for pregnant ewes (Preg.), and mated non-pregnant ewes (Non-preg).

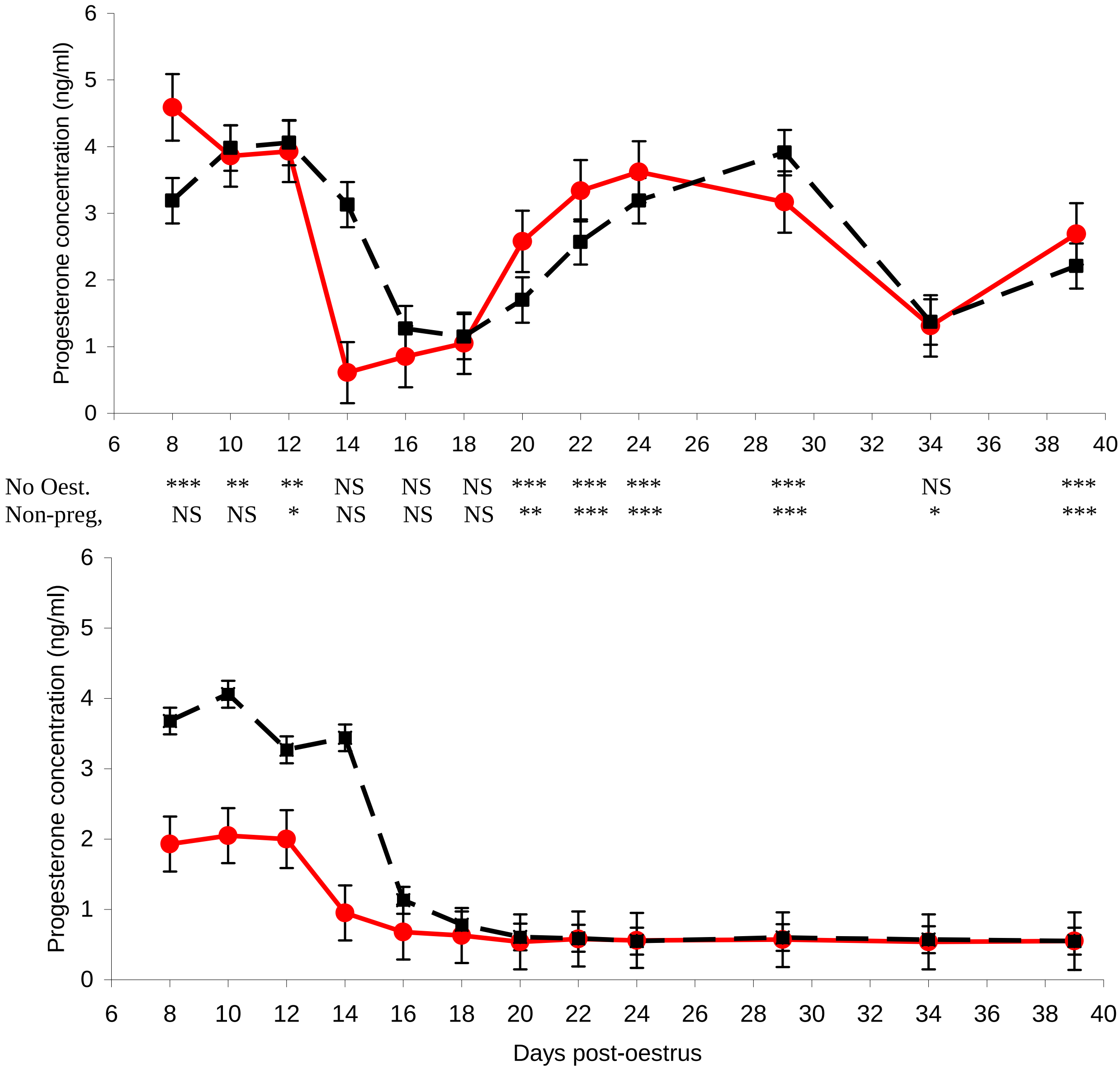

Figure 7.3 Mean progesterone concentrations (ng/ml) for March- (top) and August-bred (bottom) mixed aged ewes from Day 8 to 39 days post-oestrus. Ewes that did not display oestrus (solid line) were first sampled three days following ram introduction. Ewes that displayed oestrus and were identified as non-pregnant (dashed line) were first sampled 6 days post-oestrus display. Differences between March- and August-mated ewes are displayed between graphs for ‘no oestrus’ ewes (No Oest.), and mated non-pregnant ewes (Non-preg).

Mean plasma progesterone concentrations on Days 8, 10 and 12 (the first luteal phase) in spring-bred ewes that failed to display oestrus were lower ($P<0.001$) than in the equivalent autumn-bred ewes, and in spring-bred ewes that were mated but identified as non pregnant ($P<0.05$). Progesterone concentrations in ewes that were mated non-pregnant ewes were similar amongst autumn- and spring-bred ewes, except on Day 12 (lower in spring: $P<0.05$)

Seasonal differences in mean plasma progesterone concentrations of pregnant ewes were present on Days 12 ($P<0.05$), 20 ($P<0.001$) and 39 ($P<0.01$; Figure 7.2). On Days 12 and 20, autumn-bred pregnant ewes had higher progesterone concentrations than spring-bred ewes, but on Day 39, spring-bred ewes had higher progesterone concentrations than autumn-bred ewes. In the mated, non-pregnant ewes there were no seasonal differences until after Day 20 when the progesterone concentrations in the autumn-bred ewes began to rise.

7.4 Discussion

The objective of the current experiment was to determine the extent to which failure of ovulation or subsequent luteal function affected the reproductive outcomes of ewes that were bred in the normal breeding season (autumn; March) or out-of-season (spring; August). Analysis of progesterone profiles allows assessment of whether (a) ovulation occurred, (b) embryonic death occurred after maternal recognition of pregnancy and (c) premature luteolysis occurred. It also indicates luteal function, to the extent that circulating concentrations are a reflection of luteal secretion. Similarly, the presence of abnormal corpora lutea can be detected via peripheral progesterone concentrations. Although pregnancy failure can occur due to process involving the ram (such as low fertility and semen quality), the context of this discussion is kept with the ewe in focus.

Progesterone concentrations in autumn-mated, non-pregnant ewes displayed profiles typical of normal oestrous cycles (Cunningham et al., 1975; Karsch et al., 1980b; Pineda, 2003). Spring-mated, non-pregnant ewes showed progesterone patterns that were characteristic of ewes synchronised to breed during the non-breeding season, inasmuch as they did not return to oestrus or display regular oestrous cycles after the initial ovulation (Walton et al., 1977). Thus, ewes that were synchronised in autumn (breeding season) continued to have recurrent oestrous cycles (if they were non-pregnant), whereas those that were induced in spring (non-breeding season) all had a single post-induction oestrous cycle.

However, mean progesterone concentrations on Days 8-12 of the induced cycle were similar in ewes that did or did not conceive, regardless of whether they were bred in spring or autumn. In other words, circulating progesterone concentrations during dioestrus (the luteal phase; Days 8-12) in animals that had ovulated and displayed oestrus were unaffected by season. This finding is at variance with some reports in the literature, in which lower progesterone concentrations have been observed during the non-breeding season compared to the breeding season (Rhind et al., 1978; Forcada et al., 2003; Coelho et al., 2006). It is possible that the discrepancy from these studies can be explained by the separation in the present experiment of progesterone profiles of animals that failed to display oestrus from those which were mated but failed to conceive.

A number of previous studies have suggested that progesterone concentrations in metoestrus (Days 1-5) or dioestrus (Days 8 to 12) affect pregnancy outcomes in sheep (Brien et al., 1981; Lawson and Cahill, 1983; Ashworth et al., 1989). In the present study, however, there were no differences in progesterone concentrations during dioestrus before the onset of luteolysis in mated, non-pregnant animals compared with pregnant animals. Hence, pregnancy failure cannot be explained with reference to mean progesterone concentrations during dioestrus within each category of ewes. Some of the causes of pregnancy failure can, however, be explained with reference to individual animals' progesterone profiles. Nevertheless, progesterone concentrations during metoestrus should be further examined in out-of-season bred ewes.

It appears that ovulation had occurred in the majority (6/7: 86%) of autumn-bred ewes that did not display oestrus, and in a third of the spring-bred ewes that failed to display oestrus. DeNicolo et al. (2008; Chapter 6) found that, in both the breeding and non-breeding seasons, similar proportions of ewes (5-13%) had active ovaries but failed to display oestrus. Smith et al. (1988b) and Ungerfeld et al. (2005) reported a somewhat higher occurrence of ovulation without oestrus during the non-breeding season (38% and 36%, respectively), than deNicolo et al. (2008; Chapter 6).

High progesterone concentrations over the luteal phase of the oestrous cycle prior to the mating cycle have been reported to result in a higher conception rates (Folman et al., 1973). In the current experiment, the ewes that were bred in spring had exposure to progesterone from CIDRs only. Although progesterone concentrations in ewes administered CIDRs has not been investigated, the resulting progesterone concentrations from exposure to the CIDRs may not be high enough and it may also decline towards the end of that priming period, thus giving an inadequate elevation in circulating progesterone. This may also therefore have been a contributing factor to their poor out-of-season reproductive performance. If so, this may account for some of the failed conceptions in ewes that were induced to breed in August, since there is a need for previous exposure to adequate progesterone concentrations for subsequent normal luteal development (Legan et al., 1991; Beard and Hunter, 1994).

The occurrence of abnormal luteal activity has previously been reported during the breeding (Oldham and Lindsay, 1980; White et al., 1987) and non-breeding seasons (Walton et al., 1977; Atkinson, 1988) and as a result of induced ovulation (O'Shea et al., 1984; Southee et al., 1988). Most evidence shows that such short-lived corpora lutea undergo premature luteolysis, which can occur as early as Day 4 post-ovulation (Southee et al., 1988; Beard and Hunter, 1994; Lassoued et al., 1997; Mann and Lamming, 2000). In the present experiment, individual progesterone profiles of spring-bred ewes that did not display oestrus, indicated that a high proportion (6/9: 66%) of these had short-lived (i.e. abnormal) corpora lutea. Similarly, a number of spring-bred ewes that were mated but did not conceive appeared to have undergone luteolysis on Days 12-14 post oestrus. This also suggests that the premature luteolysis, which is characteristic of the abnormal corpus luteum, may have limited the fertility of spring-bred ewes.

7.5 Conclusion

In conclusion, serum progesterone concentrations indicated that low aseasonal reproductive performance recorded in the current experiment was not due to a large proportion of ewes (a) failing to ovulate, (b) undergoing premature luteolysis or (c) losing embryos/feotuses between Days 12 to 39. Further, there were no differences in corpora lutea function in mated ewes regardless of whether or not they conceived. However, if ewes failed to conceive, they were more likely to have had premature luteolysis and a majority of August-bred ewes that failed to display oestrus appeared to have abnormally low progesterone-secreting corpora lutea. Further research regarding the events surrounding maternal recognition of pregnancy (Days 12-14) and conception (Days 6-8) may shed light on the cause of pregnancy failure in sheep mated during the non-breeding season.

Out-of-season breeding of sheep using artificially induced long days

G. deNicolo
S.T. Morris
P.R. Kenyon
P.C.H. Morel
T.J. Parkinson

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Chapter 8 Out-of-season breeding of sheep using artificially induced long days

Abstract

This experiment investigated the effects of subjecting Romney ewes to artificially induced long days (24 L: 0 D) in spring for 30 days, then abruptly applying eight hours of darkness (16 L: 8 D) to induce the onset of reproductive activity. The treatment groups were: Progesterone + eCG (control), light + progesterone and light + progesterone + eCG (Control). Blood samples were collected over a 24 h period for analysis of serum melatonin concentrations. Ewes' ovaries were examined laparoscopically nine days after progesterone removal. Duration of secretion and maximal concentrations of melatonin were lower in ewes treated with light + progesterone (+/- eCG) compared to the control ewes. Fewer light + progesterone treated ewes displayed oestrus (66%) and were subsequently identified as being pregnant (28%) compared control ewes (97% and 65%, respectively) and ewes treated with light + progesterone + eCG (98% and 53%). Conception rates were higher in control ewes (67%) and light + progesterone + eCG (55%) compared to light + progesterone treated ewes (43%). Results obtained indicate that artificially induced long days did not improve the results of out-of-season breeding program beyond that achieved with the use of eCG.

8.1 Introduction

Reproductive seasonality is a widespread phenomenon that serves to ensure the greatest possible survival of offspring. A seasonal breeding pattern is particularly appropriate to many species of herbivores, for which seasonal changes in growth of herbage and the consequent shifts in nutrient supply are crucial determinants of the ability of their young to survive. Domestication has, however, the potential to render seasonality unnecessary, since agriculture provides the ability to control nutrient supplies. Where this is so, seasonality is an irksome inconvenience and, especially in the case of sheep and goats, a great deal of effort has gone in to developing ways of circumventing it.

Because the control of seasonality is based upon an endogenous rhythm, altering breeding seasons is difficult. Other than through thyroidectomy, it is not possible to extend the duration of the breeding season in sheep (Parkinson and Follett, 1994) without the use of exogenous hormonal administration. Moreover, attempts to alter its onset through manipulating the photoperiod are hampered by the phenomenon of photorefractoriness, which is itself a consequence of the endogenous rhythm of reproductive activity (Follett, 1982; Robinson et al., 1985b; Karsch et al., 1986; Nicholls et al., 1988; Nicholls et al., 1989; Khalid and Jackson, 1991).

Despite these difficulties, out-of-season breeding (i.e. altering the time of onset of the period of reproductive activity) has been achieved by manipulating daylength (Yeates, 1949; Ducker and Bowman, 1972; Legan and Karsch, 1980; Vesely and Swierstra, 1985; Williams and Ward, 1988; O'Callaghan et al., 1991), although reproductive outcomes to such regimes are seldom as good as in the natural breeding season. Abrupt increases in day length, followed by abrupt decreases have been reported to induce ewes to display oestrus (Ducker and Bowman, 1972; Ducker and Boyd, 1974; Legan and Karsch, 1980). This eliminates the need for light-proofed buildings to induce short day conditions and allows for sheep to be grazed outside during the day.

Whilst use of artificial short daylengths to stimulate out-of-season breeding in ewes in the Southern Hemisphere has been reported (Yeates, 1956; Evans and Robinson, 1980; Poulton and Robinson, 1987), the literature appears to be silent on the use of artificial long days followed by a return to ambient photoperiods. In sheep-rearing systems of New Zealand, provision of light-proof buildings during the summer is not feasible, but provision of additional light (i.e. to artificially increase daylength) could be warranted by the value of out-of-season lambs. The experiment reported in this chapter examines the hypothesis that exposing ewes to artificially long days for 30 days during late spring would break photorefractoriness in Romney ewes thereby inducing reproductive activity when the animals were subjected to a subsequent and abrupt transition to ambient photoperiods. Further, that this photoperiodic regime would enhance reproductive performance over and above those normally achieved with the use of progesterone and eCG.

8.2 Materials and methods

Animals and treatment regimens

The experiment was undertaken, under commercial pastoral sheep-farming conditions, at Massey University, Palmerston North (40^{o} south, 175^{o} east) from October 2005 to January 2006. In New Zealand, summer and winter solstices occur on 21st December and 21st June, respectively.

Mixed-aged Romney ewes (n=302), which were suckling lambs (1.3 lambs/ewe) were weighed and randomly allocated to one of three treatments:

i. Progesterone + eCG (control): Ewes in this group (n=93) were managed entirely at pasture under ambient photoperiods (13 Light:11 Dark). Vasectomised rams fitted with crayon mating harnesses were introduced on

Day -23. On Day -9, all ewes received a progesterone primed intravaginal device (0.3 g progesterone: CIDR; Pharmacia & Upjohn, Auckland, New Zealand). On Day 0, each ewe received 600 I.U. eCG (Folligon, Intervet Ltd, Auckland, New Zealand). Intact rams (1:24 ewes) fitted with crayon mating harnesses were introduced on the day of CIDR removal (Day 0), and remained with the ewes for 7 days. Harnessed vasectomised rams were then introduced to the flock for a further 14 days. Ewes with crayon marks from intact rams were recorded on Days 3 and 7, and from vasectomised rams on Days 14 and 21. Lambs were weaned from their dams on Day 0.

ii. Light + progesterone: For 30 days, starting on 10th October (Day -53; sun rise: 0644 hr, sun set: 1934 hr), ewes (n=102) were at pasture during the day and were housed from 1900 hrs until 0700 hrs under artificial lights. At 0700 hrs the ewes were returned to pasture. These ewes were therefore exposed to continuous lighting (24 L:0 D). The artificial light provided a mean light intensity of 80 lux at ewe head height. A light intensity within the range previously reported by Vesely and Swierstra, (1985). After 30 days (Day -23), the ewes were housed from 1900 hrs to 2100 hrs under artificial lights to give a daylength of 15 L: 9 D. Ewes remained under this lighting regimen for 23 days, during which time vasectomised rams with crayon mating harnesses (1:24 ewes) were introduced. Fourteen days after the start of the 15 L: 9 D lighting regimen (Day -9), each ewe received a CIDR, that remained in place for 9 days. Crayon marks from intact rams were recorded on Days 3 and 7, and from vasectomised rams on Days 14 and 21

iii. Light + progesterone + eCG: Ewes in this group (n=107) were managed in an identical manner to the light + progesterone-treated ewes, except that, on Day 0, each ewe received 600 I.U. eCG (Folligon, Intervet Ltd, Auckland, New Zealand). Ewes with crayon marks from intact rams were recorded on Days 3 and 7, and from vasectomised rams on Days 14 and 21.

Sampling regimens

Ewe live weights (unfasted) were recorded at Day -37, Day -18, Day 0 and Day 53. Eight ewes from each of the light + progesterone + eCG and light + progesterone treatment groups were randomly selected on Day -18 for collection of blood samples (10 mL by jugular venepuncture, lithium heparin anti-coagulant; Becton Dickinson, Preanalytical Systems, Franklin Lake, USA) every 4 h, starting at 1900 hrs, for 24 h. Control ewes underwent the same blood sampling procedure the following day. These ewes were kept away from artificial light, except when samples were being collected at night time when low intensity light from a small light mounted on a headpiece was used. Blood samples were immediately placed on ice until plasma was separated by centrifugation at 1000 g for 10 min. Plasma was stored at -20^{o}C in 1.5 mL aliquots until assayed.

Melatonin assay

Melatonin concentrations were determined by radioimmunoassay using kits manufactured by IBL-Hamburg, Hamburg, Germany (RE29301) according to manufacturer's instructions. The assay was validated for use in sheep by demonstrating parallelism between standards diluted in assay buffer and in stripped sheep plasma. The intra-assay coefficient of variation for the range 32-50 pm/mL was 8.5% and the inter-assay coefficient of variation for the range 30-75 g/mL was 15%. The limit of detection of melatonin in serum was <3.5 pg/mL.

Ovarian and pregnancy status

On Day 10, laparoscopic examination of both ovaries was performed on all ewes and the number of corpora lutea were counted. Ewes were sedated with acepromazine (10 mg:L Acezine 10%, Ethical Agents Ltd., Auckland, New Zealand). Local anaesthetic (2 x 2 mL: Lignocaine hydrochloride 20 mg/mL, Ethical Agents Ltd.) was infiltrated into the skin and abdominal muscles at the site of laparoscope insertion.

Pregnancy status and the number of foetuses present were determined by transabdominal ultrasonography using a 3.5 Mz transducer, 53 days after ram introduction (Day 53).

Analysis of data

Based on mating marks, laparoscopy observations and pregnancy status, ewes were classified into one of five categories;

i. non-responsive (ewes that did not display oestrus (as indicated by lack of crayon harness marks) and had no corpora lutea at laparoscopy),
ii. silent oestrus (ewes that did not display oestrus but had corpora lutea observed at laparoscopy),
iii. pseudo-oestrus (ewes that displayed oestrus but had no corpora lutea observed at laparoscopy and were not pregnant),
iv. non-pregnant (ewes that displayed oestrus, had corpora lutea observed at laparoscopy and were not pregnant)
v. pregnant (ewes that displayed oestrus, had corpora lutea observed at laparoscopy and were pregnant).

Univariate analyses compared the number of ewes displaying and not displaying oestrus, the number of ewes with and without corpora lutea present at laparoscopy, and the number of pregnant and non-pregnant ewes. The presence of crayon mating marks and corpora lutea, and pregnancy status were treated as binomial traits (0 vs 1). A logistical regression model was used, with treatment as the main effect in the statistical model and live weight at mating (P0) as a covariate (V8, SAS Institute Inc, Cary, NC, 2001; PROC GENMOD). The proportion of ewes within each of the five classifications described above were analysed as binomial traits. Logit function was applied to analyses of all binomial traits, after which data were back transformed for presentation. The number of corpora lutea present, and the number of foetuses identified at pregnancy diagnosis were analysed as nonparametric data (PROC GENMOD), using treatment as the main effect and live weight at mating as a covariate. Live weight and live weight changes were analysed using a general linear model (PROC GLM), using treatment as the main effect. Only ewes with complete data sets were used in the analysis (reproductive parameters n=299; live weight and live weight change n=287).

To assess the effect of lighting on plasma melatonin concentrations, only samples collected from 1900 to 0700 hrs were analysed. Data points were not normally distributed so natural log was applied to each value and analysis conducted on logged values. Repeated measure analysis of variance was used to compare changes in melatonin concentrations over the 12 h period. Ewe treatment group and time were fitted as fixed effects. Ewe within ewe treatment group was fitted as a random effect and used as the error term to test the ewe treatment group effect. Interaction between time and ewe treatment group were also included in the linear model.

8.3 Results

Melatonin concentration

Patterns of melatonin secretion are shown in Figure 8.1. Melatonin concentrations were higher (P<0.001) in the control ewes (ambient photoperiod, progesterone + eCG) at 2300 hr and 0300 hr than in ewes exposed to artificial light (+ progesterone +\- eCG). Further, the changes in melatonin concentration between 1900 hr and 2300 hr and between 0300 hr and 0700 hr were greater in the control ewes compared to the other two groups of ewes (P<0.001). At 1900 hr and 0700 hr there were no significant differences in the plasma melatonin concentrations between any of the treatment groups.

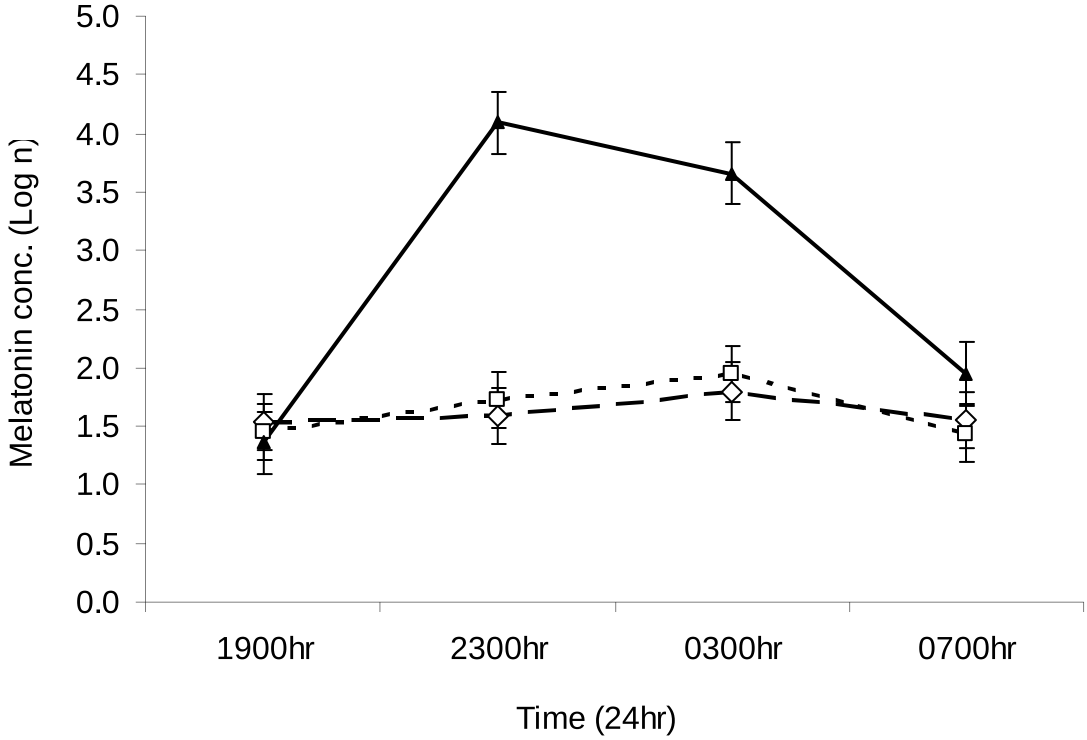

Figure 8.1 Average plasma melatonin concentrations at 1900, 2300, 0300 and 0700 hr for eight ewes not exposed to light and treated with progesterone and eCG (—▲—) and eight ewes, each exposed to artificial light and treated with progesterone (— ◇ —) or progesterone + eCG (– □ –) and. Values are least squares means of the natural logarithm with standard error bars.

Reproductive performance and ovarian activity

Oestrus rates, proportion of ewes with corpora lutea, and the average number of corpora lutea per ewe were higher in the control and light + progesterone + eCG treated ewes compared with the light + progesterone treated ewes (P<0.001; Table 8.1). Two percent of ewes returned to oestrus during the 15 day period (post mating) that the vasectomised rams were with the ewes; these were spread throughout all three treatment groups (data not shown).

Table 8.1 The effect of ewe treatment on oestrus rate, proportion of ewes with corpora lutea present, average number of corpora lutea, pregnancy rate, conception rate, foetuses scanned per ewe exposed to the ram and litter size. Data are expressed as least means squares ± standard error for untransformed logit values, and percentages (from bionomial measures) are back-transformed values.

	Progesterone + eCG		Light + progesterone		Light + Progesterone + eCG	
	LSM ± se	%	LSM ± se	%	LSM ± se	%
Oestrus rate (ewes displaying oestrus per ewe treated)	3.59 ± 0.60 ^{b}	97	0.67 ± 0.22 ^{a}	66	3.67 ± 0.60 ^{b}	98
Proportion with corpora lutea present	2.94 ± 0.47 ^{b}	95	0.98 ± 0.22 ^{a}	73	3.04 ± 0.46 ^{b}	95
Average no. corpora lutea	1.93 ± 0.10 ^{b}		1.03 ± 0.10 ^{a}		1.97 ± 0.10 ^{b}	
Pregnancy rate (pregnant ewes over number of ewes exposed to the ram)	-0.61 ± 0.22 ^{b}	65	0.93 ± 0.22 ^{a}	28	-0.13 ± 0.19 ^{b}	53
Conception rate (pregnant ewes over number of ewes that displayed oestrus)	0.70 ± 0.22 ^{b}	67	-0.27 ± 0.25 ^{a}	43	0.19 ± 0.20 $^{a b}$	55
Foetuses scanned per ewe treated	1.07 ± 0.09 ^{b}		0.43 ± 0.09 ^{a}		0.84 ± 0.08 ^{b}	
Litter size (foetuses per pregnant ewe)	1.66 ± 0.08		1.50 ± 0.12		1.58 ± 0.08	

$^{a\,b}$ Indicates significant differences within columns (P<0.05)

Table 8.2 The effect of ewe treatment on the proportion of ewes that were non-responsive (did not display oestrus and no corpora lutea at laparoscopy), displayed silent oestrus (did not display oestrus, corpora lutea at laparoscopy) or pseudo-oestrus (displayed oestrus, no corpora lutea at laparoscopy and non-pregnant), and the proportion of non-pregnant (displayed oestrus, corpora lutea present at laparoscopy and non-pregnant) and pregnant ewes. Data are expressed as least means squares ± standard error for untransformed logit values, and percentages (from bionomial measures) are back-transformed values.

	Non-responsive		Silent oestrus		Pseudo oestrus		Non-pregnant		Pregnant	
Ewe treatment	LSM ± se	%	LSM ± se	%	LSM ± se	%	LSM ± se	%	LSM ± se	%
Progesterone + eCG	-4.78 ± 1.02 [a]	0.8	-3.87 ± 0.72 [a]	2.0	-3.10 ± 0.51	4.6	-0.94 ± 0.23	28.1	0.61 ± 0.22 [b]	64.9
Light + Progesterone + eCG	-28.50	0.0	-3.56 ± 0.59 [a]	2.8	-3.05 ± 0.46	4.5	-0.44 ± 0.20	39.2	0.13 ± 0.19 [b]	53.1
Light + Progesterone	-1.26 ± 0.25 [b]	21.1	-2.12 ± 0.32 [b]	10.7	-3.23 ± 0.51	3.8	-0.70 ± 0.21	33.3	-0.93 ± 0.22 [a]	28.3

[a b] Indicates significant differences within columns (P<0.05)

The proportion of ewes with at least one corpus luteum present was higher in control ewes (95%) and the light + progesterone + eCG (95%) treated ewes compared with ewes treated with light + progesterone (73%; P<0.0.001; Table 8.1). Average corpora lutea count followed the same pattern where light + progesterone + eCG treated ewes (1.97) had the highest number of corpora lutea, but this was not significantly different from the control ewes (1.93). Both were different from light + progesterone treated ewes (1.03; P<0.001).

Pregnancy rates were highest in the control ewes (65%), followed by the light + progesterone + eCG treated ewes (53%) and were lowest in the ewes treated with light + progesterone (28%; P<0.001; Table 8.1), although ewes in the treatment groups which received eCG were similar, regardless of exposure to artificial light (P>0.05). Conception rate (ewes pregnant per ewe mated) was lower in light + progesterone treated ewes (43%; P<0.05) compared to light + progesterone + eCG (55%) and control ewes (67%). The number of foetuses per ewe treated was highest in the control ewes but not significantly different from the ewes treated with light + progesterone + eCG. Both treatment groups were eCG was administered had more foetuses per ewe than the ewes treated with light + progesterone only (P<0.001). Litter size (per pregnant ewe) did not differ between treatment groups (P>0.05).

There were less than 1% in the control ewes and no non-responsive ewes in the light + progesterone + eCG treated ewes (Table 8.2). This was different (P<0.001) from ewes treated with light + progesterone, in which 22% of ewes were non-responsive.

Compared to the control ewes (2%) and the light + progesterone + eCG (3%) ewes, more ewes treated with light + progesterone (11%; P<0.05; Table 8.2) were not marked by the ram, but had corpora lutea identified at laparoscopy (i.e. had silent oestrus). It was assumed that these animals had failed to display oestrus despite having ovulated.

A small proportion of ewes in each group were marked by the ram but had no corpora lutea present at laparoscopy (pseudo-oestrus). There was no difference between treatment groups in the proportion of ewes that were thought to have had a pseudo-oestrus.

8.4 Discussion

The most commonly used hormonal regime for the induction of reproductive activity in ewes outside the normal breeding season is intravaginal progesterone either alone, or in conjunction with eCG. With that in mind, the objective of the current experiment was determine whether photoperiodic manipulation of Romney ewes that subsequently underwent a progesterone-based oestrus synchronisation regimen in early summer (i.e. when they are at the nadir of their annual reproductive cycle) would enhance reproductive performance beyond the limits normally achieved. It was postulated that if the photorefractoriness that is present at that time of year (Nicholls et al., 1988) could be broken by an abrupt transition from artificially induced long days (24 h light) to ambient photoperiods, reproductive performance might be improved.

The photoperiod used in the current experiment failed to enhance reproductive performance of ewes treated with progesterone and eCG. In addition, the reproductive performance in the ewes subjected to artificial photoperiod and treated with progesterone was poorer than ewes maintained under ambient photoperiod and treated with progesterone + eCG. Hence, the photoperiodic regimen used in this experiment failed to provide the expected enhancement of the out-of-season reproductive activity of New Zealand Romney ewes.

The light intensity averaged 80 lux, but there was a large variation in intensity throughout the housing period (22-140 lux). Previous studies have achieved successful out-of-season reproduction with light intensities from as little as 43 (Ducker and Bowman, 1972) through to 380 lux (Poulton and Robinson, 1987). Hence, whilst it is conceivable that some ewes were in areas of the building in which light intensity was insufficient to evoke a response in ewes, during deep anoestrus, it seems an unlikely explanation for the unresponsiveness of entire groups of ewes to artificial photoperiod.

However, while the pregnancy rates achieved in the ewes treated with light + progesterone were not as high as either of the other two treatment groups, other trials have reported lower pregnancy rates when ewes were treated with progesterone alone (e.g. Andrewes et al., 1987; Smith et al., 1988a). The 28% pregnancy rate recorded in the light + progesterone treated ewes in this trial is better than those reported by Smith et al. (1988a) in Coopworth ewes bred in New Zealand in August, October or December.

Pregnancy rates obtained in ewes treated with progesterone + eCG (control ewes) in the current experiment were similar to those reported in other similar studies using progesterone and eCG (Lowe et al., 1988; Knight et al., 1989b; Morris et al., 2004), and were higher than reported in other out-of-season breeding studies (Smith et al., 1988a).

Few field experiments in which photoperiod has been manipulated have reported oestrus rates, so it is therefore difficult to compare the current trial with other studies in terms of the proportion of ewes that displayed oestrus. However, the observation of the lower oestrus and pregnancy rates in light + progesterone treated ewes compared to light + progesterone + eCG is comparable with the results of other experiments where progesterone was used without eCG (Smith et al., 1988a; Zeleke et al., 2005) and without concurrent manipulation of photoperiod.

The relative lack of success of the current experiment to induce out-of-season pregnancies is probably indicative of the relative depth of anoestrus in Romney to during the non-breeding season, when compared to results achieved with other breeds subjected to abrupt decreased in day length (Ducker and Bowman, 1972; Ducker and Boyd, 1974; Legan and Karsch, 1980). Poulton and Robinson (1987) reported significantly higher serum prolactin concentrations (which are negatively associated with reproductive activity) in Romney ewes compared with Merino ewes, and therefore, could be considered as an indicator that the Romney is more seasonal than the Merino ewe.

While many published lighting experiments were conducted at least three decades ago, different breeds of sheep were used and considerably higher pregnancy and/or conception rates were reported (Ducker and Bowman, 1972; Williams, 1974; Robinson et al., 1975; Vesely, 1975; Mears et al., 1979; Vesely and Swierstra, 1985). Hence, results from the present study are compatible with the view that anoestrus in Romney ewes is deeper than in other breeds (viz. Finnish Landrace, Suffolk or Dorset), so it is more difficult to induce reproductive activity in the non-breeding season.

Earlier work with synchronised Finnish Landrace x Polled Dorset spring-bred ewes reported conception rates of 84% after ewes were exposed to 30 days of 18 L: 6 D (Robinson et al., 1975). Conception rates achieved in the present experiment were higher than Vesely (1978), but progesterone was used to induce oestrus, whereas Vesely (1978) did not use hormone oestrus induction. On the other hand, these results were lower than those of Robinson et al. (1975), but, in the case of the current experiment, a more seasonal breed of sheep was used. It is therefore difficult to directly compare the results of the current experiment with those previously published.

8.5 Conclusion

In conclusion, exposure to artificially induced long days (in addition to progesterone and eCG treatment; 53%) did not increase the out-of-season reproductive performance of the Romney ewes in comparison to those ewes treated with progesterone + eCG in ambient photoperiod (65%). Further, ewes treated with light + progesterone displayed the poorest reproductive performance (25%). Pregnancy rates for the two groups of ewes receiving eCG was comparable to other out-of-season sheep reproduction studies. However, the number of lambs gained per 100 ewes treated was lower in both the groups exposed to artificial photoperiod. The results achieved in this study suggest that the use artificially induced long days to breed Romney ewes out of season does not warrant industry application due to the costs, and the reduced pregnancy, conception rates and number of lambs per ewe treated compared to the use of progesterone and eCG alone.

The next chapter investigates the use of melatonin implants as another alternative method for circumventing reproductive seasonality in Romney ewes bred during the non-breeding season.

Melatonin-improved reproductive performance in sheep bred out of season

G. deNicolo
S.T. Morris
P.R. Kenyon
P.C.H. Morel
T.J. Parkinson

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Chapter 9 Melatonin-improved reproductive performance in sheep bred out of season

Abstract

The effects of melatonin implants on out-of-season breeding in New Zealand Romney composite ewes, was determined by comparison of reproductive performance in ewes treated with progesterone + eCG (Control; n=107), melatonin + progesterone + eCG (n=97) or melatonin + progesterone (n=96) during the early summer period. Conception rates in melatonin + progesterone + eCG treated ewes (67%) were higher than in the Control ewes (P<0.01; 47%). Pregnancy rates were higher in melatonin + progesterone + eCG treated ewes (55%; P<0.001) compared with the Control ewes (40%). Fewer melatonin + progesterone treated ewes displayed oestrus (14%; P<0.001) and subsequently became pregnant (6%). Oestrus rates in melatonin + progesterone treated ewes (14%) were lower than both the melatonin + progesterone +eCG treated (82%) and Control ewes (86%; P<0.001), which were similar to each other. The number of foetuses per pregnant ewe was similar in all three treatment groups. Serum melatonin concentrations at Day -9 were higher in the ewes treated with melatonin and there was a large variation between individual ewes, but concentrations were similar for pregnant and non pregnant ewes. The combination of higher conception rate and the trend for more lambs per pregnant ewes resulted in more lambs being born per ewe treated in melatonin + progesterone + eCG treated ewes compared to the other two treatment groups. These results suggest that melatonin implants, in conjunction with administration of progesterone and eCG, may be suitable as a means of increasing the number of lambs born per ewe treated in an out-of-season breeding program in New Zealand sheep flocks while melatonin and progesterone is not.

9.1 Introduction

In New Zealand, sheep reproduction is seasonal and lambs are born to coincide with spring pasture growth. There can however, be economical advantages from breeding sheep either outside the normal breeding period or more frequently than once-yearly. Despite this, the world-wide use of these management practices are limited due to out-of-season pregnancy rates being variable and as low as 3%, even when exogenous reproductive hormones have been used (Carpenter and Spitzer, 1981; Smith et al., 1988a; Knights et al., 2003; Morris et al., 2004; deNicolo et al., 2006; deNicolo et al., 2008; Chapter 6).

Melatonin initiates a series of events resulting in the onset of the breeding season (Barrell et al., 2000; Rosa and Bryant, 2003). Administration of melatonin, either orally (Wheaton et al., 1990; Robinson et al., 1992) or subcutaneously (Forcada et al., 1992; Staples et al., 1992), has been used to induce reproductive activity in ewes. Research administering melatonin to New Zealand ewes bred in summer (latitude ~40^{o}S) gave poor results (26% ewe mated in first cycle; Knight et al., 1992). In contrast, in Turkey (latitude 41^{o}N) more recently pregnancy rates in summer-bred ewes were reported to be as high as 95% (Horoz et al., 2003).

The purpose of the current experiment was to find a means of improving aseasonal reproductive performance. It was postulated that a recently-redeveloped melatonin implant when used in conjunction with progesterone and eCG, could improve late spring/early summer pregnancy and conception rates above that seen in the standard progesterone/eCG regime, and therefore provide a practical implementation for out-of-season breeding programs. A further objective was to ascertain if the use of this implant when used with progesterone, could improve the reproductive performance of late spring/early summer-bred ewes, above the standard progesterone + eCG treatment used and could therefore be used as a replacement for eCG.

9.2 Materials and methods

The study was undertaken on the Massey University Tuapaka farm, 15 km south-west of Palmerston North, New Zealand (40^o south, 175^o east, summer solstice; 21st December; winter solstice; 21st June) from October (spring) 2005 to January (summer) 2006.

In early October, three-hundred mixed-aged lactating Romney Composite ewes (½ Romney, ¼ Texel and ¼ Finnish Landrace) that were presumed to have lambed 4-8 weeks prior to experiment commencement, were allocated to one of three groups;

i. Control: progesterone primed controlled internal drug releasing devices (CIDR, Pharmacia & Upjohn, New Zealand; 0.3 g progesterone) + equine chorionic gonadatrophin (eCG; Folligon, Intervet Ltd, Auckland, New Zealand; 600 I.U.)
ii. Melatonin implants (Regulin, 18mg melatonin, Ceva Sante Animale, France) + progesterone + eCG
iii. Melatonin + progesterone.

Reproductive hormonal treatment of the control ewes was based on the standard reproductive induction regime for out-of-season reproduction in New Zealand Romney and Romney Composite ewes (Smith et al., 1988a; Knight et al., 1989b; Morris et al., 2004) and is hereafter referred to as the "Control" group.

All ewes were weighed (unfasted) at the commencement of the experiment (Day -39). Ewes treated with melatonin had the implants inserted subcutaneously near the base of the ear, for 35 days (as per manufacture instructions) starting on Day -35 (11 October). On Day -9 ewes in all treatment groups had CIDRs inserted. Day 0 was defined as the day of CIDR removal. To ascertain if the implants had been administered or remained in place for the duration of the pre-mating period, blood samples (10 ml) were collected by jugular venepuncture (lithium heparin anticoagulant: vacutainers;

Becton Dickinson, Preanalytical Systems, Franklin Lake, USA) on Day -9 (between 9.00 am to 1.00 pm). Blood samples from 50 ewes in the Control group, 90 ewes in the Melatonin + progesterone + eCG treatment group and 90 ewes in the Melatonin + progesterone treatment group were collected and immediately placed on ice. Samples were centrifuged at 1000 g for 10 minutes, and the serum was frozen (-4^{o}) until analysis.

On Day 0, ewes were weighed, CIDRs were removed and 600 I.U. of eCG was administered by intramuscular injection to Group 2 and Control ewes. Crayon-harnessed Suffolk rams were introduced (ratio 1 ram:12.5 ewes) and crayon mating marks recorded on Day 3 and 7. Rams were removed on Day 7 and harnessed vasectomised rams were introduced for a further 15 days (Days 7 to 22) to detect if any ewes cycled subsequent to removal of the entire rams. New crayon mating marks were recorded on Day 22 and the vasectomised rams were removed. Ewes were managed as one flock throughout the experimental period.

On Day 11, laparoscopic examination of both ovaries was performed on all ewes and the number of corpora lutea were counted. Prior to laparoscopy, ewes were sedated with acepromazine (10 mg: Acezine 10%, Ethical Agents Ltd; Auckland, New Zealand) and local anaesthetic (Lopaine, Lignocaine hydrochloride, 2x2 ml, 20 mg/ml, Ethical Agents Ltd, Auckland, New Zealand) was used at the site of laparoscope insertion.

On Day 67, pregnancy status was determined by transabdominal ultrasonography using a 3.5 MHz sector transducer applied over the caudodorsal flank fold.

Melatonin assay

Melatonin concentrations were determined by radioimmunoassay using kits manufactured by IBL-Hamburg, Hamburg, Germany (RE29301) according to manufacturer's instructions. The assay was validated for use in sheep by demonstrating parallelism between standards diluted in assay buffer and in stripped sheep plasma. The intra-assay coefficient of variation for the range 32-50 pg/mL was 8.5% and the inter-assay coefficient of variation for the range 30-75 pg/mL was 15%. The limit of detection of melatonin in plasma was <3.5 pg/mL.

Analysis of data

Oestrus rate was defined as the number of ewes marked by the ram per ewe exposed to the ram. Conception rate was defined as the number of ewes pregnant per ewe marked by the ram, and pregnancy rate was defined as the number of pregnant ewes per ewe exposed to the ram.

Following pregnancy diagnosis, ewes were placed into one of five categories based on the presence or absence of mating marks, copora lutea and foetuses (deNicolo et al., 2008). The five categories were:

i. non-responsive (ewes that did not display oestrus (as indicated by lack of crayon harness marks) and had no corpora lutea at laparoscopy),
ii. silent oestrus (ewes that did not display oestrus but had corpora lutea observed at laparoscopy),
iii. pseudo-oestrus (ewes that displayed oestrus but had no corpora lutea observed at laparoscopy and were not pregnant),
iv. non-pregnant (ewes that displayed oestrus, had corpora lutea observed at laparoscopy and were not pregnant)
v. pregnant (ewes that displayed oestrus, had corpora lutea observed at laparoscopy and were pregnant).

All data were analysed using SAS (2001). Only ewes with complete data sets were used in the analysis (n=299). Ewe live weight was analysed using a general linear model (PROC GLM) using ewe treatment as the main effect and lactational status as a fixed effect.

Oestrus rate, pregnancy status, and the presence of at least one corpus luteum (1 versus 0) were analysed as binomial traits using a logistical regression model (PROC

GENMOD). The effect of treatment on conception rates was analysed as a binomial trait with treatment as the main effect. Live weight on Day 0 was fitted as a covariate.

Lactation status was originally included in all statistical models for the various reproductive parameters, but was removed as it had no significant effect.

The proportion of ewes within each of the five classifications (no oestrus, silent oestrus, pseudo oestrus, non pregnant and pregnant) were analysed as binomial traits using a logistical regression model.

Logit function was applied to all analysis of binomial traits which was then back transformed to determine percentages.

The number of corpora lutea present at laparoscopy, fertility (number of foetuses per ewe exposed to the ram) and litter size (number of foetuses per pregnant ewe) were analysed as nonparametric data a logistical regression model with treatment as the main effect, live weight on Day 0 as a covariate and lactation status as a fixed effect. Litter size was analysed by using data from pregnant ewes only. Lactation status had no effect and was subsequently removed from the statistical model.

Melatonin concentrations after which, the log values were analysed using a general linear model procedure with live weight on Day 0 used as a covariate. Due to the large variation in melatonin concentrations, the two groups of ewes that received melatonin implants were split into subgroups for further analysis of melatonin concentrations (less than or greater than 20 ng/ml) and to assess the effect of melatonin on oestrus rates, conception rates, pregnancy rates and litter size. A value of 20 ng/mL was chosen because it was 1.5 standard deviations above the highest value in the Control ewes (i.e. the ewes not treated with exogenous melatonin) and was similar to the value reported in other breeds of sheep during hours of daylight (Kennaway et al., 1981; 1982).

Melatonin concentrations were not taken for all Control ewes, and therefore melatonin concentrations could not be used in the previously explained models (as a covariate) for oestrus rate, pregnancy rate, conception rate, fertility and litter size. Consequently, to assess if melatonin concentration on Day -9 had an effect on reproductive parameters, analysis was re-run using the transformed melatonin concentrations as a covariate for those ewes (90 ewes from each treatment group that received melatonin implants and 50 Control ewes) that were sampled. Melatonin concentrations on Day -9 had no significant effect in any of the models used, so it was not used in the final statistical models for oestrus rate, pregnancy rate, conception rate, fertility and litter size.

9.3 Results

Ewe live weights

There were no live weight differences between treatment groups at the start of the experiment (Day -39; Control; 62.1 ± 0.9, melatonin + progesterone + eCG; 61.4 ± 0.9, melatonin + progesterone; 62.1 ± 0.9 kg), mating (Day 0; Control; 65.5 ± 1.3, melatonin + progesterone + eCG; 65.3 ± 1.3, melatonin + progesterone; 64.8 ± 1.3 kg) or at pregnancy diagnosis (Day 67; Control; 58.9 ± 1.4, melatonin + progesterone + eCG; 59.7 ± 1.4, melatonin + progesterone; 59.4 ± 1.4 kg).

Melatonin concentrations

Melatonin concentrations in the Control ewes (range 0.13-14.56 pg/ml) were lower than in the melatonin + progesterone + eCG (range 0.60->150 pg/ml) and melatonin + progesterone treated ewes (range 0.50->150 pg/ml; $P<0.001$; Figure 9.1). While the melatonin implants increased mean plasma melatonin concentrations, only 5.6 and 2.2% of ewes in the melatonin + progesterone + eCG and melatonin + progesterone treatment groups, respectively, had melatonin concentrations >100 pg/mL (Figure 9.1). Further, over half of the ewes in those two treatment groups had plasma melatonin concentrations <20 pg/ml. Live weight on Day 0 had no effect on melatonin concentration, and melatonin concentrations in pregnant and non-pregnant ewes did not differ.

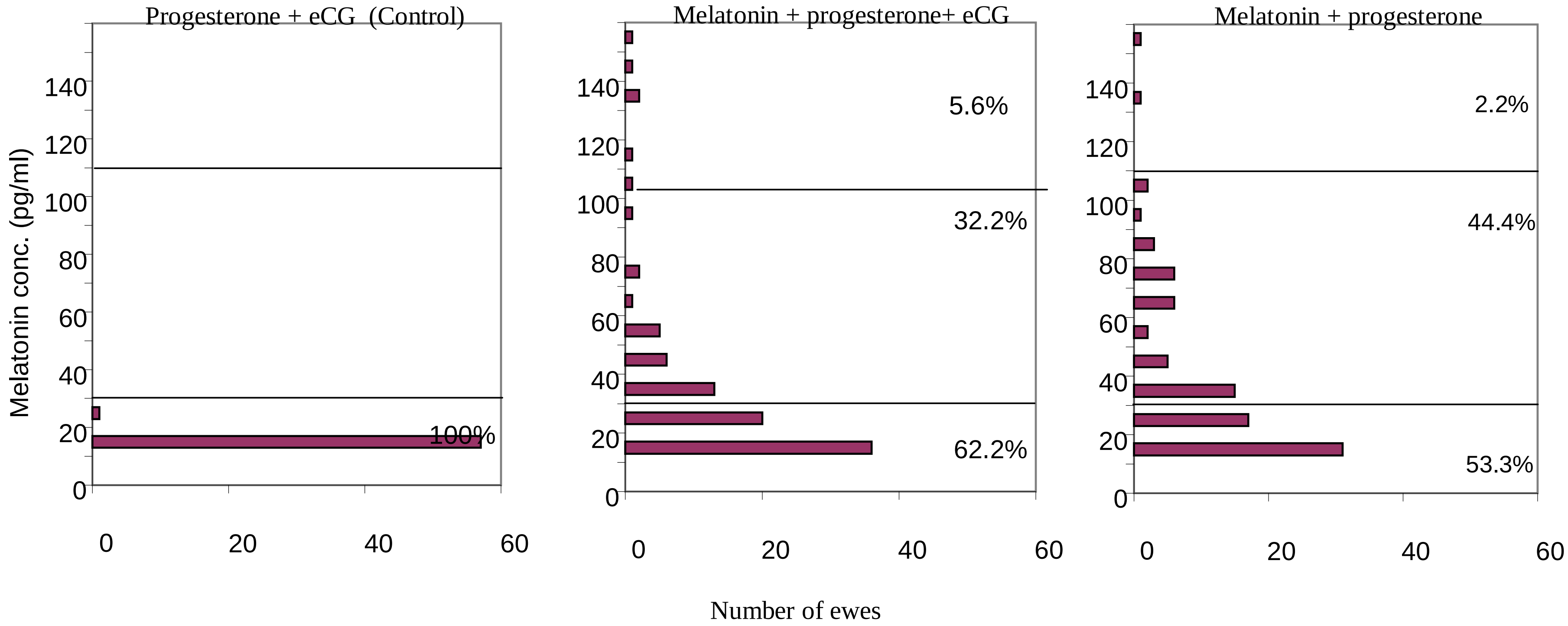
There were no significant differences in melatonin concentrations on Day -9 in ewes that did, or did not, conceive, across all treatment groups.

Reproductive performance

A higher proportion of Control and melatonin + progesterone + eCG treated ewes displayed oestrus compared with melatonin + progesterone treated ewes (P<0.001; Table 9.1). No ewes returned to oestrus between Days 7 and 22.

Table 9.1 Effect of ewe treatment (melatonin + progesterone; melatonin + progesterone + eCG; progesterone + eCG) on oestrus rate (number of ewes marked by the ram per ewe exposed to the ram), proportion of ewes with corpora lutea present (CL) and average number of CLs. Values are back-transformed percentages and least means squares ± standard error. Different superscripts within rows indicate significant differences (P<0.05).

	Ewe treatment		
	Progesterone + eCG	Melatonin + progesterone + eCG	Melatonin + progesterone
n	107	97	96
Reproductive parameter			
Oestrus rate	85.8% [b] 1.80 ± 0.28	81.5% [b] 1.49 ± 0.26	13.5% [a] -1.86 ± 0.29
CL present	92.6% [b] 2.77 ± 0.46	90.5% [b] 2.26 ± 0.35	43.4% [a] -0.27 ± 0.21
Average no. CL	1.45 ± 0.09 [b]	1.61 ± 0.09 [b]	0.70 ± 0.10 [a]



Mean melatonin concentration	1.28 ± 0.10 (3.2) [a]	1.22 ± 0.07 (24.0) [b]	0.64± 0.08 (28.1) [b]
n	58	90	90

Figure 9.1 The proportion of ewes within each treatment group with plasma melatonin concentrations less than 20 pg/ml, between 20 and 100 pg/mL and over 100 pg/ml. Mean log-transformed melatonin concentrations (plus raw values) and the total number of blood samples collected for each treatment group are shown at the bottom of the figure.

Table 9.2 The effect of ewe treatment (melatonin + progesterone; melatonin + progesterone + eCG; progesterone + eCG) on the proportion of ewes displaying no oestrus (non-mated ewes without corpora lutea), silent oestrus (non-mated ewes with corpora lutea), pseudo oestrus (mated ewes without corpora lutea), non-pregnant (mated ewes with corpora lutea, but diagnosed non-pregnant) and pregnant (mated ewes with corpora lutea and diagnosed pregnant). Values are back-transformed percentages and least means squares ± standard error. Different superscripts within rows indicate significant differences ($P<0.05$).

Classification	Ewe treatment					
	Progesterone + eCG		Melatonin + progesterone + eCG		Melatonin + progesterone	
	LSM ± SE	%	LSM ± SE	%	LSM ± SE	%
No oestrus	-2.98 ± 0.46	4.8% [a]	-3.12 ± 0.51	4.2% [a]	0.37 ± 0.21	59.2% [b]
Silent oestrus	-2.28 ± 0.33	9.4% [a]	-1.88 ± 0.30	13.5% [a]	-0.98 ± 0.23	27.3% [b]
Pseudo oestrus	-3.53 ± 0.59	2.9%	-2.94 ± 0.47	5.0%	-28.40	0.0%
Non pregnant	-0.29 ± 0.20	42.8% [c]	-1.33 ± 0.25	21.0% [b]	-2.37 ± 0.37	8.6% [a]
Pregnant	-0.42 ± 0.20	39.7% [b]	0.18 ± 0.20	54.5% [c]	-2.73 ± 0.42	6.1% [a]

More ewes in the melatonin + progesterone + eCG and Control treatment groups were identified as having at least one corpus luteum at laparoscopy, compared with the melatonin + progesterone treated ewes (P<0.001; Table 9.1). Fifty-nine percent of melatonin + progesterone treated ewes did not display oestrus and had no corpora lutea identified at laparoscopy (‘no oestrus’; Table 9.2). This was different from the melatonin + progesterone + eCG treated and Control ewes (*P*<0.001). Compared with the melatonin + progesterone + eCG treated and Control ewes, a higher proportion of melatonin + progesterone treated ewes failed to display oestrus despite having at least one corpus luteum present (‘silent oestrus’; *P*<0.01). There was no treatment difference in the proportion of ewes classified as having a pseudo oestrus.

Pregnancy rates (number of ewes pregnant per ewe exposed to the ram) were higher in the melatonin + progesterone + eCG treated ewes (55%; Table 9.2), compared with the Control group (40%); which was different to the melatonin + progesterone treated ewes (6%; P<0.001).

Conception rate (number of ewes pregnant per ewe mated) for melatonin + progesterone + eCG treated and Control ewes did not differ significantly from melatonin + progesterone treated ewes (Table 9.3). The low number of mated ewes in melatonin + progesterone treatment group (n=6) resulted in a high standard error and, when the Control and melatonin + progesterone + eCG treatment groups were analysed separately, there was a significant difference (*P*<0.001) between these two groups.

Litter size (number of foetuses per pregnant ewe) did not differ between treatment groups (Table 9.3). When the Control and melatonin + progesterone + eCG treatment groups were analysed separately, litter size was significantly higher in the melatonin + progesterone + eCG treated ewes relative to the Control ewes (*P*<0.001). Fertility (number of foetuses per ewe exposed to the ram) was different between all treatment groups (P<0.001) and was highest in the melatonin + progesterone + eCG treated ewes.

Values in the Control ewes were also higher than in the melatonin + progesterone treated ewes($P<0.001$).

Table 9.3 Effect of ewe treatment (melatonin + progesterone; melatonin + progesterone + eCG; progesterone + eCG) on conception rate (ewes pregnant per ewe mated), litter size (number of foetuses per pregnant ewe) and fertility (number of foetuses per ewe exposed to the ram). Values are back-transformed percentages and least means squares ± standard error. Different superscripts within rows indicate significant differences ($P<0.05$).

	Ewe treatment		
	Progesterone + eCG	Melatonin + progesterone + eCG	Melatonin + progesterone
Conception rate	46.6% [a] -0.14 ± 0.21	66.7% [b] 0.70 ± 0.24	42.9% [a b] -0.29 ± 0.54
Litter size	1.47 ± 0.08	1.66 ± 0.07	1.63 ± 0.22
Fertility	0.60 ± 0.07 [b]	0.93 ± 0.08 [c]	0.11 ± 0.08 [a]

9.4 Discussion

The present experiment was undertaken to determine whether the administration of melatonin implants in conjunction with standard progesterone/eCG-based regimens would improve the efficiency of out-of-season reproductive activity in New Zealand Romney composite ewes by co-stimulation of photoperiod-sensitive pathways. The main finding of the experiment was that ewes which received melatonin in addition to progesterone + eCG had higher conception and pregnancy rates, and a larger litter size, than those treated with progesterone and eCG. Conversely, in the absence of eCG, melatonin was ineffective in inducing out-of-season reproductive activity, even though the ewes were co-treated with progesterone. Indeed, results were such (25% of melatonin + progesterone treated ewes in oestrus and 6% pregnant) that the level of reproductive success induced by this regimen in the Romney Composite ewes in this experiment is unlikely to be of any commercial value. In other words, melatonin administration appeared to have augmented the response to a standard out-of-season progesterone + eCG regimen (Smith et al., 1988; Knight et al., 1989; deNicolo et al., 2006), whilst the better response in ewes treated with progesterone + eCG (86% in oestrus and 40% pregnant) compared to those treated with progesterone + melatonin underlines the value for eCG in stimulating out-of-season breeding in ewes.

The failure of melatonin to start the processes of pre-ovulatory follicle growth and ovulation in early spring, on the other hand, warrants further consideration. Previous studies have reported pregnancy rates of over 90% in melatonin + progesterone + eCG treated ewes (Williams et al., 1992; Horoz et al., 2003), although, as the control groups achieved pregnancy rates of over 80% in those studies, some difficulties exist in making comparisons with the present experiment. Further, the time at which melatonin was administered in relation to the start of endogenous breeding season might have affected the outcomes. For example, Williams et al. (1992) gave melatonin implants to Romney Marsh ewes in early January (mid summer) so that they could be bred in late January (mid/late summer). However, they also induced Border Leicester x Merino ewes into reproductive activity during the non-breeding season using the same melatonin treatment regime, which allowed mating to occur in mid November (i.e at a similar time to that of the present experiment).

The duration of melatonin treatment is also worthy of consideration. Williams et al. (1992) gave melatonin implants to one group of Romney Marsh ewes 21 days prior to mating, while another group received one implant 65 days prior to mating and a second implant 14 days later (i.e. a total of 65 days of artificial melatonin exposure). There was no difference in the proportion of ewes that were pregnant between these two treatment groups. These animals were, however, bred in January. A closer analogy to the present experiment is in the responses of Border Leicester x Merino ewes that received melatonin implants in November (spring). Ewes that received an implant for 21 prior to mating had higher pregnancy rates that those which had melatonin for a total of 65 days (Williams et al., 1992). Moreover, in the current experiment, the time between implantation and breeding (35 days) was as instructed by the manufacturer of the implants. In other words, both the time of onset of melatonin administration and its duration would have been expected to have stimulated out-of-season reproductive activity in the current experiment, with an acceptable pregnancy rate.

Nonetheless, it is clear that ewes are more likely to respond to out-of-season breeding that is initiated in the summer (January) than earlier in the year, given that the transition from non-breeding to breeding seasons starts to take place at around that time of year (Smith et al. 1988). Consequently, it would have been expected that the magnitude of the effect upon pregnancy rate (Smith et al., 1988; Williams et al., 1992) would have been greater when ewes were in a shallower phase of anoestrus than when in deeper anoestrus. Moreover, breed may have affected the outcome of the earlier trials, since the depth of anoestrus in Merino ewes is less than in breeds such as the Romney (Smith et al., 1989). Likewise, Knight et al. (1992) found that Romney ewes (and other European sheep breeds with a long non-breeding season) exhibited a relatively poor response to melatonin implants under New Zealand husbandry conditions. Durotoye et al. (1991) reported increased pregnancy and conception rates, and an increased occurrence of multiple births in melatonin treated ewes, and later, Gomez et al. (2006) found a 48% increase in productivity in melatonin-treated Mediterranean ewes compared to untreated control ewes.

However, it may be that the lack of a response to the melatonin, in terms of inducing out-of-season oestrous cycles should be attributed to a failure of the treatment regime to effectively deliver enough melatonin over an adequate period. Certainly, the plasma concentrations recorded in the present experiment were lower and more variable than have been reported elsewhere (Rondon et al., 1996; Santiago-Moreno et al., 2004). On the other hand, the concentrations that were present on Day -9 need not have been reflective of those that were present when peak values were attained, given that the implants had been placed 26 days previously. Moreover, it was clear that the melatonin-treated ewes exhibited differences in pregnancy rates from the untreated ewes, and, whilst most of the literature concentrates on the effects of melatonin upon the central neuroendocrine axis, there is also evidence to suggest that it has effects that are not the result of its effects upon that system.

For example, one mechanism which could underlie this could be that suggested by Abecia et al. (2002), who found that melatonin treatment can increase fertility and litter size by improving luteal function and embryonic survival, probably through inducing a uterine environment that is more conducive to pregnancy. Alternatively, some research has shown that prolactin concentrations are suppressed by treatment with melatonin (Kennaway et al., 1982; Lincoln and Ebling, 1985; Poulton et al., 1987) and elevated prolactin concentrations are thought to have negative or inhibitory effects on reproduction (Kann and Martinet, 1975; Fitzgerald and Cunningham, 1981). If so, this may imply that there was a degree of stimulation of gonadotrophic activity by melatonin, but that this was not sufficient to complete ovulation. However, when combined with eCG (which did permit ovulations to occur), this stimulation was sufficient to augment reproductive outcomes.

9.5 Conclusion

In conclusion, the current experiment showed that treatment with melatonin and progesterone alone is not a viable means of increasing pregnancy rates in ewes bred outside of the normal breeding season. Treatment with melatonin, progesterone and eCG resulted in higher pregnancy and conception rates, and larger litter sizes and fertility than ewes treated with progesterone and eCG alone (Control ewes). Ewe productivity was 67% higher in the melatonin + progesterone + eCG treated ewes compared with the Control ewes. This suggests that melatonin implants, when used in conjunction with progesterone and eCG may be a feasible option for use in out-of-season breeding programs in Romney composite ewe flocks in New Zealand.

Effect of weaning pre- or post-mating on performance of spring-mated ewes and their lambs in New Zealand

G. deNicolo
S.T. Morris
P.R. Kenyon
P.C.H. Morel

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Chapter 10 Effect of weaning pre- or post-mating on performance of spring-mated ewes and their lambs in New Zealand

Abstract

The objective of this experiment was to determine the effect of lactation over the breeding period and early gestation on ewe reproductive performance and live weight. Romney ewes (n=206) with lambs at foot were allocated to either Early or Late weaning groups, synchronised with CIDRs and joined with Suffolk rams 69 days postpartum (Day 0). Lambs from the Early group were weaned at Day 0 while lambs from the Late group were weaned on Day 21. The ovaries of each ewe were observed laparascopically on Day 9. Late weaned lambs were significantly heavier ($P<0.001$) on Day 21 and Day 47 than lambs in the Early group. There was no effect of ewe treatment on ewe reproductive performance, live weight over the breeding period, number of corpora lutea present, pregnancy rates, or on live weight of the ewes at the subsequent lambing and lactation. Birth and live weights of subsequent lambs were not affected by the treatment of the ewe over the breeding period. This research suggests that the breeding of suckling ewes in an accelerated lamb production system has no effect on ewe reproductive performance or on subsequent lamb production.

10.1 Introduction

In accelerated lamb production systems, shortened lambing-to-breeding intervals are desirable to reduce the interval between successive lambings. However, suckling lambs can increase the length of the postpartum anoestrus interval (Mallampati et al., 1971; Kann and Martinet, 1975; Pope et al., 1989) and reduce fertility levels (Hulet et al., 1983). To avoid such effects, lambs are often weaned at an earlier age than in a traditional once-yearly lambing. Previously reported accelerated lamb production systems have weaned lambs as young as 28 days of age (Speedy and FitzSimons, 1977), 40-60 days of age (Wheaton et al., 1992) and around 70 days (Lewis et al., 1996; Rodriguez et al., 1998; Morris et al., 2004). If ewes could be successfully bred while they are suckling lambs, weaning of lambs in accelerated lamb production systems could be delayed until after the breeding period. This would result in greater weaning weights of lambs while still maintaining a shortened lambing to breeding interval.

Uterine involution takes longer in lactating ewes compared to non-lactating ewes and longer in spring than in autumn (Cognie et al., 1975). While lactation is reported to lower fertility when ewes were bred within 30 days postpartum (Restall et al., 1978) and increase the postpartum anoestrus interval (Mallampati et al., 1971), Hulet and Foote (1983) found no effect of lactation on the number of ewes lambing when breeding occurred 30-90 days postpartum. In Australia, Dawe et al. (1969) achieved 65% pregnancy rates in Border Leicester x Merino ewes that had been lactating for nine weeks prior to the mating period, during the non-breeding season. That result is similar to that obtained by other researchers in non-lactating ewes bred out-of-season (Smith et al., 1988a; Knight et al., 1989b; Ungerfeld and Rubianes, 2002; Morris et al., 2004).

To date, the effects on the ewes' reproductive performance and the effects on the subsequent set of lambs from breeding with lambs at foot under New Zealand pastoral conditions has not been examined. Therefore, the objectives of this study were to determine the effect of lactation over the breeding period and early gestation on ewe reproductive performance and live weight, and to determine if this had any effect on the live weights of the ewe's present and subsequent progeny.

10.2 Materials and methods

Trial design

Two hundred and six mixed-aged Romney ewes suckling lambs (n=302), were allocated, within rearing rank, to either an "Early" (day zero of synchronised mating; Day 0) or a "Late" weaning (P21) group. Lambs in the Early group were weaned at Day 0 (69 days of age) and lambs in the Late group were weaned at Day 21 (91 days of age). At Day -14 all ewes had progesterone primed controlled internal drug releasers (CIDRs; Pharmacia & Upjohn, New Zealand; 0.3 g progesterone) inserted. Ewes and lambs were managed as one mob under normal farm practice from Day -14 to P0. At P0, CIDRs were removed and 800 I.U. of pregnant mare serum gonadotrophin (PMSG; Folligon, Intervet Ltd) was injected intra-muscularly (i.m.). At P0 ewes and lambs from the Late group were then randomly split into two mobs and were grazed in two separate paddocks, denoted block A or B. Lambs from the Early group were weaned (average age = 69 days) and randomly split into two mobs and assigned to either block A or B while their respective dams were grazed on the opposite block. This design allowed for both Early and Late weaned animals to be run on each block so that any difference in lamb weaning weight was due to milk production. Pasture mass of block B had 190 kg DM/ha greater than that of block A, therefore ewes and lambs on the respective blocks were set stocked at differing rates from Day 0 to 21 (13.6 and 22.8 ewes/ha for block A and B, respectively).

Suffolk rams were introduced to the ewes at a ratio of 1:9 on Day 0 and crayon tup marks recorded daily for 6 days post-CIDR withdrawal. The CIDRs were washed and re-inserted on Day 9 to induce non-cyclic and non-pregnant ewes to recycle (Knight et al. 1989). These CIDRs were again removed on Day 14. Harness crayon colours were changed on Day 9 to record ewes returning to oestrus from Day 9-21. At Day 21, Late lambs were weaned (average age of 91 days).

Nine days after CIDR removal (Day 9), laparoscopic examination was performed on all ewes. Ewes were sedated with acetyl promazine (1 ml, i.m., 10 mg/mL Acezine 10%, Ethical Agents Ltd) and local anaesthetic (Lignocaine hydrochloride, 2x2 ml, 20mg/ml, Ethical Agents Ltd) was used at the incision site. The number of corpora lutea and follicles were counted on each ovary and recorded.

Lambs present at mating were weighed at Days 0, 21 and 47, and ewes were condition scored (CS; scale 0-5; Jefferies, 1961) and weighed unfasted at Days 0 and 21. Ewe pregnancy status was determined using ultrasound at Day 62. Ewes were managed as one group from the end of the mating period (Day 21) until 6 days (Day 140) prior to the planned start of lambing. Ewes were weighed and set stocked at 12.2 ewes/ha until the end of the lambing period (21 days after the start of lambing; L21, where "L" refers to the period following the synchronised breeding period).

Within 12 hours of birth, lambs born to the synchronised breeding were identified to their dam, tagged, sexed, recorded for birth-rank, and weight, crown-rump length (CRL) and girth size were measured. Following the end of lambing, ewes and lambs were managed as one mob under commercial conditions until the end of the study (L73). Three ewes from Late group and six ewes from Early group were not recorded as having lambed despite being scanned pregnant. Ewes and lambs were weighed unfasted at L35 and L73.

The present study was undertaken during the period of 6th October 2004 (Day -14) to 27th May 2005 (L73) and was carried out with approval from the Massey University Animal Ethics committee. The location of the study was at the Massey University Keeble farm, 5 km south-east of Palmerston North (40^{o} south, 175^{o} east), New Zealand.

Statistical analysis

Data were analysed using SAS (V8, SAS Institute Inc, Cary, NC, 2001). Ewe live weight, and lamb birth and live weights were analysed using a general linear model (PROC GLM). Interactions were fitted in all models and removed if not significant ($P>0.05$). The statistical model for ewe live weights up to Day 21 fitted rearing rank (single versus twin) and weaning treatment group (Early versus Late weaning) as fixed effects. Models for ewe live weight for the subsequent set of lambs fitted litter size. Block had no effect and was dropped from general linear models. The statistical model used for live weights and growth rates of lambs present at mating included sex of lamb, litter size, block and ewe treatment group fitted as fixed effects. Age of lamb was used as a covariate in models for lamb live weights and growth rates.

The presence or absence of corpora lutea at Day 9, and pregnancy data (pregnant versus non-pregnant) were analysed as binomial traits (PROC CATMOD) using rearing rank (i.e. lambs present or weaned at Day 0) and weaning treatment as fixed effects. The number of corpora lutea present were analysed as nonparametric data (PROC GENMOD) with rearing and treatment group as fixed effects. Ewe condition score at mating was only used in statistical models for oestrus and pregnant rates, as it was not significant in other models. Live weight was not used as it did not affect any of the parameters measured.

10.3 Results

Lambs present at the start of the breeding period

Singleton lambs were heavier than their twin-born counterparts at Day 0 ($P<0.01$) and Day 21 ($P<0.01$; Table 10.1). Between Days 0 and 21, single-born lambs had greater growth rates than twin-born lambs (245 ± 11 versus 201 ± 9 g/day; $P<0.01$). However, between Days 21 and 47, twin-born lambs had higher growth rates than singletons (158 ± 5 versus 139 ± 7 g/day, respectively; $P<0.05$).

At both Day 21 (P<0.001) and Day 47 (P<0.001) Late weaned lambs were heavier than Early weaned lambs (Table 10.1). This difference was due to higher growth rates from Days 0-21 in the Late weaned lambs (186 ± 10 versus 260 ± 10 g/day; P<0.001). However, there were no lamb growth-rate differences between treatment groups from Days 21 to 47, but overall growth rates (Days 0-47) were higher in the Late weaned lambs (P<0.001; 165 ± 6 and 203 ± 6 g/day in the Early and Late weaned lambs, respectively).

Table 10.1 The effect of Early (average age = 69 days; Day 0) and Late (average age = 91 days; Day 21) weaning and rearing rank (single versus twin) on the live weights on Day 0 (first day of synchronised breeding), Day 21 and Day 47 (least squares means ± SEM) of lambs present at the start of the synchronised breeding period. Means within treatment or rearing rank and columns with different superscripts are significantly different (P<0.05).

	Lamb live weight (kg)					
	n	Day 0	*n*	Day 21	*n*	Day 47
Treatment						
Early	146	16.3 ± 0.3	144	19.71 ± 0.2 [a]	141	24.2 ± 0.3 [a]
Late	143	16.9 ± 0.3	140	21.22 ± 0.2 [b]	138	25.9 ± 0.3 [b]
Rearing rank						
Single	115	17.5 ± 0.4 [b]	111	21.8 ± 0.2 [b]	109	25.4 ± 0.3
Twin	174	15.8 ± 0.3 [a]	173	20.7 ± 0.2 [a]	170	24.8 ± 0.2

Ewe live weight

There was no significant differences in ewe live weight between weaning treatments at Day 0 (47.9 ± 0.6 kg and 49.5 ± 0.6 kg for the Early and Late groups, respectively), Day 21 (51.9 ± 0.6 kg and 53.9 ± 0.6 kg, respectively), Day 140 (64.2 ± 1.5 kg and 64.2 ± 1.5 kg, respectively), L35 (55.2 ± 1.55 kg, and 56.3 ± 1.7 kg, respectively) or L73 (53.2 ± 1.7 kg and 52.3 ± 1.9 kg, respectively). Live weight for ewes rearing singles did not differ from those rearing twins at Day 0 (48.1 ± 0.6 kg and 49.6 ± 0.7 kg, respectively), Day 21 (52.9 ± 0.5 kg and 53.9 ± 0.5 kg, respectively), Day 140 (63.4 ± 1.5 kg and 65.0 ± 1.5 kg, respectively), L35 (55.5 ± 1.0 kg and 55.9 ± 2.4 kg, respectively) or L73 (54.4 ± 1.1 kg and 51.0 ± 2.7 kg, respectively).

Ewe reproductive performance and laparoscopic observations

Ewes that were rearing multiple lambs had higher average number of corpora lutea than those rearing singletons (P<0.05; Table 10.2). The number of ewes marked by the ram, number of ewes with corpora lutea present, or the average number of corpora lutea or follicles present did not differ between weaning treatments. There was no effect of ewe treatment at mating on proportion of ewes marked by the ram (91% and 90% for the Late and Early weaned groups, respectively) or on pregnancy rates (36% and 33% for Late and Early weaned groups, respectively).

Table 10.2 The effect of Early (69 days post partum) and Late (91 days post partum) weaning and rearing rank (single versus multiple) on the average number of follicles and corpora lutea (CL) present at laparoscopy nine days after the start of synchronised mating (least squares means ± SEM), and number of ewes with or without corpora lutea present. Means within treatments and columns with different superscripts are significantly different (*P*<0.05).

		Average number of		Number of ewes with	
	n	Follicles	CL	No CL present	CL present
Treatment					
Early	102	0.21 ± 0.04	1.53 ± 0.09	7	95
Late	103	0.10 ± 0.04	1.62 ± 0.09	7	96
Rearing rank					
Single	116	0.16 ± 0.04	1.43 ± 0.08 [a]	10	106
Multiple [1]	89	0.15 ± 0.04	1.72 ± 0.09 [b]	4	85

[1] Ewes rearing twin and triplet lambs were allocated to “multiple” rearing rank.

Lambs born to synchronised breeding

There was no effect of ewe treatment on weight of lamb at birth (L0), L35 or L73 (Table 10.3), or on CRL and girth size at birth. Single-born lambs were heavier than their twin-born counterparts at birth, L35 and L73 (P<0.001). Crown-rump length measurements were greater (P<0.05) in single-born lambs compared to twin-born lambs, but girth size was not different.

Survival to docking was not affected by ewe weaning treatment but was affected by birth rank (P<0.05; 88 versus 65% in singletons and twins, respectively). Weaning percentage (lambs weaned over ewes exposed) was 25% and 32% in the Late and Early weaning groups, respectively but was not significantly different.

Table 10.3 Effect of ewe treatment (Early versus Late weaning) and litter size (single versus twin) on the lamb crown-rump length (CRL) and girth measurements, and live weight at L0, L35 and L73 (least squares means ± SEM). Means within treatments and columns with different superscripts are significantly different (*P*<0.05).

		CRL	Girth	Live weight (kg)				
	n	(cm)	(cm)	L0	*n*	L35	*n*	L73
Treatment								
Early	36	49.1 ± 0.6	37.6 ± 0.9	4.3 ± 0.1	30	12.6 ± 0.4	32	20.2 ± 0.6
Late	36	49.5 ± 0.6	39.5 ± 1.0	4.3 ± 0.1	26	11.9 ± 0.5	26	18.5 ± 0.8
Litter size								
Single[1]	41	50.3 ± 0.6 ^{b}	38.9 ± 0.9	4.7 ± 0.1 ^{a}	42	13.3 ± 0.4 ^{b}	44	21.6 ± 0.5 ^{b}
Twin[1]	34	48.3 ± 0.6 ^{a}	38.3 ± 1.0	3.9 ± 0.1 ^{b}	14	11.2 ± 0.7 ^{a}	14	17.1 ± 1.0 ^{a}

[1] Litter size at L0 was based on birth rank, and at L35 and L73 it was based on rearing rank.

10.4 Discussion

The objectives of the present study were to determine the effect of lactation on the reproductive performance and live weight of ewes bred outside of the normal breeding season, and to assess any effect on the ewe's present and subsequent progeny.

While the pregnancy rates obtained in this trial in both treatment groups were low (33%) compared to in-season pregnancy rates, it is recognised that breeding ewes during the seasonal anoestrus period, irrespective of their lactational status, results in low pregnancy rates, both in New Zealand (11-47% Smith et al. 1988; 42-71% Morris et al. 2004) and worldwide (35-44% Ungerfeld & Rubianes 2002; 47-54% Knights et al. 2003).

While mating lactating ewes has been shown to prolong postpartum intervals in some studies (Mallampati et al., 1971; Pope et al., 1989), it has also been reported to increase pregnancy rates, ovulation rates, or litter size in others (Cognie et al., 1975; Pope et al., 1989; Fogarty et al., 1992b). The current experiment showed breeding suckling ewes did not enhance or adversely affect ovarian corpora lutea counts, oestrus activity, pregnancy rates or litter size in ewes bred 68-73 days postpartum. Breeding at this time would have ensured uterine involution was complete and because the lambs suck less often and for shorter periods at that stage of lactation (Obregon et al., 1992), less prolactin is released (Kann and Martinet, 1975) which would thereby have less or no effect on ovarian activity.

In agreement with Goulet and Castonguay (2002), the present study found no difference in ewe live weight between ewes lactating for 73 or 94 days, either at 73, 94 or 120 days postpartum, or at their subsequent lambing.

In the current experiment, lambs that were suckled for a further three weeks were heavier at weaning and 120 days of age than their earlier weaned counterparts. This is most likely due to the later weaned lambs having access to both herbage and milk. Gaili (1992) weaned feedlot lambs at 75 or 90 days of age and reported higher daily weight gain in later weaned lambs between 90 and 180 days. Similarly, Gibb & Treacher (1979) reported higher growth rates in lambs still suckling ewes, compared to weaned lambs. Therefore, if weaning age can be increased, the likely result will be increased live weights at weaning and increase growth rates after weaning.

There were no carry over effects of ewe treatment at breeding on the subsequent set of lambs. The lack of an effect suggests ewes can be bred out-of-season while they are still suckling lambs, thereby increasing lamb weaning weights without negatively affecting the ewe. To our knowledge, there are no other studies examining birth weight of lambs born to ewes that were lactating over the breeding period and early pregnancy. The lack of an effect is mostly likely due to the low energy demand of the foetus during early gestation (Robinson et al., 2002).

Lamb losses in the second set of lambs in the current trial were particularly high in twin lambs (35%). Previous reports suggest that mortality rates of 12-20% in twin-born lambs are more normal (Litherland et al., 1999; Kenyon et al., 2002). Dead lambs did not undergo post-mortem examination therefore causes of death were unknown and comments can not be made.

In a year-round lamb production study, Morris et al. (2005) showed that Romney ewes can maintain live weight and body condition over a two-year period in which weaning occurred at mating (at 73 days postpartum). Although the ewes are towards the end of their lactation, a further 21 days lactating on a continuous cycle may challenge the ewes in their ability to maintain live weight long term, when lactating over the breeding period and early gestation. This needs to be assessed before the practice of delaying weaning and breeding ewes suckling lambs is promoted in an accelerated lambing system where ewes lamb five times in three years.

10.5 Conclusion

It is possible that a combination of factors (older lambs requiring less milk, stage of lactation and postpartum interval) have led to the results obtained. Therefore, it can be concluded from this experiment that delaying weaning in an accelerated lambing system can be used to increase lamb weaning weights without impairing ewe live weight or reproductive performance.

General Discussion:

Accelerated and out-of-season lamb production

G. deNicolo

Chapter 11 General discussion

11.1 Introduction

Sheep farming is a significant component of New Zealand's agricultural economy as lamb contributes to nearly half of the annual export earnings from meat and meat products – 2.11 billion dollars in 2005 (MWNZ, 2006b). By increasing the frequency with which ewes lamb, annual lamb production could be increased without having to resort to increasing litter size, thereby avoiding low birth weights and higher lamb mortality rates (particularly triplet-born lambs). Thus, increasing the number of times a ewes lambs in one year has exciting potential for farmers and for increasing New Zealand's lamb trade.

Accelerated lamb production differs from out-of-season lamb production in that ewes lamb more frequently than once a year, whereas out-of-season lamb production incorporates a proportion of a flock, or the entire flock, being bred once a year outside the traditional autumn breeding period. Accelerated lamb production systems have been trialled over a number of years with results ranging from 1.81 lambs per year in Australia (Fogarty et al., 1992a) to 4.03 lambs per year in Finland (Goot and Maijala, 1977).

McCutcheon et al. (1993) suggested, in a non-refereed New Zealand publication, that accelerated lamb production could be used as a way of increasing the number of lambs born each year within a flock. Until now, this has not been evaluated in a research environment and/or under pastoral conditions in New Zealand. The main focus of this PhD research was to examine and compare an accelerated lamb production system with the more usual practice of once-yearly spring lamb production, and to provide proof of concept to the sheep industry. Indications early in the experimental period led to a more thorough investigation of out-of-season pregnancy rates, reasons why they were impaired and possible methods of increasing pregnancy rates or circumventing seasonality.

11.2 Summary of experimental chapters and conclusions drawn

Ewe reproductive performance was monitored in two breeds of sheep (East Friesian Composite (EF) and Romney) over a three-year period in two different lamb production systems; an Accelerated and a Conventional once-yearly lamb production system (Chapter 3). Live weights at birth and weaning, and growth rates of the lambs resulting from the breeding of the ewes in those two systems were also assessed and compared. Average yearly pregnancy rates in the Accelerated lamb production system were markedly lower than in the Conventional system, and although lamb live weights at weaning were lighter in the Accelerated system, more frequent breeding of ewes resulted in a greater number of lambs born and weaned over the three years, and therefore a greater lamb output. Ewe efficiency (number of lambs born per ewe per year) was higher in the Accelerated system as a result of the increased frequency of breeding. East Friesian composite ewes had higher pregnancy rates in the Accelerated system than Romney ewes, but in the Conventional system, there was no breed difference.

Two factors that were not examined in Chapter 3 were the labour requirements for the main animal husbandry tasks and energy requirements of the ewes in the different systems. These were calculated in Chapter 4 and, as expected, both labour input for the system and energy requirements of a ewe were higher in the Accelerated than in the Conventional system. Labour requirements were calculated on a per animal basis, with assistance from the farm manager, and the final calculation indicated that labour input was 8% higher per lamb weaned, in the Accelerated system. The tasks that contributed to a major portion of this difference were factors associated with the breeding period, and as there were more breeding periods within the Accelerated system, and exogenous reproductive hormones were administered, the labour input was expected to be higher.

In order to provide a direct comparison between the two systems, energy requirements for a ewe in each system were based on a ewe of the same weight (60 kg) grazing the same contour (rolling hill country). Factored into these calculations were the number of lambs born and weaned per ewe per lambing period, and lamb live weights at birth and weaning from Chapter 3 (averaged for both breeds). Due to the design of the Accelerated system, the requirements for three different scenarios were calculated based on when a ewe was bred (e.g. January/August, March/November or June). January-bred ewes had two gestations and one lactation, but due to a lower number of lambs born and weaned, and lighter live weights at birth and weaning compared to the Conventional system, required 8% less energy than a ewe in the Conventional system. A ewe bred in March or June in the Accelerated system however, had 1½ gestations and two lactations, and required 7% more energy than a ewe in the Conventional system. On average a ewe in the Accelerated system requires 6% more energy than a ewe in the Conventional system and if the weaning live weight in the Accelerated system can be improved by 4.5 kg by delaying weaning approximately three weeks (Chapter 10), energy requirements would be, at most, 16% higher. However, per kilogram of lamb weaned, a ewe in the Accelerated system required 6% less energy than a ewe in the Conventional system.

Although lamb output and ewe efficiency was higher in the Accelerated system, the overall pregnancy rates were disappointing. Chapter 5 focused on the Accelerated lambing flock, and on the five different breeding and lambing periods each year. Aseasonal pregnancy rates are pivotal to the success of any accelerated or out-of-season lamb production system, and while it was expected that aseasonal pregnancy rates would be suboptimal in comparison to seasonal breeding periods, values as low as 33% were recorded. Of the two breeds chosen, the Romneys used in this research had lower pregnancy rates during the aseasonal breeding periods (August, November and

January). East Friesian Composite ewes also had low pregnancy rates in August and November, but had significantly higher pregnancy rates than the Romney ewes in January, the transition back into the breeding season, which indicates a shorter aseasonal breeding period.

If low aseasonal pregnancy rates can be addressed, there is potential for this Accelerated lamb production system to be improved. Therefore, identification of causes of low reproductive performance and methods of improvement were investigated in Chapters 6 to 9.

Data gathered early in the experiments related to Chapters 3 and 5 indicated that ewes were being marked by the ram (i.e. they were being mated), but at pregnancy diagnosis were identified as being non-pregnant. The success of events related to pregnancy, or lack thereof, between mating (Day 1-3) and pregnancy diagnosis (Day 62) was unknown, and it was hypothesised that these could include reduced ovarian activity, conception or implantation failure, or an inability to maintain pregnancies.

In Chapter 6, it was postulated that ovarian observations would elucidate the extent to which inactive ovaries were responsible for low out-of-season pregnancy rates. Ovaries of the ewes were examined laparoscopically on Day 9 of the five breeding periods in the accelerated lamb production system (14th January, 28th March, 9th June, 21st August and 2nd November). It was found that a majority of the ewes had corpora lutea present on their ovaries at all breeding periods, therefore ovarian inactivity was disregarded as a limiting factor for unsuccessful aseasonal pregnancies.

The findings of Chapter 6 suggested that events normally resulting in pregnancy were failing to occur somewhere between Day 9 and Day 62. In Chapter 7 it was hypothesised that serum progesterone concentrations from Day 8 to 39 would indicate whether ovulation occurred, if embryonic mortality post maternal recognition occurred or whether abnormal corpora lutea were present (whether they be low-progesterone secreting or short-lived corpora lutea). Ewes were sampled in the spring and autumn breeding periods only and, following pregnancy diagnosis were categorised into groups for analysis; non-mated, mated but non-pregnant or pregnant. A small proportion of ewes were judged to have had no ovulation, abnormal (low progesterone secreting) corpora lutea, early luteolysis (short-live corpora lutea) or early embryonic mortality. Mean progesterone concentrations indicated that ovulation was occurring and early embryonic mortality was not. There are many events which may be contributing to low aseasonal reproductive performance (including maternal recognition of pregnancy, unsatisfactory uterine environment and seasonal effects on the ram). The next logical step for further research would be to focus on factors surrounding maternal recognition of pregnancy.

In an attempt to improve aseasonal pregnancy rates, Romney ewes were subjected to artificially induced long days (Chapter 8). It was postulated that exposure to 24 hours of light (artificial + natural) in spring, when day light hours were increasing, would break the photorefractoriness associated with seasonality in sheep and induce reproductive activity. This experiment encompassed the hormonal induction regime used in Chapters 3 and 5, and compared the reproductive performance with ewes treated with progesterone and eCG, and exposed to light. Further, a secondary objective was to assess if the addition of artificially induced long days could eliminate the use of eCG. Lighting did not improve any of the reproductive parameters measured and when eCG was not used (progesterone + light), pregnancy rates were significantly lower than either of the other two treatments. Results obtained highlighted the necessity of eCG in out-of-season breeding programs.

Another potential method for inducing ewes to breed out-of-season is administration of melatonin implants. The hypothesis for this experiment was that melatonin would increase the reproductive performance of ewes bred during the spring anoestrus period (October). This experiment followed the same hormonal induction regime used in Chapters 3 and 5 in addition to melatonin (for 2/3 of the ewes), which were treated with melatonin implants. The results showed promise, but only when progesterone and eCG were used in conjunction with melatonin implants (Chapter 9).

Ewes treated with melatonin + progesterone + eCG had higher pregnancy rates, conception rates and litter size compared with ewes treated with progesterone + eCG. Reproductive performance was disappointing when melatonin + progesterone were used with nearly 60% of treated ewes failing to display oestrus, and only 6% subsequently becoming pregnant. The increased reproductive performance of ewes treated melatonin + progesterone + eCG resulted in 61% (111 vs 69) more lambs produced per 100 treated ewes compared with the ewes treated with progesterone + eCG. This suggests melatonin implants may have a place in accelerated and out-of-season breeding programs in New Zealand when used in conjunction with progesterone and eCG.

In the Accelerated lamb production system, lamb live weights at weaning are lighter than in the Conventional system (Chapter 3). This was primarily due to the age of the lambs at weaning as they were weaned at an average age of 69 days compared to 96 days in the Conventional system. In the final experimental chapter it was postulated that weaning could be delayed by three weeks as a means of increasing lamb live weight at weaning, and that ewes could be bred during the non-breeding season whilst they were suckling lambs. In Chapter 10, ewes and their lambs were either weaned at 69 or 90 days post partum. Results were again promising, with no difference in reproductive measurements between the lactating and non lactating ewes, indicating that it would not be deleterious to breed lactating ewes in an accelerated lamb production system. Lamb live weights at 90 and 120 days of age were significantly heavier in the lambs that were weaned at 90 days compared to lambs weaned at 69 days. These results suggest that it is possible to delay weaning (to achieve heavier lamb weaning weights) and breed lactating ewes in an accelerated or out-of-season lamb production system.

11.3 Limitations and weaknesses identified

Experimental design limitations

Ideally, at the start of the experimental period, different techniques for inducing aseasonal reproductive activity should have been investigated prior to the Accelerated system beginning. The techniques chosen were based on induction regimens that were (a) considered to be practical for industry use and (b) had previously been reported to be successful. If the experiment were to be done again, it is recommended that different techniques be tested for each of the different breeding periods, particularly as two sheep breeds were used and these two breeds appeared to have differing performances at certain breeding periods. Results from Chapters 3, 5 and 6 provide information that East Friesian Composite ewes respond differently than Romney ewes during the January breeding period.

Lack of adequate ram and semen testing

In Chapters 3, 5 and 6, rams underwent examinations by a veterinarian to ensure they were in a condition fit to breed and semen tests were conducted (mobility, proportion normal and proportion alive). Season is known to affect reproductive activities and semen characteristics, but a more conclusive and in-depth analysis of seminal properties or characteristics was not undertaken. For future research with aseasonal breeding programs, it is recommended that have a more comprehensive ram testing regimen be included.

Breed selection

More than half of the New Zealand sheep flock contains Romney genetics, including composites (MWNZ, 2001). For this reason, the Romney was selected as one of the breeds to be trialled. The other breed choice available was the East Friesian Composite, chosen for out-of-season reproduction and increased milk production, proved to be more suitable for aseasonal reproduction.

Confounding breeding periods and eCG dose rates

Month of breeding and eCG dose rate were confounded in Chapters 3 and 5 as the aim of the experiment was not to choose which regimens were optimal for each breeding period. Therefore, the effect of eCG and month of breeding could not be separated, nor could the effect of eCG, month of lambing, or season be assessed for its effect any of the reproductive variables measured.

Number of ewes available for intervention studies

In Chapter 8 (the lighting experiment) and Chapter 9 (the melatonin experiment), additional treatment groups should have been included in order to more effectively compare the effects of melatonin or light. These two experiments were conducted in spring, and the availability of a sufficient number of ewes with the minimum post partum interval (for uterine involution) posed a problem. Group sizes of 100 animals were required for a power of 80% and for a 12% difference in pregnancy rates between treatments to be significant. It is recommended in the future to increase the number of treatment groups, ideally, to 6 (as represented in Table 11.1). If this design were to be used, direct comparisons between the use of melatonin/light, progesterone and eCG could be made (e.g. Treatment number 1 vs 4, 2 vs 5 and 3 vs 6 etc). One additional limitation with the lighting experiment was the size of the shed in which ewes were housed. This limited the number of sheep that could be exposed to light, although a control group could have been included (Treatment number 1 in Table 11.1).

Table 11.1 Proposed experimental groups and treatments for further experimentation into the effects of melatonin implants or artificial light on reproductive performance in sheep bred during the non-breeding season.

Treatment number	Melatonin	Lighting
1	Control (- Mel, - progesterone, -eCG)	Control (- Light, - progesterone, -eCG)
2	+ Progesterone	+ Progesterone
3	+ Progesterone, + eCG	+ Progesterone, + eCG
4	+Mel	+ Light
5	+ Mel, + progesterone	+ Light, + progesterone
6	+ Mel, + progesterone, + eCG	+ Light, + progesterone, + eCG

11.4 Recommendations for further research

The successful establishment and maintenance of pregnancy following copulation is very complicated and relies on the success of a great number of steps: The ram needs to produce and ejaculate normal, functional spermatozoa, and the ewe needs to produce and ovulate normal, fertilisable ovum. Some of these stages that could be considered more pertinent in the context of out-of-season reproduction in sheep are discussed below, and are further broken down into stages related to the ewe (Figure 11.1) and those more relevant to the ram (Figure 11.2).

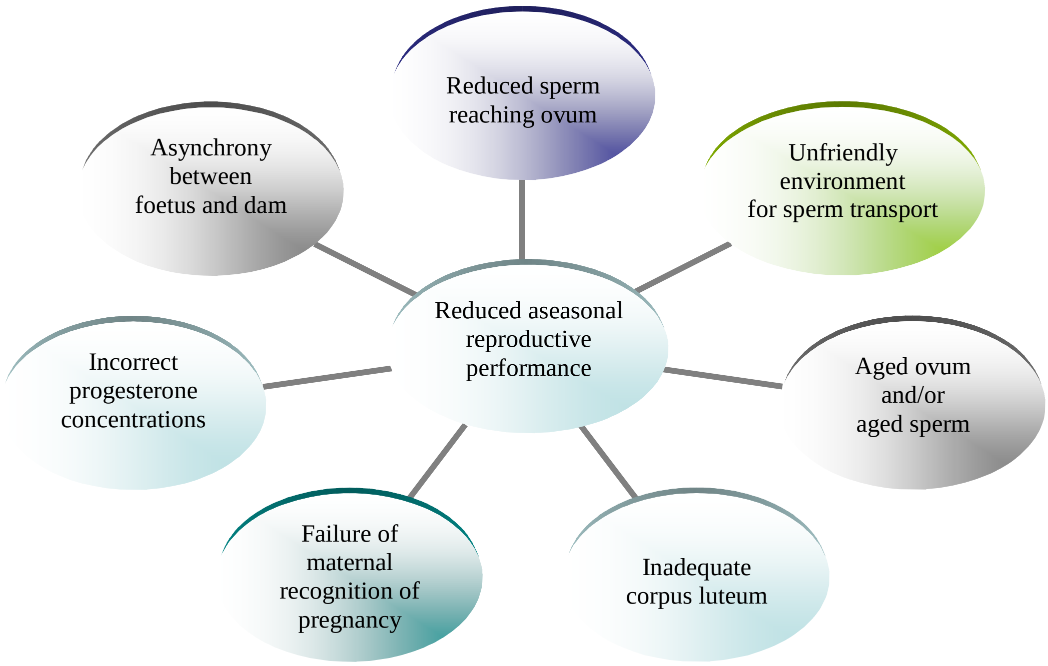

Figure 11.1 Possible explanations for reduced reproductive performance in ewes bred out of season.

Breed differences and genetics

The possibility of using other breeds of sheep should be further investigated and since the breed of ram has been shown to influence the onset of oestrus (Tervit and Peterson, 1978) or increase reproductive performance (Nugent et al., 1988), changing ram breed and using that ram as a terminal sire should also be investigated. Differences in the length of the breeding season, and onset of oestrus and anoestrus have previously been demonstrated in different breeds of ewes (Wheeler and Land, 1977). For example, Finn Sheep and Dorset (horned and polled) are both breeds that have been shown to be successful in accelerated lamb production systems (Walton and Robertson, 1974; Goot and Maijala, 1977; Fahmy, 1990). While selection based on the genetic ability of sheep to breed during the anoestrus period may be slow, Al-Shorepy and Notter (1997) have suggested that genetic selection can be used improve fertility in autumn-lambing sheep flocks. A melatonin receptor gene has also been located in sheep (e.g. (Messer et al., 1997; Pelletier et al., 2000; Notter et al., 2003)) and through genetic testing, can be located in individual sires, although this may be an expensive means to improving aseasonal reproduction that may also take a long period of time.

Effects of exogenous progesterone

One possible explanation for poor aseasonal pregnancy rates is related to the use of exogenous progesterone and its effects on cervical mucous, uterine contractions and sperm. Several studies conducted in the 1970s indicated that exogenous progesterone affects cervical mucous flow, viscosity (Croker and Shelton, 1974; Rexroad and Barb, 1977) and volume (Smith and Allison, 1971) which are important in the migration of sperm through the reproduction tract (Gibbons and Mattner, 1966; Moghissi, 1966). Higher reproductive losses due to increased fertilisation failure and embryonic mortality have been reported in progesterone/eCG-treated ewes during the breeding and non-breeding seasons, accompanied by a decrease in the number of accessory sperm per ovum (Lunstra and Christenson, 1981). An asynchrony between the embryo and the uteri/dam was thought to be responsible for the increased embryonic mortality (Goff, 2002). This is an area that has received little attention in recent years, both during the breeding and non-breeding seasons, and is an area that warrants further investigation.

Maternal recognition of pregnancy

Analysis of progesterone concentrations indicated there were no seasonal differences and observations of individual ewe progesterone profiles showed that most ewes did not experience embryonic mortality. The next stage is to investigate events associated with the maternal recognition of pregnancy.

The major cause of preimplantation embryonic mortality is thought to be caused by a lack of signal between the embryo and the uterus (Lafrance et al., 1989; Goff, 2002). Failure of the embryo to provide an adequate signal (between Day 10 and Day 21 of gestation) can lead to an asynchrony between the embryo and the maternal uterine environment, thus leading to embryonic mortality (Roberts et al., 1999). The identification and measurement of cytokines produced by the peri-implantation embryo (Spencer et al., 2004) can be used to ascertain if adequate embryonic to maternal signally is occurring. While speculative, this area has not been investigated in relation to aseasonal reproductive failure in sheep, and is perhaps an area worth investigating.

Ewe – foetal relationship

Examination of the literature would suggest there are no reports specifically focused on effects of season (i.e. the non-breeding season) on the synchrony between the conceptus and the uterus. Nevertheless, by linking the findings of several areas of research, an association between season and the ewe-foetal relationship can be found. For example, progesterone concentrations over the oestrus cycle or early pregnancy, albeit induced, in the non-breeding season are lower than that measured during the breeding season (Rhind et al., 1978; Forcada et al., 2003; Coelho et al., 2006). Low progesterone concentrations at or around ovulation, mating and early gestation have been directly associated with early embryonic mortality (Brien et al., 1981; Ashworth et al., 1989) due to a lack of foetal to ewe signalling (Lafrance et al., 1989; Goff, 2002). Therefore, one could speculate that the low progesterone concentrations in ewes bred out of season may result in embryonic mortality, thus contributing to the low out-of-season pregnancy rates, despite the display of oestrus by the majority of ewes presented to the ram. It is recommended that progesterone concentrations before, during and post oestrus be investigated, and factors associated with the maternal recognition of pregnancy be examined.

Interleukin- 8 (IL-8)

Mitchell et al. (2002) found that the expression of IL-8 on the cervix of sheep was reduced during the oestrous cycle after induction with intravaginal progesterone or intramuscular prostaglandin administration, and proposed the IL-8 was responsible for the dilation of the cervix required for passage of the sperm across the cervix. The expression if IL-8 is under the influence of reproductive hormones (Critchley et al., 1999; Garcia-Velasco and Arici, 1999; Mitchell et al., 2002), hence, any hormonal imbalance could be influencing the expression of IL-8. Further, due to the use of artificial progesterone in accelerated and out-of-season lamb production systems, investigation is required to ascertain its effect on the expression of IL-8 during the breeding and non-breeding seasons.

Ram seasonality and seasonal differences

In addition to possible complications or failures of various stages of reproduction in the ewes, the ram can also contribute to failure of reproduction in the ewe. This PhD research has focused on the ewe, although the effect of seasonality on the ram can not be disregarded as having a direct effect or having at least some contribution to low out-of-season reproductive performance. However, indications of possible stages of reproductive failure associated with the ram are highlighted in Figure 11.2 and are briefly mentioned in the text. Figure 11.2 shows where some of these complications or failures may arise and all these factors have previously been shown to be affected by season and/or linked directly to practices associated with aseasonal reproduction.

Hormone concentrations in seminal plasma affect fertilisation capabilities (Hess et al., 1997; Luconi et al., 2002) and these concentrations can vary throughout the year (Dimov and Georgiev, 1977; Mandiki et al., 1998; Lincoln, 2002; Shore et al., 2003). The addition of prostaglandin to semen had previously been shown to increase fertility in artificially inseminated ewes (Dimov and Georgiev, 1977).

Interluekin-8 has been shown to play on important role in transportation of sperm across the cervix (Mitchell et al., 2002) and this expression of IL-8 is controlled by hormones, primarily oestrogen (Arici et al., 1996; Garcia-Velasco and Arici, 1999) triggering the release of prostaglandin from the uterine tissue (Claus et al., 1987; 1990; Willenburg et al., 2004), which in turn, dilates or softens the cervix (Rigby et al., 1998; Calder and Embry, 1973). Experiments with IL-8 (Mitchell et al., 2002) have shown that the expression of IL-8 is triggered by semen. The changes in seminal hormonal concentrations may be contributing to an overall poor reproductive performance during the non breeding season.

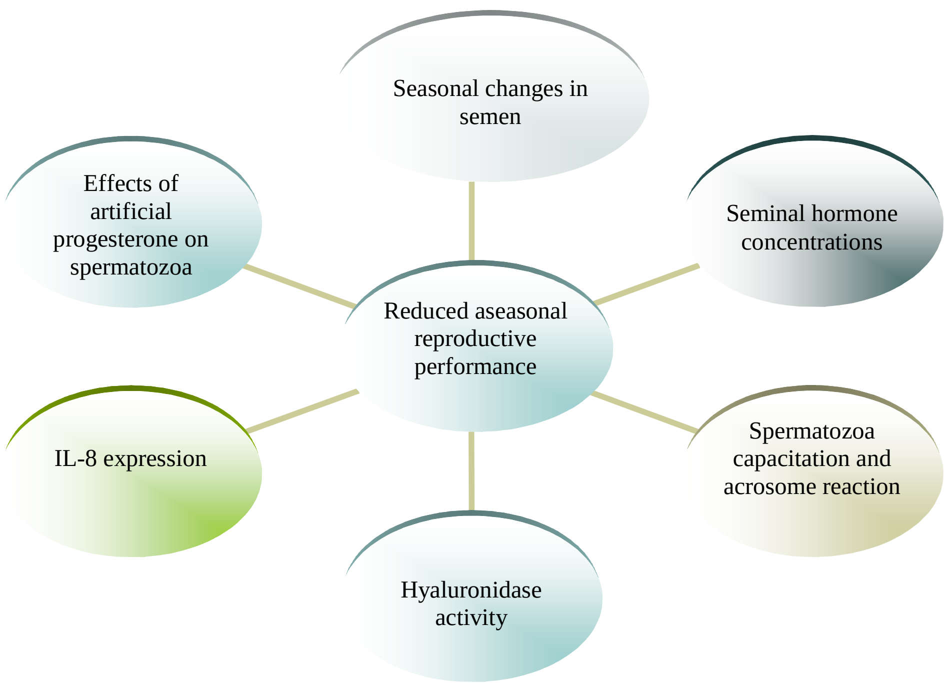

Figure 11.2 Possible reasons for reduced seasonal reproductive performance in ewes as a result of seasonal affects on the ram.

Further, progesterone and oestrogen play essential roles in spermatozoa capacitation and acrosome reactions, both of which are essential for successful fertilisation (Hunter et al., 1999; Lukoseviciute et al. 2004; 2005). The enzyme hyauronidase is also important in the maturity of sperm and this too has been shown to differ between seasons (Mandal et al., 2004). Research is these areas have been scant and seldom has the experimental animal been the ram. Further research in this area is recommended to elucidate if there is in fact differences in seminal hormone concentrations and with hyauronidase.

Artificial progesterone has been shown to affect spermatozoa and sperm transport. Several studies have reported decreased numbers of spermatozoa in the uterus, oviducts and/or fallopian tubes of progesterone treated ewes relative to untreated ewes (Quinlivan and Robinson, 1969; Hawk and Conley, 1971; 1972; 1975; Hawk and Cooper, 1977), lower sperm survival (Quinlivan and Robinson, 1969) and increased sperm breakage (Hawk and Conley, 1971; 1973). While this research was done some time ago, little attention has been directed towards this area and this also, is an area worthy of further investigation, particularly since accelerated lamb production systems depend on the usage of out-of-season breeding and therefore artificial progesterone.

11.5 Overall summary and conclusions

One of the main objectives of this PhD research was to assess an accelerated lamb production system, and to compare it with a conventional once-yearly lamb production system. The accelerated lamb production system chosen for this research was designed to have five breeding periods within one calendar year, thereby giving individual ewes the opportunity to lamb five times in three years. The research period ran from March 2003 when the first breeding period began, to August 2006 when the lambs were weaned from the last group of ewes that were mated, and included 15 breeding and lambing periods.

This research showed that accelerated lamb production has the potential to be used in the sheep industry New Zealand providing some of the weaknesses identified, can be addressed. The first and perhaps biggest of these weaknesses is the poor reproductive performance of ewes during the non-breeding season. Methods of overcoming this inadequate aseasonal performance were investigated and were not entirely successful, although melatonin implants used in conjunction with progesterone and eCG during the spring-breeding period yielded 61% more lambs per 100 ewes treated compared with progesterone and eCG alone. This increase however, did not come without the use of artificial progesterone and eCG indicating the importance of these two artificial reproductive hormones in aseasonal breeding. Artificial photoperiod was also examined as a means of increasing reproductive performance of spring-bred ewes, although it proved to be unsuccessful and impractical for use in the New Zealand sheep industry.

Investigations into time input and ewe energy requirements over one year indicated that time input and ewe energy requirements were higher in the Accelerated system. However, energy requirements per kilogram of lamb weaned was lower in the Accelerated system compared to the Conventional system, due to more frequent breeding and lambing.

Two experiments focused on the identification of the specific time when pregnancy was failing. Via ovarian examination, it was found that a majority of ewes had active ovaries and therefore, ovarian inactivity can be eliminated as a cause of low out-of-season reproductive performance. The other experiment was successful in the elimination of embryonic death as a factor responsible for aseasonal reproductive failures. Although a small number of ewes did appear to loose their conceptus during the early part of gestation, a majority of ewes that were mated appeared to be failing to conceive. Whether the failure of this conception was due to factors attributable to the ewe or to the ram was not identified in this research. Fertilisation of the ovum, and the implantation and growth of the conceptus is an intricate, complicated process with intertwining actions of many hormones, proteins, cells and signals. This is an area of research that requires more attention if aseasonal breeding is to become successful with seasonal breeds of sheep. The choice of sheep breed (ewe and/or ram) may be used to mitigate some of the poor reproductive performance achieved during the non-breeding season.

11.6 Concluding remarks

One of the first objectives of this research was to provide proof of concept to the sheep industry that an accelerated lamb production system would work in New Zealand. This research showed that such a system could work, but that there are particular areas which require more research to further improve the system, namely aseasonal reproductive performance. Assessment of labour and ewe energy requirements indicated that both these factors are increased in an accelerated lamb production system, but can be offset with an increased number of lambs weaned per ewe per year. However, farmers wishing to implement an accelerated lamb production system should consider the increased requirements of both labour input and feed (due to increased energy requirements) despite the increased lamb output. The use of exogenous reproductive hormones increase the cost of operating an accelerated or out-of-season lamb production system and this also needs to be considered. Finally, to achieve higher returns per lamb weaned (i.e. increased weaning weights), breeding lactating ewes should be considered as an option in an accelerated lamb production system, although this increases the energy requirements of ewes. Nevertheless, accelerated lamb production can work under pastoral conditions in some regions in New Zealand and aseasonal breeding may be an option for other areas where climatic conditions permit or warrant.

The overriding factor that will decide if farmers will adopt this system is the premium they will receive for out-of-season bred lambs. Incentives to produce lambs outside of the normal breeding seasons are required in advance to allow farmers to plan these systems.

"I count him braver who overcomes his desires than him who conquers his enemies; for the hardest victory is over self." Aristotle BC 384-322

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