B.GOA.1902 Final Report (Literature Review)

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ACRONYMS

AI	Artificial insemination
AFR	Alternative feed resources
AHA	Animal Health Australia
ART	Assisted reproductive technologies
ASBV	Australian Sheep Breeding Value
AWI	Australian Wool Innovation
BCS	Body condition score
BWBL	Best Wool Best Lamb
CAMAL	Cornell Alternate Month Accelerated Lambing
CIDR	Controlled internal drug release (device)
CL	Corpus luteum
CP	Crude protein
CRC	Cooperative Research Centre
DINZ	Deer Industry New Zealand
DMI	Dry matter intake
DPI	Department of Primary Industries
DSE	Dry sheep equivalent
EBV	Estimated Breeding Value
eCG	Equine chorionic gonadotropin
ET	Embryo transfer
FAWC	Farm Animal Welfare Council (UK)
FOO	Feed on offer
FSH	Follicle-stimulating hormone
GnRH	Gonadotropin-releasing hormone
GH	Growth hormone
GICA	Goat Industry Council of Australia
HPA axis	Hypothalamus–pituitary–adrenal axis
HPG axis	Hypothalamus-pituitary-gonad axis
IGF	Insulin-like growth factor

JIVET	Juvenile in-vitro embryo technology / transfer
LH	Luteinising hormone
LOPU	Laparoscopic ovum pick-up
LW	Liveweight
MAFF	Ministry of Agriculture, Forestry and Fisheries (NZ)
MLA	Meat & Livestock Australia
ME	Metabolisable energy
MOET	Multiple ovulation embryo transfer
NEFA	Non-esterified fatty acids
NKB	Number of kids born (EBV)
NKW	Number of kids weaned (EBV)
NLIS	National Livestock Identification System
NRC	National Research Council (USA)
NSW	New South Wales
NZ	New Zealand
OSU	Ohio State University
PBS	Phosphate buffer solution
PMSG	Pregnant mare serum gonadotrophin
SCA	Standing Committee on Agriculture
SE	Standard error
UK	United Kingdom
UOC	University of California
USA	United States of America
USDA	United States Department of Agriculture

1. INTRODUCTION

This literature review of advanced breeding systems was undertaken as part of the ‘Dough from Does’ project for Meat & Livestock Australia (MLA). The literature review includes both goats and other small ruminant species and was undertaken to identify information gaps, recommend topics for additional research if needed, and recommend services, decision aid tools and resources for producers.

The consultants engaged the University of Melbourne Faculty of Veterinary and Agricultural Sciences Library to undertake the literature search. Below is a list of the main searches conducted, which were done without year of publication constraints.

- (("weaning") OR ("kid production" OR "kidding" OR "kidding interval" OR "kidding rate" OR "kidding season")) AND ("meat goat")
- (reproduction) AND ("meat goat")
- ("boer goats" or Rangeland or "kalahari reds") AND (reproduction)
- (("optimal breeding") OR ("best practice")) AND ("sheep" OR "ewe" OR "ewes")
- (("optimal breeding") OR ("best practice")) AND ("deer" OR "deer farming")
- ‘accelerated kidding’ and ‘accelerated lambing’
- ("goat kid*") AND (care) AND (wean* or "post wean*").

Many of the articles could be freely obtained online, while the remainder were purchased, mostly through Science Direct. In all, over 400 papers were reviewed.

There was a large number of articles about sheep reproduction specifically, many that were more generally about small ruminant reproduction and a modest number about goats specifically. There were very few relevant articles on deer reproduction. The goat literature included studies from all over the world including a diverse range of climates, production styles and breeds of goat. Thus, caution must be applied when interpreting these studies for potential application to Australian breeds and conditions.

The literature review provides detail on the female reproductive cycle. It then provides a review of the literature on the various means by which those features can be manipulated to optimise reproductive success. The strategies are divided into those that may be considered ‘natural’ and non-invasive, which includes maximising those characteristics and behaviours that occur naturally in breeding animals; and those that involve chemical or physical intervention, such as the use of hormones, artificial insemination or embryo transfer.

A considerable proportion of the literature reported data from academic studies which involved small numbers of animals in artificial experimental situations. It is difficult to directly extrapolate this information into ‘real life’ production systems. They do however provide a background of what is possible and identify ways in which new technologies and management techniques could be further investigated for realistic implementation onto Australian farms.

The literature review includes many references on research in sheep rather than goats specifically. While in some cases similar findings have been later substantiated in goats, and the two species do have some reproductive similarities, it cannot be assumed that all findings would be true for both species.

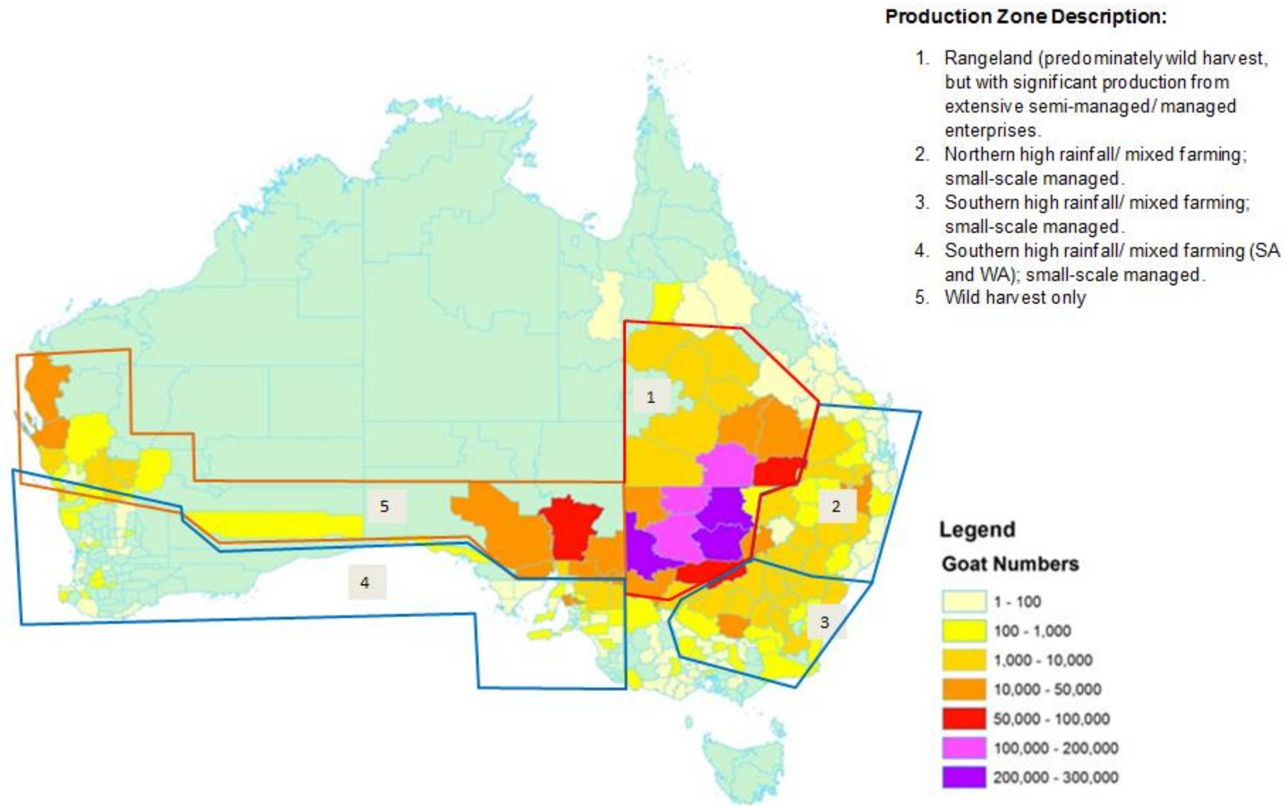
It should be noted that a quite recent (2012) special issue of the Journal Animal Reproduction Science (vol. 130), entitled ‘Reproductive Health Management of Sheep and Goats’, provides an excellent and more detailed scientific review of much of the material covered in this report.

2. INDUSTRY OVERVIEW

Australia's goat meat production has grown substantially over the last twenty years (MLA 2018a). Ninety percent of Australia's annual goat meat production is from Rangeland goats. Australia is a relatively small producer of goat meat on the global scale (MLA 2018a) but is the world's largest exporter of goat meat (50% of international trade). Ninety percent of goat meat produced in Australia is exported (MLA 2018d). Australia also exports live goats for meat. Of the $260 million total export value of goat meat only 1% is from live goats (MLA 2018d). The main export destination for live goats from Australia is Malaysia (MLA 2018b).

In 2017 there was estimated to be 4-6 million Rangeland goats and around 200,000 farmed meat goats in Australia (AgriFutures 2017). In Australia, goatmeat production occurs in a diverse range of climates and the management style also varies considerably. **Figure 1** shows the distribution of goats across Australia.

Originally, Rangeland goats were mostly harvested from wild and unmanaged populations. Although this type of production system requires minimal financial input, it can be significantly impacted by the season and is a challenging way to provide consistency in supply (MLA 2019b). Some rangeland producers are moving away from opportunistic harvesting alone towards more managed production systems and this has resulted in increased returns with improved supply, consistency, quality and weight of carcases (GICA 2019). However, a study of 31 goat meat-producing enterprises in New South Wales and Queensland in 2013 found 48% of producers interviewed were still reliant on opportunistic harvesting (Nogueira et al. 2015e), including 15 of the 17 producers (88%) from the pastoral region. The pastoral zone, as defined in this study includes Western New South Wales (NSW), south-western Queensland and central-western Queensland. None of the producers in the high rainfall area reported any opportunistic harvesting activities. Goats were considered the most important livestock enterprise on 55% of properties studied (Nogueira et al. 2015e). Fifty-three percent of producers from the pastoral area advised that the lack of continuity of goat meat supply was exacerbated by the long distances to abattoir and thus the cost of transport (Nogueira et al. 2015e) .



Source: Atkinson and Smith Unpublished; NLIS Ltd

Figure 1: The number of goats supplied from each NLIS region in Australia during the 2016-2017 financial year, overlaid with geographical production zones.

The volume of goat meat production varies considerable between states. The percentage of supply per state for the 2016-17 financial year is shown in Table 1 (MLA 2017).

Table 1: Goat meat supply by state

STATE	GOATS PROCESSED ANNUALLY AS % OF THE NATIONAL TOTAL
New South Wales	68%
Queensland	15%
South Australia	13%
Western Australia	3-4%
Victoria	Less than 1%

Source: (MLA 2017)

The survey of NSW and Queensland producers by Nogueira et al in 2012-2013 found that as the rainfall increased so did the stocking rate, and as the property size increased the stocking rate decreased, which would be expected (Nogueira et al. 2015e). The variation in use of management tools that might improve reproductive performance varied considerably between properties:

- Only among stud breeding enterprises was there a 'mating season' – that is, the females and males were separated during the non-breeding season.
- Thirty-five percent of producers carried out condition scoring and this was generally as simplistic as classifying condition as either 'good or bad'.
- Ultrasound was used to diagnose pregnancy in does in about 10% of enterprises.
- Weaning was a part of management on 61% of enterprises, and the target weaning weight was 25kg across all property types.
- Fifty-two percent of enterprises castrated male kids, and this was done between 3-6 months of age.
- The majority of enterprises had a 12-month interval between kidding.
- High rainfall producers used more criteria to select bucks and routinely culled stock compared to opportunistic harvesters that did not routinely cull. Pastoral farms kept 16% more young does for breeding stock than did high rainfall enterprises.
- All of the high rainfall enterprises provided supplementary feed to their goats and only this group used grain and crops as part of their supplementation. Forty-one percent of pastoral farms provided some supplementation. Across all farming types the majority of supplementation was given to does (68%), kids (61%) and bucks (55%) (Nogueira et al. 2015a).

Vaccinations were used on all seed stock properties but only two of the pastoral properties The study compares other reproductive outcomes between high rainfall and pastoral enterprises but differences in breeds, environmental factors and management styles make direct comparisons difficult. Although the target weaning weight for all enterprises was 25kg, this took longer to achieve on pastoral properties, and the weight gain per day varied from 105g/day to 204g/day. The average age of first mating and kidding for maiden does was significantly higher on pastoral properties. The high rainfall properties averaged 1.6 kids per doe while drier areas recorded 0.9 kids per doe. Kid mortality figures were not available for some properties but, where recorded, the average was 12% on high rainfall properties and 33% on drier, more remote properties. The pastoral producers reported that the common causes of death included starvation, dehydration, predators and old age. Predators included foxes, kangaroos, wild dogs and feral pigs (Nogueira et al. 2015b).

Full-blood Boer goats were used in high rainfall enterprises, while pastoral properties all ran Rangeland and Boer-cross goats. Thirty-five percent of producers interviewed had breeds other than Boer and Rangeland including Anglo-Nubian, Toggenburg, Saanen and Savannah. Some producers had tried introducing Boar goats into their rangeland enterprises to improve liveweight and carcase weight. There were reports that full-blood Boer bucks had poor reproductive outcomes with the Rangeland does (Nogueira et al. 2015b).

A natural breeding season was reported by 87% properties. This extended from December to May and the non-breeding season from June to December (Nogueira et al. 2015b).

Twenty-six of the 31 producers interviewed reported that they were willing to make changes over the following five years to improve profitability. Of the changes identified, the following can be linked to reproductive potential. The number of respondents who agreed that they would consider making changes in each area is also included:

- Use better-quality bucks (11/31);
- Reduce age at turn-off (6/31);
- Increase herd size (6/31);
- Reduce death rate (5/31);
- Increase marking rate (5/31); and
- Increase turn-off rate (5/31) (Nogueira et al. 2015e).

3. GOAT BREEDS

3.1 KIKO

The Kiko has been bred for meat production. It is a composite breed developed by selective cross breeding of feral does and with dairy breed bucks and the interbreeding of their offspring ((Batten 1987), as cited by (Browning et al. 2006)). The Kiko can produce well in a variety of conditions (Nye and Moore 2004).

In a study comparing the reproductive performance of Boer and Kiko goats raised in a semi-intensive production system in Alabama, United States of America (USA), the Kiko had a greater litter size at weaning and also had a significantly higher proportion of females that weaned kids. The Kiko also had significantly higher birth and weaning weights of kids (Okere et al. 2011).

3.2 BOER

The Boer goat has had a great impact on the goat meat industry globally, becoming known for its carcase quality, growth rate and conformation. Cross-breeding with Boer goats has also improved the performance of many indigenous breeds (Lu 2001). A study by Cameron et al (2008) compared the growth and slaughter characteristics of Boer cross Spanish and Boer cross Angora with a pure Spanish breed. The kids were raised artificially from 72 hours after birth on limited milk replacer and ad libitum access to a commercially prepared pellet diet. The average daily gain of the Boer cross goats was greater than the Spanish goats over the 16-week growth period. The dressing percentage and quality grade score of carcases, however, was similar between the groups (Cameron et al. 2001).

The precise origin of the Boer goat is unclear, although there are thought to have been genetic contributions from Indian, Angora, European dairy and indigenous goats of Africa. Five types of Boer goat are described in the literature ((Boer Goat Breeders Association 1998), as cited by (Erasmus 2000)), but it is the 'Improved Boer' goat that is used by commercial breeders. Breed standards are set by Boer goat breeder associations in particular countries and these vary slightly (Lu 2001).

The Boer goat is generally considered to be adaptable and able to survive in a variety of climatic conditions (Casey and Van Niekerk 1988). It tends to graze from a height of 160cm down to 10cm ((Aucamp and Du Toit 1980), as cited by (Casey and Van Niekerk 1988)). It also tends to eat a ration of 83% bush to 16% grass ((Viljoen 1980), as cited by (Casey and Van Niekerk 1988)). The use of Boer goats to manage bush encroachment and regrowth has been successful (Du Toit 1972).

The growth rate of Boer goats in good conditions can be 200g/day within the first 12 months. The benefit of this fast growth rate compared to that of other breeds is that Boers can meet market weights sooner and can breed earlier (Lu 2001).

The production and reproductive characteristics of Boer goats are presented in Table 2 and Table 3 respectively.

Table 2: Production features of Boer goats

CHARACTERISTIC	VALUE
Birth weight	3-4kg
Weight at weaning	20-25kg
Mature weight of bucks	90-130kg
Mature weight of does	80-100kg

Source: (Lu 2001)

Table 3: Reproductive features of female Boer goats

CHARACTERISTIC	VALUE
Conception rate*	90%
Kidding rate*	189%
Fecundity rate*	210%
Weaning rate at 120 days*	29 kg
Oestrus interval**	18-21 days
Mean oestrus length**	37.4 hours
Mean gestation length**	148 days
Post-partum anoestrus**	37 days (or 60 days if out of kidding season)
Sexual activity peak (southern hemisphere)**	April and May
Average litter size**	Almost 2
Female goat maturity**	6 months
Male goat maturity**	5-6 months
Doe: buck breeding ratio**	15:1 at 6 months of age 25:1 at 8 months of age or maturity

CHARACTERISTIC	VALUE
Milk production in first 12 weeks*	1.8-2.5 kg/day

Source: * (Malan 2000) (abstract only); ** (Lu 2001); *** (Raats et al. 1983)

Unlike most of the goat breeds, Boer goats are partially seasonal breeders. In one study complete anoestrus did not occur when does were provided with good rearing conditions. Boer does tend to cycle every 18 to 21 days. A cycle of less than 13 days is seen in 17% does, and a cycle of more than 25 days in 10% of does (Greyling 1990). This can be exploited to assist in overcoming the seasonality of goat meat production. Care in continuous breeding systems is required to ensure that underdeveloped doelings are not exposed to bucks (Lu 2001).

The naturally occurring oestrus cycles of Boer goats were studied in Irene (South Africa, 28^{O}13'S, 25^{O}55'E) over the period 1980-1982. The Boer doe was found to have an extended breeding season and be seasonally polyoestrous. The peak of sexual activity was in autumn, with the lowest activity observed in late spring and mid-summer. A significant negative correlation was found between the does' sexual activity and day length but a period of complete anoestrous was not observed in the Boer goat flock. It should be noted that the longest day length was recorded in December and January and during these months approximately 15% and 10% of the does were cycling (Greyling 1987).

The high rate of reproduction and extended breeding are important qualities of Boer goats in a meat-producing enterprise (Naude and Hofmeyr 1981).

In a contrasting study ovarian follicular activity in a small number of Boer goats (14) in the tropics of Queensland (Townsville, 19^{O}30'S, 146^{O}49'E) was compared in the breeding and non-breeding season. It was found that, during September and October (spring), all the goats were anoestrus, and by April all were cycling. Examination revealed that ovaries remained active during the non-breeding season and follicles continued to develop to preovulatory size. During the breeding season, however, larger follicles developed and there was greater follicular growth. The formation of follicular cysts and short oestrus cycles may affect the ovulation rate in the breeding season (Nogueira et al. 2015c). This differs from the findings of Lu (2001) and Greyling (1987) who found that Boer herds did not have an apparent anoestrus period. The difference may be explained by the different locations (latitude), different conditions (diet, stress), presence of male and technique to detect oestrus. In Greyling's (1987) study, oestrus was determined by the use of vasectomised rams while in the Nogueira et al (2015c) study, does were housed without males and anoestrus was described based on an absence of corpus luteum on concurrent ultrasounds. This variation in techniques, especially the presence of the buck could explain the variation in these results.

In a study comparing the fitness indicators and reproductive rates of Boer, Kiko and Spanish goats on subtropical pastures in the United States, it found that Boer goats were not as fit or productive as Kiko or Spanish goats. The Boer goats had a significantly higher incidence of lameness and internal parasites than the other two breeds. Reduced fitness is likely to result in higher costs, higher losses and reduced production. The Spanish and Kiko goats had better general disease resistance and were seemingly more suited to the subtropical conditions. The Boer goats had lower litter size and litter weight per doe than the Kiko and Spanish goats (Browning et al. 2006).

3.3 RANGELAND

Australian Rangeland goats have evolved from domesticated breeds of goats introduced during European settlement that have become well adapted to their environment. Rangeland goats are recognised as being hardy and able to survive in harsh dry conditions while still maintaining high fertility. They exhibit hybrid vigour when crossed with other breeds. The meat products from Rangeland goats are suitable for the goat meat trade and live trade (GICA 2019). Rangeland goats make up the bulk of Australian goat meat production, contributing 90% of the 1.5 million goats slaughtered annually (MLA 2019a). Mature feral does are thought to produce an average of 150-180% kids per year over their lifetime. When maiden does are joined at 18 months of age they very rarely produce twins (Norton 1985).

There are several different Rangeland goat enterprise options. These are summarised in Table 4.

Table 4: Rangeland goat enterprise options

ENTERPRISE	CHARACTERISTICS	POSITIVES	NEGATIVES
Pure wild harvest	⌖ Trap or muster goats from an unfenced environment. ⌖ Held briefly prior to transport.	⌖ Requires minimal infrastructure investment. ⌖ Suited to all areas frequented by Rangeland goats. ⌖ Opportunity to expand business to provide a service to other landholders. ⌖ Low labour and management requirement.	⌖ Limited capacity to add value or market livestock. ⌖ Limited access to livestock seasonally dependent - unable to supply consistently. ⌖ Can be periodically labour intensive. ⌖ Limited opportunity to respond to market signals. ⌖ Immediate need for trucks once goats are yarded.

ENTERPRISE	CHARACTERISTICS	POSITIVES	NEGATIVES
Harvest and hold – goat paddock/s	⌖ Trap or muster goats from an unfenced environment and confine in one or more goat paddocks. ⌖ Holding is generally for the accumulation of goats or the growing out of goats to market specifications.	⌖ Ability to control stocking rate within fenced area. ⌖ Increased ability to respond to market signals. ⌖ Can add value to confined goats.	⌖ Goat paddock fence investment and maintenance requirement. ⌖ Confined goats must be actively managed (i.e. provided with sufficient feed and water). ⌖ Grazing and stocking in the holding areas needs to be well managed to avoid pasture degradation. ⌖ Animal health issues. ⌖ Additional management costs such as those associated with identification tags.
Low input goat breeding	⌖ Multiple paddocks. ⌖ Semi-controlled breeding usually uses existing Rangeland bucks selected for desirable traits. ⌖ These are joined selected existing Rangeland does.	⌖ Ability to control stocking rate within fenced areas. ⌖ Ability to target specific markets. ⌖ Breeders are selected for conformation and to meet market specifications etc. ⌖ Greater control of cashflow.	⌖ Increased management requirement and cost. ⌖ Limited gene pool as there are no introduced does or bucks.

ENTERPRISE	CHARACTERISTICS	POSITIVES	NEGATIVES
High input goat breeding	Multiple, well fenced paddocks. Usually cross breeding Rangeland does with a meat goat such as a Boer buck. Accessible paddocks able to be readily mustered.	Increased ability to control stocking rate within fenced areas. Greater control of cashflow. Ability to target specific markets. Increased meat production potential. Hybrid vigour. Potential to turn off goats at market weight more quickly.	Increased management requirement. Higher buy in costs. Increased infrastructure costs. Limited high value marketing opportunities.
Depot	Aggregating large numbers of goats in confined areas for on-selling to buyers. Usually buying from other producers. Highly intensive, secure holding yards. Bulk goat handling facilities.	Reduced exposure to market variation as goats are usually traded on a margin basis. Ability to value-add through drafting, holding to aggregate lines or holding to add weight and grow into saleable goats.	Need to maintain throughput. High labour and management requirement. High reliance on transport.

Source: (MLA 2018c)

3.4 KALAHARI RED

The Kalahari Red originates from southern Africa. The breed is known for its ability to adapt to the arid and semi-arid savannah of southern Africa as well as its good foraging and excellent mothering ability (Kotze et al. 2004). Kalahari Reds are reported to have good resistance to parasites and disease and to require low labour input. It is reported that does normally kid without assistance, can breed year-round and have been known to kid three times in two years. The distinctive red colour provides good camouflage from predators when grazed on natural pastures. Kalahari Reds can be crossed with other breeds to improve carcase size and hardiness (Desilva 1995).

3.5 ANGLO-NUBIAN

The Anglo-Nubian is a British breed, created from a cross between British and Nubian breeds. They were imported into Australia in the late 1950s. It is generally regarded as a dual-purpose breed (milk and meat) and its breeding ability is less influenced by season than many other breeds. Anglo-Nubians are not heavy milkers but have been used to increase milk and meat production by crossing them over native stock in some tropical countries. They are better suited to the hot Australian conditions than some other dairy breeds and have become a popular milking breed in Australia (DPI 2019). Mature does should weigh at least 60kg and bucks 80kg (Nye and Moore 2004).

3.6 ANGORA

The popularity of Angora goats has wavered considerably over time. Imports to Australia began in 1853 and the number of animals increased until the 1900s before the flock size plummeted during the 1920-1930s and the grew again over the 1960-1970s. Angoras are mainly kept for their mohair, but they also provide meat which has been sold on both the domestic and export markets (DPI 2019). The Angora is not as prolific as some other goats breeds and twins are less common. The Angora carcase generally has a lower dressing percentage than sheep. Meat from young goats in good condition are considered a delicacy by some. From birth the kids need good protection from the weather as they do not tolerate cold and wet weather. After shearing. adult Angoras are also very susceptible to the weather conditions. Storms at these vulnerable times can cause excessive losses (OSU 1996).

3.7 SAANEN

The Saanen is an improved dairy breed that was first introduced into Australia in 1913. Like Anglo-Nubians, Saanens have been used in upgrading local breeds. The does are heavy milk producers and are efficient reproducers. Saanens are best suited to the cooler climates as they are sensitive to the sun (DPI 2019). They weigh around 65kg (OSU 1996).

3.8 MYOTONIC

The Myotonic goat is able to breed out of season. Does are able to kid twice a year and may have a litter size from 1-4. This breed has a recessively inherited trait called myotonia. When startled, Myotonics develop muscle stiffness, their hind legs and neck extend, and they often fall over (also called fainting). Each episode will last for 10-20 seconds (Luginbuhl 2015b). The Myotonic has been used as crossbreed stock for Boer goats. Normally the fainting is not expressed in crossbred animals as it is a recessive trait (Nye and Moore 2004). Myotonics are also known to be good mothers (OSU 1996).

3.9 SPANISH

The Spanish goat has been recognised for its toughness, coping with difficult conditons and good foraging qualities. They are able to breed out of season (Luginbuhl 2015b) They have been used for upgrading programs (DPI 2019). Bucks can weigh around 90 kgs and does 59 kgs. Spanish goats have been used to clear undesirable plants from pasture and rangeland (Nye and Moore 2004). They are known to have a small udder, which is desirable in rough rugged terrain as it is less likely to be damaged by the rough terrain and plants (OSU 1996).

3.10 CASHMERE

The Cashmere is a type of goat, one which produces a woolly undercoat or 'down', rather than a specific breed. Goats carry a gene for the down which can be selected for over time. The Cashmere goat is native to Mongolia (UOC 1992). The down coat protects Cashmere goats from harsh cold winters and they are also able to tolerate hot summers and drought periods. Cashmere goats are able to eat coarse grass but can also graze down to the roots of plants which can be destructive, leading to soil erosion and degradation of the land (Hays 2012).

3.11 TOGGENBURG

The Toggenburg is another dairy breed, arriving in Australia for the first time in the 1940s. It is not known to produce as well as the Saanen but it does produce milk over long periods. Toggenburgs prefer a cooler climate and cope with tropical conditions the least of the dairy breeds (DPI 2019). The does weigh around 55kg (OSU 1996).

3.12 BRITISH ALPINE

As the name suggests, this breed was developed by crossing local British goats with Alpine goats (from Switzerland). British Alpines were originally imported into Australia in 1958 (DPI 2019). The breed has been upgraded by crossing with Saanen and Toggenburg does (OSU 1996). It has been used extensively for upgrading native breeds. It is best suited to temperate climates with low humidity, where it is a medium to heavy milk producer (DPI 2019). British Alpines also tend to have an extended lactation and milk well through the winter (OSU 1996).

3.13 PYGMY

The Pygmy is a dwarf goat used mostly for meat production in West Africa while in the USA it is mostly a show breed. It copes well with humid weather, tends to breed year-round, and does commonly have twin kids (Luginbuhl 2015b).

The various breeds and their mature weights are summarised in Table 5.

Table 5: Mature liveweight of various goat breeds including their main production purpose

BREED	GENOTYPE	MATURE WT (KGS)	AUTHOR
Alpine (France)	Dairy	80-90	Fehr *et al* (1976) cited by McGregor (1985)
Anglo-Nubian	Dual purpose	80-90	Going into Goats (2006)

BREED	GENOTYPE	MATURE WT (KGS)	AUTHOR
Angora	Fibre	60-80	Going into Goats (2006)
Angora (Texas/Australia)	Fibre	50-60	Shelton & Huston (1966) cited by McGregor (1985)
Barbari (India)	Meat	35-45	Singh *et al.* (1980) cited by McGregor (1985)
Boer	Meat	100-110	Going into Goats (2006)
Boer - Improved (Sth Africa)	Meat	100-110	Campbell cited by Naude & Hofmeyr (1981) cited by McGregor (1985)
Condoblin	Rangeland	80-100	Going into Goats (2006)
Damascus (Cyprus)	Dairy	80-90	Louca *et al*. (1977) cited by McGregor (1985)
Kalahari	Desert	100-110	Going into Goats (2006)
Kambing/Katjang (Malaysia & Indonesia)	Meat	25-30	Devendra (1967) cited by McGregor (1985)
Rangeland	Rangeland	45-80	Going into Goats (2006)
Rangeland (Australia)	Rangeland	45-55	McGregor *et al* (1982) cited by McGregor (1985)
Saanan	Dairy	90-100	Going into Goats (2006)
Saanen (Britain, Australia)	Dairy	90-100	McGregor (1980) cited by McGregor (1985)

Source: Compiled by (Jolly 2013) from various sources as per the table (Devendra 1966, Louca et al. 1977, Lewis et al. 1996)

(Shelton and Huston 1966, Fehr et al. 1976, McGregor 1980, Singh et al. 1980, Naude and Hofmeyr 1981, McGregor et al. 1982, McGregor 1985, Blackburn 1995, MLA 2006)

4. FEMALE REPRODUCTIVE CYCLE

The breeding season in goats (and sheep) occurs in response to decreasing day length in late summer and early autumn. This leads to seasonal variation in the volume of meat production, with consequent effects on price (Abecia 2012) .

The onset of the breeding season and the length of the season varies with:

- Breed;
- Day length (photoperiod);
- Absence/presence of male;
- Nutrition;
- Environmental factors (humidity, temperature rainfall);

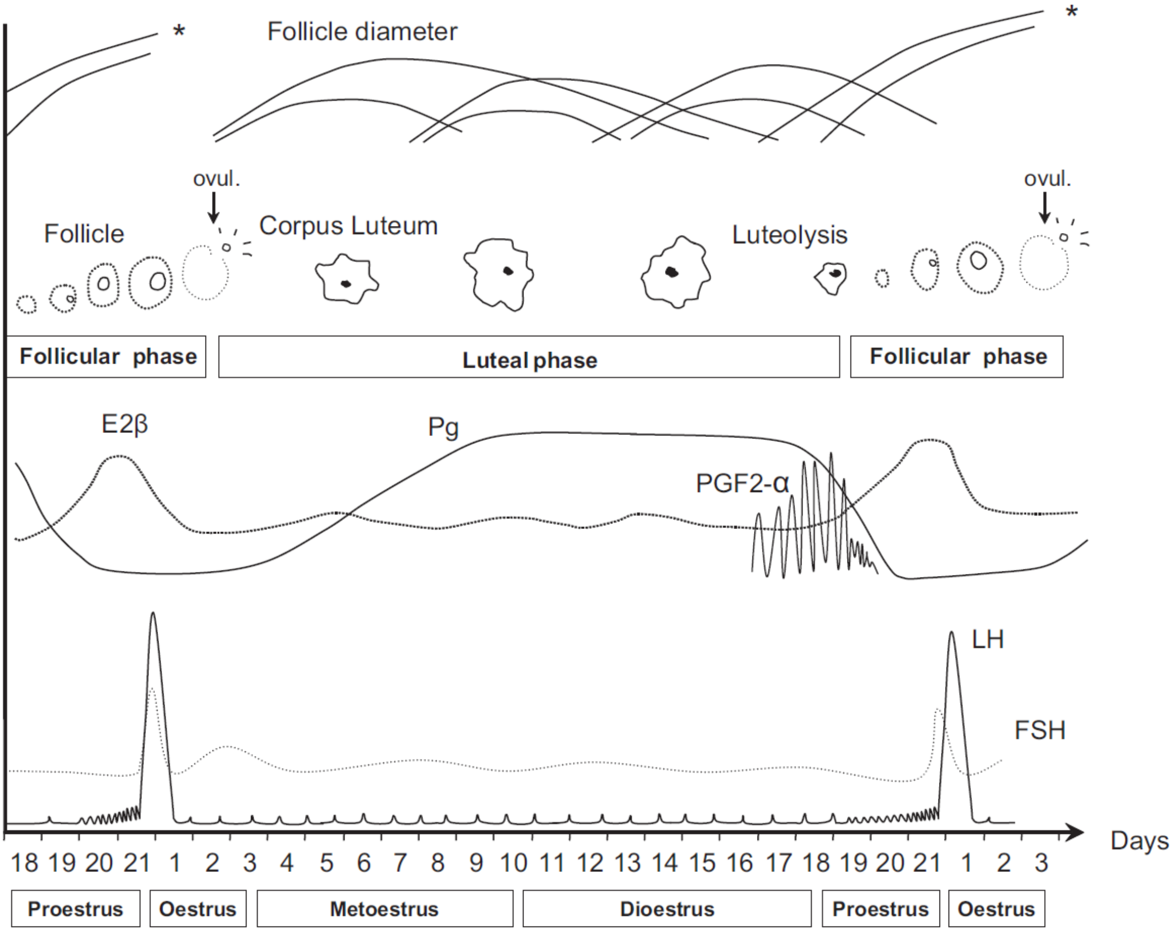
- Body condition;
- Physiological stage; and
- Breeding system.

Goats are polyoestrous – they have multiple oestrus cycles over the breeding season – and they ovulate spontaneously. Goats are generally regarded as seasonal reproducers, where the breeding season is generally shorter and restricted in temperate regions and longer or continuous in tropical regions. Food availability may influence reproduction with restricted food availability resulting in prolonged anoestrus and reduced production (Fatet et al. 2011).

4.1 GOAT REPRODUCTIVE PHYSIOLOGY

Goats generally have seasonal reproductive activity that varies with the photoperiod (which is discussed further below). Ovarian cyclic activity begins at puberty. During the ovarian cycle, ovulation occurs after a series of morphological, biochemical and physiological changes to the ovaries. There are two defined phases in the ovarian cycle: the follicular phase and the luteal phase.

Figure 2 is a schematic diagram of the physiological events of the goat oestrous cycle. It shows the follicular development, the hormonal changes and the names of the various stages of the cycle.



Source: (Baril 1993, Evans 2003) as cited by (Fatet et al. 2011)

Figure 2: Physiological events of the goat oestrous cycle

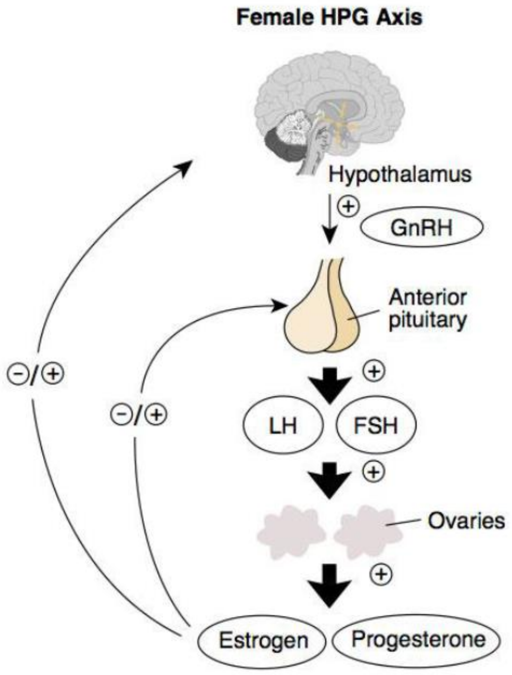
During the follicular phase there is development of a follicle to form an ovulatory follicle under the influence of follicle-stimulating hormone (FSH) from the pituitary gland. Recruitment of a number of 2-3mm gonadotropin-dependent antral follicles occurs, then the follicles enter terminal growth. Two-three of these follicles reach 4mm in diameter and enter the dominance phase. Luteinising hormone (LH) influences the follicle to reach the pre-ovulatory stage (6-9mm). Subordinated follicles degenerate in a process called follicular atresia. The larger follicles secrete oestradiol 17-beta, which induces oestrous behaviours and acts on the gonadotropic axis. Increased gonadotropin secretion induces an LH surge and ovulation which occurs 20-26 hours later. Luteinisation of the follicular cells follows (Fatet et al. 2011).

The luteal phase begins at ovulation. The cells of the ovulating follicle become luteal cells and form a corpus luteum (CL). Progesterone is produced by the CL and the concentration remains high for 16 days. Gonadotropin-dependant follicular growth continues during this phase but ovulation is inhibited by the progesterone. At 16-18 days, if the doe has not become pregnant the uterus produces prostaglandin F2 alpha, which induces the CL to regress (called ‘luteolysis’). Consequently, there is a decrease in the progesterone concentration in the blood which removes the inhibition of secretion of gonadotropin hormones. A new follicular phase then begins ((Baril 1993), as cited by (Fatet et al. 2011)).

Joining normally occurs before ovulation, so sperm will be present in the oviduct at the time of ovulation. Survival time for sperm once in the oviduct is about 30 hours. Some sperm is retained in the cervix where it can survive for three days. It is continuously released into the uterus over that time ((Hulet 1980) as cited by (Fatet et al. 2011)). Ova remain viable for 10-25 hours. Fertilisation usually occurs within a few hours of ovulation in the ampullae of the oviduct. The fertilised ovum then begins to divide and moves down the oviduct and reaches the uterus in 4-5 days. The embryo implants 18-22 days after the beginning of oestrus. In goats the functioning CL provides a vital source of progesterone to maintain the pregnancy. The progesterone produced in the placenta of goats is insufficient to maintain pregnancy ((Sheldrick 1981), as cited by (Fatet et al. 2011)).

Gestation averages 149 days. Progesterone levels drop 12-24 hours before labour and parturition (Fatet et al. 2011).

Figure 3 shows the female hypothalamus-pituitary-gonad (HPG) axis and the interaction of the various hormones that are involved in the reproductive cycle. The positive and negative feedback of the hormones onto the hypothalamus and the pituitary are also shown (Kong et al. 2014).



Source: (Kong et al. 2014)

Figure 3: Female hypothalamus-pituitary-gonad endocrine axis

4.2 PUBERTY

Puberty is generally identified as the time when either males and females are capable of breeding. The time of onset of puberty varies with breed, the season in which the animal was born and its nutrition. Animals provided with poor nutrition will have delayed onset of puberty. Kids born in spring tend to reach puberty sooner than those that are born in autumn (Fernandez 1977). Generally, goats reach puberty at 4-6 months of age ((Fernandez 1977) and (Luginbuhl 2015a)). It is recommended that females are not joined, however, until they reach 60-70% of their adult weight (Fernandez 1977). Determination of when to breed a doe should consider weight and body condition of the doe, her age and size (USDA 2015).

Table 6 shows the age at puberty for some meat producing goat breeds. The table shows the variation in onset of puberty of the Boer goat when born in seasonal anoestrous compared to the breeding season (Rekik et al. 2012).

Table 6: Age at puberty of some meat producing breeds of goats.

BREED	COUNTRY	AGE AT PUBERTY (DAYS)	SPECIFIC INFORMATION	REFERENCE
Boer	South Africa	191	Born during seasonal anoestrus	Greyling (2000)
Boer	South Africa	157	Born during the breeding season	Greyling (2000)
Creole	Mexico	172 (128-204)	Born between August and December	Delgadillo et al (1997)
Black Bengal	NS	196		Bhattacharrya et al (1984)
Baladi	Syria	180-210		Kassem (2005)
Damascus	Cyprus	220-270		Mavrogenis (2005)
Matou	China	108 (79-216)	Based on first oestrus	Moaeen-ud-Din et al (2008)

Source: (Mavrogenis 1983, Bhattacharrya 1984, Delgadillo 1997, Greyling 2000, Kassem 2005, Moaeen-ud-Din 2008), refigured by (Rekik et al. 2012). NS=not specified

4.3 OESTRUS CYCLE

During each breeding season, a doe may have several oestrus cycles and the number of these varies with the length of the breeding season and the goat breed. The average length of the oestrus cycle in goats is 21 days although this varies considerably. The cycle length is the time between successive ovulations or expressions of oestrus. It is not uncommon to have a high number of short cycles in goats. The proportion of short cycles can be altered by managing factors such as nutrition and photoperiod. There is also an increase in the number of short cycles if ovulation is induced either during the breeding system or just before (Fatet et al. 2011).

4.4 OVULATION RATE

The ovulation rate is the number of eggs that the ovary releases during an oestrus cycle. Ovulation rate is a vital determinant of fertility in females. Increasing the number of eggs released in a cycle increases the chances of multiple pregnancies. Many breeding programs target improving the ovulation rate of females to enhance breeding rates.

The impact of season and nutrition on the ovulation rate varies between breeds. The ovulation rate will respond more positively to an improvement in nutrition in some goat breeds more than others (Fatet et al. 2011). The average ovulation rate for Boer goats is 1.7 (Greyling 2000).

4.5 GESTATION

There is some variation in gestation length between goat breeds but the average is 149 days (Fatet et al. 2011). The gestation for Boer goats is 148.2 +/- 3.7 days (Greyling 2000). (Mellado et al. 2000) reported that the breeding season, parity, breed of dam and litter weight can affect gestation length. Gestation might be slightly longer for goats bred in the summer, and as the parity (that is, the number of times a doe has kidded in her lifetime) increases, the gestation length progressively reduces (Fatet et al. 2011).

Table 7 and Table 8 show the litter size and gestation period for seven breeds of goat in Georgia over three years (note most are pure dairy breeds). The type and amount of nutrition supplied was not reported. The Pygmy goats showed the shortest gestation and Toggenburgs the longest (Amoah et al. 1996).

Table 7: Litter size by breed (adjusted for within-breed mating weight deviation) in goats in Georgia

BREED[B]	LITTER SIZE[A]	SE	RANGE
American Alpine	1.9	.12	1-4
Dairy Crossbred	1.9	.08	1-3
French Alpine	1.7	.07	1-3
Nubian	2.0	.07	1-4
Pygmy	1.9	.13	1-3
Saanen	1.7	.11	1-3
Toggenburg	1.6	.20	1-3

[A] Regression of litter size on mating weight deviation from breed means = .033, SE = .015, P = .025. There was no evidence for heterogeneity of regression, P = .44. [B] Significant difference, P < .028. SE=standard eror

Source: (Amoah et al. 1996)

Table 8: Least square means of gestation period by breed and mating month (and regression coefficients for gestation period on litter size and parity in Georgia goats)

EFFECT	CLASS	GESTATION PERIOD (D)	SE	RANGE (D)
Breed[a]	American Alpine	149.7	.7	148-151
	Dairy Crossbred	150.1	.7	148-152
	French Alpine	151.3	.5	150-152
	Nubian	151.1	.4	150-152
	Pygmy	149.4	.9	148-151
	Saanen	150.5	.6	150-152
	Toggenburg	152.1	.7	151-154
Month[b]	January	148.1	.6	147-149
	February	152.3	1.1	150-155
	March	151.1	1.9	148-155
	April	151.5	1.0	150-154
	May	-	-	-
	June	150.3	1.2	148-153
	July	151.8	.8	151-153
	August	150.7	.5	150-152
	September	151.0	.4	150-152
	October	150.6	.4	150-151
	November	150.1	.4	149-151
	December	148.4	.6	148-151
Litter size[b]		-.92	.19	
Parity[a]		-.22	.10	

[a] denotes significant difference at $P < .035$, [b] denotes significant difference at $P < .002$

Source: (Amoah et al. 1996)

4.6 POST-PARTUM ANOESTRUS

Reproductive efficiency is influenced by the interval between parturition and the first post-partum oestrus (Greyling 2000). The normal endocrine processes that control ovulation in the ewe are interrupted post-partum and this results in a period of anoestrus (Morales-Terán et al. 2011). The processes of post-partum anoestrous in the goat are very similar to those of sheep and cattle. There is an increase in oestradiol feedback at the hypothalamus-pituitary axis and consequently insufficient LH pulses to promote follicle development at the ovary (Rekik et al. 2012).

The length of the post-partum anoestrous period in goats varies and is influenced by:

- Breed*
- Nutrition*
- Season**
- Suckling**
- Presence of the male**
- Origin of the breed***
- Parity***

* (Riera 1982) as cited by (Greyling 2000), **(Greyling 2000), ***(Rekik et al. 2012).

4.6.1 BREED

The average post-partum anoestrous period in the Boer goat is 55.5 +/- 24.9 days, this being shorter for single-bearing kids than for does bearing twins (53 +/- 14.3 and 58.5+/- 30 days respectively) (Greyling 1988).

Freitas et al 2004 studied the post-partum anoestrous period in Anglo-Nubian and Saanen goats in Sobral, north Eastern Brazil (3^{O}42’S). The kids were removed from the does at birth and the does were observed for oestrus twice daily from one-week post kidding. The breeds did not significantly differ in the length of their post-partum anoestrus period. The average anoestrous periods were 79 days and 95 days for Anglo-Nubian and Saanen goats respectively. Does of both breeds on their first or second pregnancy had a longer post-partum anoestrous period compared to those that were kidding for the third or more time. There was no difference in the anoestrus length between does that were having one or multiple kids (Freitas et al. 2004).

Other breeds also studied in the dry season in Brazil showed a post-partum anoestrous period of 46 days ((Maia 1998) as cited by (Freitas et al. 2004)) and mixed breed goats 52 days ((Andrioli 1992) as cited by (Freitas et al. 2004)).

4.6.2 NUTRITION

When the body weight of Criollo does (in tropical conditions in Mexico) was higher (above 47.25kg) the post-partum anoestrous period tended to be shorter than that of lighter goats. This was also seen for does older than three years ((Torres-Acosta 1996) as cited by (Greyling 2000)).

4.6.3 SEASON

The resumption of reproductive activity post-kidding occurs sooner when the kidding season coincides with the natural breeding season. In one study the return to reproductive activity varied from 3.5 months to 5.5 months with kidding occurring at different times of the year (Delgadillo 1997). Boer does kidding in late autumn had a significantly shorter anoestrous period than those kidding in early summer: 37.3+- 12.5 versus 59.9+- 18.0 days (Greyling 1988).

4.6.4 SUCKLING

A review article by Rekik et al (2012), notes that there is controversy of the effect of suckling on post-partum does. In a study of small sample size, does(Rekik et al. 2012)(Rekik et al. 2012) bearing twins tended to have a longer post-partum anoestrus than does having a single kid, although these findings were not statistically significant ((Mbayahaga et al. 1998) as cited by (Rekik et al. 2012)). In another study in North Mexico, kids were weaned at 2, 30 or 90 days, and there was no difference in the post-partum anoestrus period ((Delgadillo 1994) as cited by (Rekik et al. 2012)).

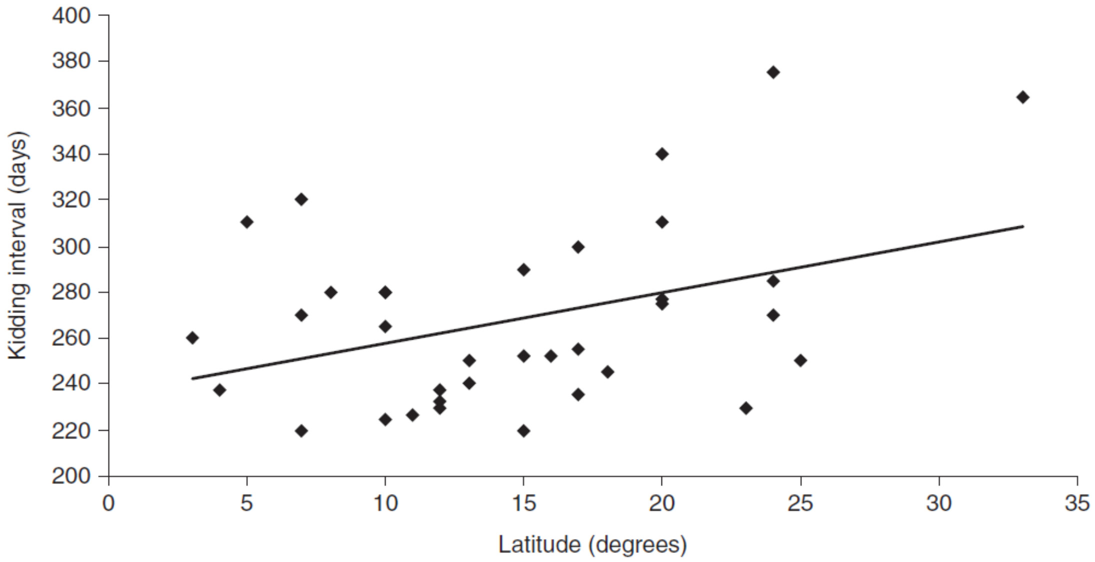
A study in Pelibeuy sheep looked at the effect of controlled suckling with the male effect on ovarian activity post-partum in Mexico (latitude 19^{O}29'N). From seven days post birth, ewes and lambs were divided into four groups, comparing continuous with controlled suckling (two 30-minute sessions per day) with and without the presence of a male. Results showed that ewes with controlled suckling and ram presence ovulated before the ewes in the other groups. There was no significant difference in the time to ovulation between the other three groups. One hundred percent of these ewes ovulated within 45 days post-partum, while only 35.7% of those with continuous suckling and no ram had ovulated by 60 days post-partum. Although controlled suckling is not likely to be a practical management tool to shorten the anoestrus period, the finding does emphasise the impact of suckling on return to cycling time in sheep. The was no difference in the liveweight of the ewes or lambs between the groups (Morales-Terán et al. 2011).

4.6.5 PRESENCE OF THE MALE

The presence of the male can influence the length of the post-partum anoestrus period. This is covered in detail in the section 7.3.5 below on the ‘buck effect’.

4.6.6 ORIGIN OF THE BREED

A correlation has been found between the location of origin of the breed and the kidding interval. Figure 4 shows that as the latitude of the location of origin increases (further away from the equator) so does the kidding interval. This relationship could be modifying other factors such as seasonal anoestrous, body condition, breed, nutrition, parity, number of kids and presence of the male (Rekik et al. 2012).



Source: (Rekik et al. 2012) redrawn from (Delgadillo 1997)

Figure 4: Relationship between latitude of location of origin of breed compared to the kidding interval

4.6.7 PARITY

The parity of the doe can also influence the post-partum anoestrus period. Does that had one to two pregnancies tended to have a longer anoestrus than goats that had three or more pregnancies (Freitas et al. 2004). It is hypothesised that this might be due to older does having faster uterine involution and/or a quicker return to responding to gonadotropin-releasing hormone (GnRH) after kidding (Rekik et al. 2012).

4.7 REPRODUCTIVE COMPLICATIONS

Reproductive complications can significantly impact on the productivity of does. Abortion is one cause of reproductive loss that can result in significant financial loss (Menzies 2007a.). There are many causes of abortion and it is important to diagnose the cause so that affected animals can be treated and management changes enacted to control the risk of spread. Many causes of abortion in animals can also affect humans and thus pose a health risk to farm workers. Causes of abortion include infectious agents such as viruses and bacteria, stressful events, toxic plants, nutritional deficiencies and some therapeutic agents. Some infectious causes of abortion are Q-fever, toxoplasma, listeriosis, leptospirosis and salmonellosis (Mauldin 2016).

Hydrometra or pseudopregnancy is a condition where aseptic fluid accumulates within the uterus and there is a high circulating progesterone level as is seen during pregnancy. This condition is well described in does. Older does are more likely to be affected, as are goats bred out of the natural breeding season or after induced ovulation (Fatet et al. 2011).

5. BUCK SEXUAL ACTIVITY

Although the focus of this project is on the reproductive outcome from the does, the sexual maturity and activity of the buck plays an obvious role in the overall reproductive success of an enterprise.

Bucks become sexually mature between 4-8 months and 1-4 years depending on the breed (Elwishy and Elsawaf 1971). There is seasonal variation in buck sexual behaviour, testicle size and sperm production, with reductions associated with increases in the photoperiod in the spring (Loubser et al. 1982), (Rouger 1974).

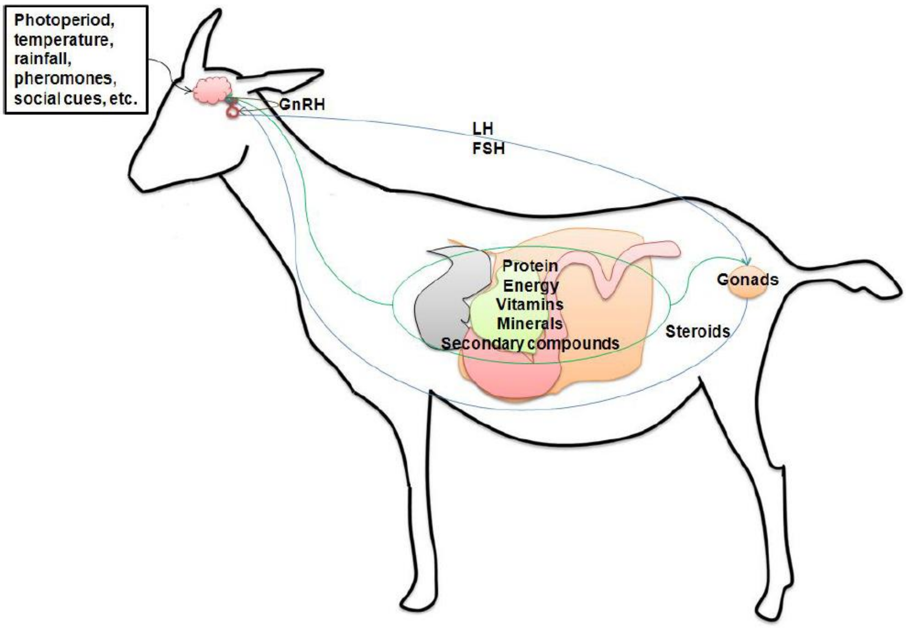
In France, bucks of the Alpine and Poitevine breeds were found to have a decrease in the volume of ejaculate in the non-breeding season (spring and summer). This decrease in volume is associated with the decrease in activity of the accessory glands producing the seminal fluid which occurs when testosterone levels are lower (Leboeuf et al. 2000). This is associated with an increase in sperm concentration in the ejaculate ((Corteel 1977), as cited by (Leboeuf et al. 2000)).

The quality of the spermatozoa was found to be increased with a high percentage of motile spermatozoa in the sexual season and a lower percentage in the non-breeding season (Delgadillo 1990). The proper management of semen collection, storage and use is essential to the success of artificial insemination (Elwishy and Elsawaf 1971).

6. VARIABILITY IN DOE BREEDING

6.1 SUMMARY

Figure 5 shows schematically the various factors that can influence a doe's reproductive success, and how these interact with the hormones that control the reproductive axis.



Source: (Vázquez-Armijo et al. 2011) adapted from (Wade and Jones 2004, Blache et al. 2008)

Figure 5: Summary of factors that influence a doe's reproductive success

6.2 INFLUENCE OF PHOTOPERIOD AND OTHER ENVIRONMENTAL FACTORS

Photoperiod is an important consideration in animals such as goats, sheep and deer that show breeding seasonality (Fatet et al. 2011), (DINZ 2019).

Photoperiod is also referred to as day length, that is, the amount of light compared to dark in a 24-hour period. The degree of variation of photoperiod increases in locations that are further from the equator and the maximum variation in photoperiod is seen at the poles, where in summer there is virtually no darkness and in winter no light (DINZ 2019). Animals located in tropical (equatorial) regions are exposed to less variation in photoperiod and temperature and tend to have a longer breeding season. Goats dwelling in temperate regions tend to display much more marked seasonal variation in breeding (Fatet et al. 2011).

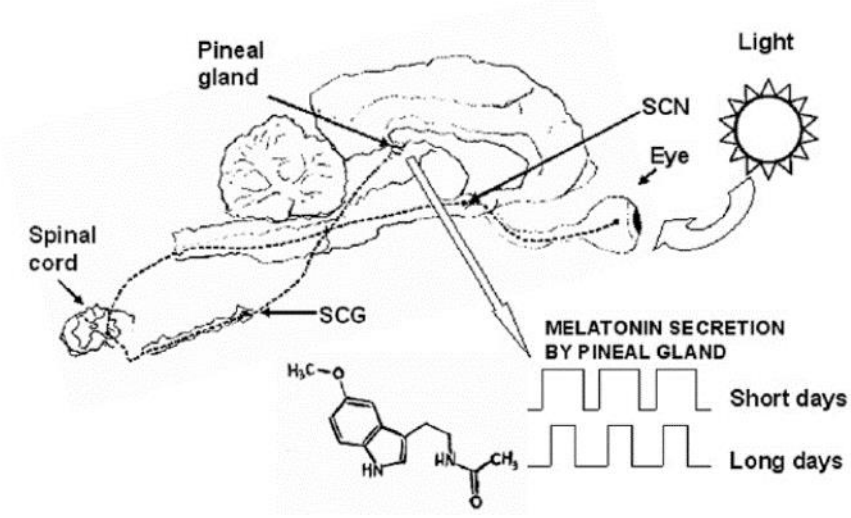
Seasonal breeding has evolved to ensure that births occur at times when the seasonal conditions and available nutrition are most favourable and offspring are therefore most likely to survive (Notter 2012), (DINZ 2019). In commercial farming enterprises, however, seasonal breeding restricts reproductive productivity and makes it more challenging to meet market demands.

There is variation in seasonality between breeds but also between locations within breeds. Tropical breeds are generally classified as aseasonal, where their breeding is not influenced by the day length but instead reflects the feed availability (Notter 2012), (DINZ 2019). Interestingly, though, in a study where tropical breed sheep and goats were taken to a temperate climate where the day length was variable, both displayed reproductive seasonality (Chemineau et al. 2004).

Daylight is perceived through the eye to the optic nerve and brain of animals. Reduced light, during the shorter days of winter, stimulates the pineal gland to increase its production of melatonin (DINZ 2019), (Barrell et al. 2000). Melatonin is released in a circadian pattern; that is, the amount secreted varies over a 24-hour cycle. Using pinealectomised ewes treated exogenously with melatonin, Barrell et al (2000) found that the circadian pattern of melatonin release was insufficient of itself to 'entrain' the ewes into a circannual reproductive rhythm (that is, one that follows an annual cycle). A pattern of melatonin release mimicking that seen in the summer was needed, whilst a winter pattern was not effective (McMillan and Knight 1982).

Melatonin works to regulate the production of reproductive hormones. Increased melatonin stimulates an increase in both male and female reproductive function through the testes and ovaries. From an evolutionary perspective, this is a more robust system for aligning an animal's reproductive cycle with the annual rhythms of the environment than relying on triggers from the weather which are much more variable from season to season (DINZ 2019).

Figure 6 shows the interaction between light, the pineal gland and melatonin production. Light is perceived by the eye and that photic information is converted to neural information. The information passes through the spinal cord to the anterior cervical ganglion, then along the neural path to the pineal gland. The neural information is then converted to hormonal information. Dark hours cause a larger amount of melatonin to be released. The duration of increased melatonin indicates the length of dark hours (Ungerfeld and Bielli 2012).



Source: (Ungerfeld and Bielli 2012)

Figure 6: Impact of photoperiod on melatonin release by the pineal gland

Although the photoperiod cannot be changed at a specific location, the animal's perception of it can be artificially manipulated by the use of melatonin and/or artificial lighting. This manipulation can be used to lengthen the breeding season. However, some within the industry view this intervention as interfering with natural farming systems and believe that it might prove unfavourable in the marketplace (DINZ 2019).

A study in 2011 comparing fall (autumn) and spring kidding in Boer goats in the south-eastern United States (latitude 38°12'N) found that does kidding in the fall had a lower conception rate but a higher total weaning weight. The season however did not appear to impact on the number of kids born per doe that kidded nor the bodyweight or survival of kids to 90 days. There was an economic trade-off between the increase in price paid for kids born in the fall against the overall decrease in the number of kids born. The difference in conception rate was the greatest difference between the reproductive performance of spring and fall kiddings. The authors suggested that more economic evaluation of the difference in production costs between the two kidding times needed to be undertaken (Andries 2011).

In sheep, an improvement is spring fertility has been successful through genetic selection of ewes (Notter 2008b), (Vincent et al. 2000).These ewes have a marked reduction in seasonality of breeding potential. The genes involved in seasonal breeding have not yet been identified in sheep but there appears to be genetic variance for this trait between breeds (Notter 2008b). It is considered possible therefore, with careful selection over time, to breed sheep (or goats) that are non-seasonal breeders (Vincent et al. 2000).

Other factors influencing the commencement of the breeding season in goats include environmental factors such as rainfall, temperature, humidity and food supply and the body condition of the doe (Chemineau et al. 1992a, Duarte et al. 2008) as well as the breed of goat.

The reproductive season of a particular breed of goat may also vary as they move between climates especially after being given time to adapt. Goats that have previously reproduced all year around in a tropical area may develop a restricted breeding season if they are exposed to a photoperiod more like that seen in a temperate environment (Fatet et al. 2011).

Nogueria et al (2015) found that 100% of a group Rangeland does in northern Queensland had ovulated by April. In contrast, in a study by Restall (1992) in north-eastern NSW found that 30% of Rangeland does ovulated between April and May while the majority (60%) ovulated between June and July. The difference in findings between the two studies was likely be due to differences in day length (Nogueira et al. 2015d).

In northern Queensland, where the variation in day length is much less notable then in the southern states, it has been proposed that nutrition is the major influence on sexual activity in goats ((Scaramuzzi and Martin 2008), as cited by (Nogueira et al. 2015d)). This nutritional influence can be either negative and positive. Inadequate nutrition can adversely affect ovulation and result in inhibition of reproduction. On the other hand, fecundity of females already ovulating can be increased through nutritional supplementation ((Scaramuzzi and Martin 2008), as cited by (Nogueira et al. 2015d)).

6.3 INFLUENCE OF BREED

Breed-specific characteristics have been discussed in more detail in section 3 above.

In the study of (Nogueira et al. 2015d), a group of anoestrus Boer and Rangeland goats was fed above nutritional maintenance and time of first ovulation (as determined by the concentration of progesterone in blood) was identified. It was found that the mean time to first ovulation was 23 days earlier in the Boer goats than the Rangeland goats. This may be explained by genetic variation in sensitivity to photoperiod between the breeds (Nogueira et al. 2015d).

Rangeland goats were found to have a greater flight zone and were thus likely (although this was unconfirmed) to have higher blood levels of cortisol, which may supress the onset of the breeding season (Nogueira et al. 2015d).

6.4 INFLUENCE OF TEMPERAMENT

In sheep, research has found that variation between breeds in lamb survival may be explained by the temperament of the dam (Martin et al. 2004a). Murphy et al (1994) found that calm ewes were better mothers than those that were nervous. Calm mothers spent more time with their lambs, returned to their lambs faster and had a shorter flight distance (Martin et al. 2004a). Lamb mortality in calm ewes was approximately half that of nervous ewes in one study, and poor mothering ability of the nervous ewes was thought to be the reason for this (Martin et al. 2004a).

Other aspects of reproduction can be influenced by a temperament, as outlined in Table 9 below.

Table 9: Effect of temperament on various factors influencing reproduction potential in sheep and cattle

TRAIT	FINDINGS	REFERENCE
Length of oestrus cycle	Severe stress lengthened oestrus by a few days in ewes.	(Braden and Moule 1964) as cited by (Martin et al. 2004a)
Ovulation	Environmental stress influenced the time of ovulation with oestrus in Scottish black-faced ewes.	(Doney et al. 1973)
	Severe stress-induced ovulation without oestrus in anoestrus sheep	(Braden and Moule 1964) as cited by (Martin et al. 2004a)
Sexual behaviour	Sexual behaviour can be affected by the temperament, sexual experience and/or age of sheep	(Gelez et al. 2003)
Growth rate	Cattle that were calmer and quieter had higher daily weight gains compared to cattle that were more readily agitated during routine handling	(Voisinet et al. 1997)
Milk yield	Calmer dairy ewes in Hungary had a longer lactation, higher milk production and a lower somatic cell count	(Gábor et al. 2017)
Meat quality	Reproductive and production performance of Simmental cattle was much better in calm animals than nervous ones; selecting for animals with a calmer temperament can result in a shorter calving interval, faster milking speed and milk with increased milk, fat and protein yields	(Cziszter et al. 2016)

6.5 INFLUENCE OF NUTRITION, DOE BODY WEIGHT AND BODY CONDITION SCORE

Nutrition can have a significant effect on reproductive performance. Good herd or flock nutrition is essential over the whole reproductive cycle in any production system of animals (Blache et al. 2008).

Animals are described as being in a 'negative nutritional balance' when they require more nutrition than that which is currently available, which necessitates the mobilisation of body stores. An animal in a 'positive energy balance' will store excess energy or disperse it as metabolic heat. Table 10 shows the metabolic and reproductive consequences of these different energy balance situations. There is a very complex interaction between nutrition, metabolic hormones and the reproductive system. Although these are very relevant in explaining an animal's reproductive response to nutritional manipulation they are too complex to explore fully in this literature review.

Table 10: Some known associations between energy balance and reproduction in the ewe

METABOLIC STATE	METABOLIC CONSEQUENCES	EFFECT OF REPRODUCTION
Negative energy balance	Weight loss Fat stores depleted Muscle wasting Hypoinsulinaemia Hypoglycaemia Elevated βOH butyrates and non-esterified fatty acids (NEFA) Elevated growth hormone (GH) Low leptin Reduced metabolic heat Suppressed insulin-like growth factor (IGF) system Elevated urea	Inhibition of GnRH secretion by the hypothalamus Absence of LH pulses Low FSH concentrations Inhibition of folliculogenesis Low oestradiol High negative feedback sensitivity Anovulation Anoestrus Delayed puberty
Energy balance	Weight maintained Fat stores maintained Normal insulin Normoglycaemia Low NEFA and βOH butyrate Normal GH Normal leptin	Normal GnRH secretion by the hypothalamus Normal LH pulsatility Normal FSH concentrations Normal folliculogenesis Normal oestradiol and inhibin Normal negative feedback Ovulation

METABOLIC STATE	METABOLIC CONSEQUENCES	EFFECT OF REPRODUCTION
	Normal IGF system Normal urea	Oestrus Ovulation rate below natural maximum
Positive energy balance	Long-term weight gain Fat stores increased Hyperinsulinemia Hyperglycaemia Low NEFA and βOH butyrate Low GH Elevated leptin Increased metabolic heat Stimulated IGF system Urea normal but can be high if dietary nitrogen is high	Normal GnRH secretion by the hypothalamus Normal LH pulsatility Increased FSH concentrations Enhanced folliculogenesis Reduced oestradiol Reduced negative feedback Ovulation Oestrus Maximum natural ovulation rate Advanced puberty Increased milk supply – better weaner growth rates.

Source: (Scaramuzzi et al. 2006)

Long et al (2014) found that offspring born to ewes that had been provided with 50% of their nutrient requirements had a reduced stress response compared to the controls. When pregnant at 10 months, these offspring produced less progesterone, which could lead to an increase in embryonic mortality (Long et al. 2010).

In another study, does of similar breed and body condition were induced to ovulate while fed either maintenance or 25% of maintenance. Does receiving the restricted diet had a slower onset of oestrus following synchronisation. Overall pregnancy and ovulation rates were also lower ((Mani et al. 1992), as cited by (Bretzlaff and Romano 2001)). In a study of Payoga goats in Spain, nutrition was varied from maintenance to 1.5 times maintenance in conditions of a constant natural photoperiod (latitude 37^{O}15’N). Those animals with a higher plain of nutrition were observed to have a longer breeding season, by about one month (Zarazaga et al. 2005).

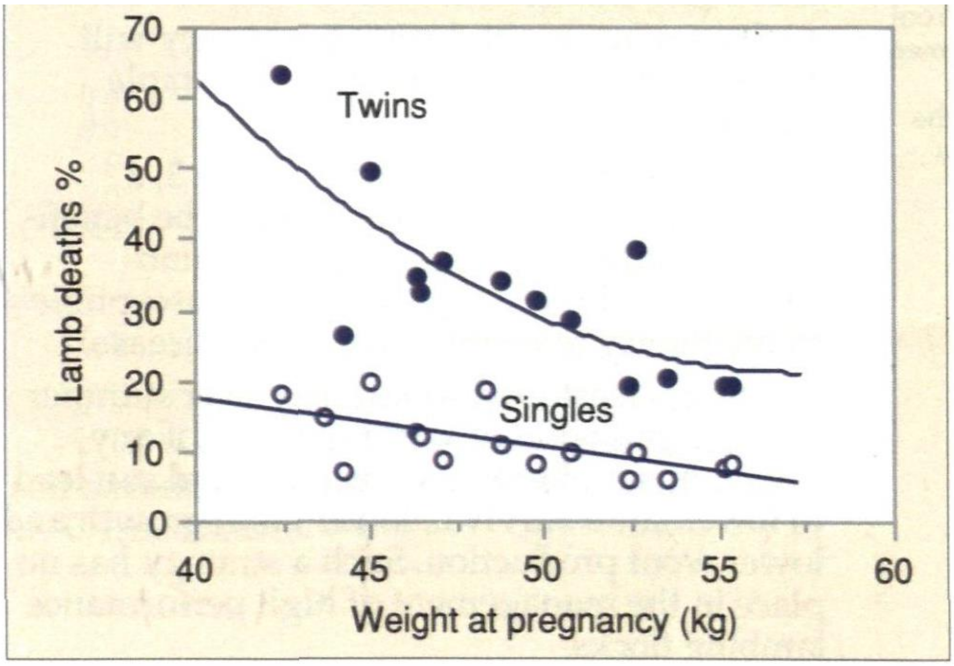
A study in Scottish black-faced ewes compared reproductive performance of ewes in good, moderately good and poor condition at the time of joining. It found that irrespective of the feeding regime prior to joining, ewes in poor condition had a suppressed or delayed oestrus. A correlation was also found between increased body condition and increased ovulation. Ewes that had the lowest embryonic mortality were in good condition and fed well prior to joining. Ewes in condition score 2.5 (out of 5) had an embryonic mortality of 34% while this figure was 63% in ewes in poor condition (Gunn and Doney 1975).

The effect of supplementary feeding sixty ‘hairy goats’ on body weight, milk yield, birth weight and growth rate of kids up to weaning was studied by (Cheema et al. 2002). Goats that were supplemented showed an increase in milk yield, decreased kid mortality and higher weight gains for kids. The marginal rate of return from providing

0.75 kilograms of supplementation every second day compared to no supplementation was 128% (Cheema et al. 2002).

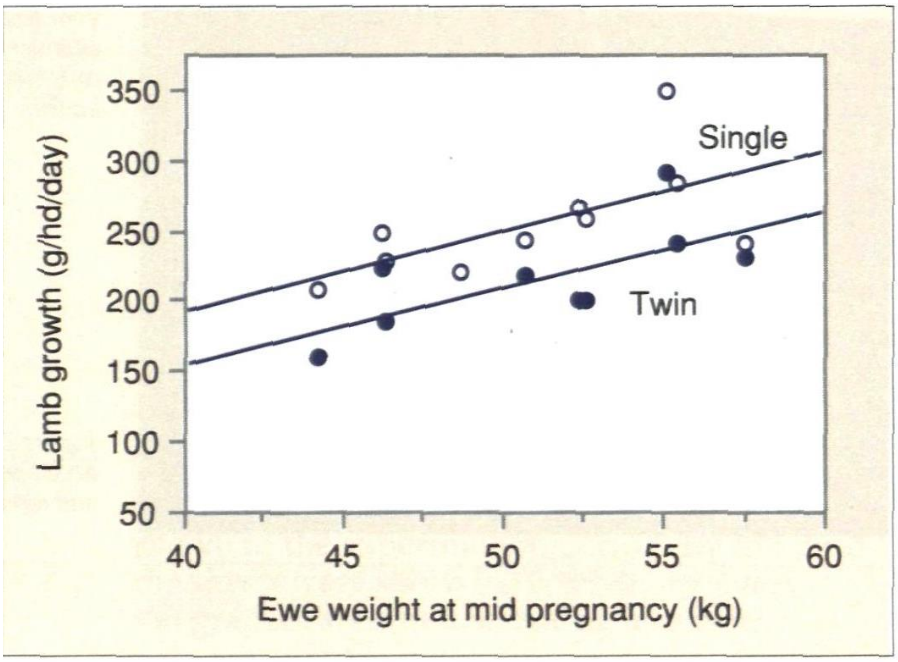
Overfeeding can have negative consequences. Martin et al (2004a) note that 'It has long been acknowledged that overfeeding ewes in the final weeks of pregnancy may cause excessive foetal growth leading to dystocia and an increase in lamb mortality'. Excessive foetal growth can occur with overfeeding in the last few weeks of pregnancy, resulting in incompatibility between birth canal and foetal size and possible dystocia (birthing difficulty) (Martin et al. 2004a). In addition, some have suggested that fat ewes store progesterone in their fat and that this can disrupt the parturition process, causing a lack of oxygen and central nervous system damage to the lamb (Holst et al. 2002). Whilst ewe colostrum production can be boosted by a short period of supplementary feeding that should not affect lamb birth weight accuracy in the timing of the supplements at this point in the reproductive process Martin et al (2004a).

Research carried out in 1988-1989 by Kelly and Ralph (1990) showed trends between ewe weight and productivity. Figure 7 and Figure 8 show that as the weight of the ewe increases at mid-pregnancy there is reduction in lamb mortality and an increase in lamb growth to weaning. Figure 9 shows the relationship between foetal growth, placental weight and vascular development over the pregnancy of the ewe (Kelly and Ralph 1990). This developmental timing highlights the trigger for increased nutrition during pregnancy.



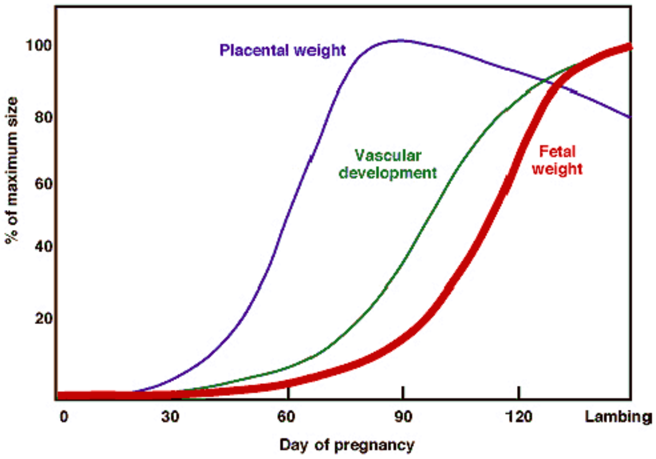
Source: (Kelly and Ralph 1990)

Figure 7: Relationship between average flock weight in mid-pregnancy to lamb mortality



Source: (Kelly and Ralph 1990)

Figure 8: Association between lamb growth to marking and ewe weight in mid-pregnancy



Source: (Kelly and Ralph 1990)

Figure 9: Foetal weight, placental growth and vascular development of Merino ewes

The static and dynamic effects of body condition score (BCS) on conception and fecundity on 174 mixed-age White Suffolk ewes was studied on demonstration farms in Australia by Long (2014). In particular, the possibility that an animal could be too fat to perform optimally was to be reviewed. One group of ewes were fed to allow weight gain and increased BCS between weaning and joining (BCS+) while the other group were fed to maintain or only marginally increase live weight and BCS (BCS=). Table 11 and Table 12 show the difference in performance of the two groups in terms of condition scores and weight change of the does and percentage of dry, single- and twin-bearing ewes. The results suggest that a higher lambing percentage may be achieved when ewes are in BCS between 3-3.5 coming into joining and fed on a maintenance diet over that time (Long 2014).

Table 11: Change in condition score between and weaning and end of joining in Merino ewes

TREATMENT	WEANING	START OF JOINING	MID-JOINING	WEIGHT MID-JOINING (KG)	END OF JOINING
BCS+	Range 3.3-3.6	Ave 4.5	Ave 4.4	85.7	Ave 4.0
BCS=	Range 3.2-3.4	Ave 3.3	Ave 3.5	77.5	Ave 3.3

Source: (Long 2014)

Table 12: Percentage of dry, single- and twin-bearing ewes in two groups of Merinos

TREATMENT	DRY EWES %	SINGLES (% SIL)	TWINS (% SIL)	TOTAL (% SIL)	TOTAL (JOINED)
BCS+	6.8%	41%	59%	159%	148%
BCS=	9.9%	32%	68%	168%	151%

SIL=scanned in lamb

Source: (Long 2014)

This study also looked at the following Australian Sheep Breeding Values (ASBVs), to access their impact or otherwise on the findings: Pwwt (post weaning weight, growth rate), Pfat (post weaning leanness) and Peme (post weaning muscling). The study found that in ewes in the BCS+ group there was a higher incidence of twins when the Pfat ASBV became leaner. The Pwwt did not affect the foetal twin number in either group. With an increase of one unit of genetic fat in the BCS= group there was an increase of 22% of twins while in the BCS+ group for every one unit increase there was an apparent decrease in twins conceived. The report suggests that if animals have a lower amount of genetic fat this may help to offset a higher condition score (Long 2014).

At the Makerere University farm in Uganda (0°28'N, 32°37'E), six bucks and 60 does were selected from a herd of Mubende goats (one of four goats breeds in Uganda) and were studied to measure the effect of both maternal and paternal size on the growth and survival of kids. The does and kids were grazed on open pasture. The weights of the kids at birth and at 10, 20 and 30 weeks for both elite (average 78.4cm girth size) and control (average 72.2cm girth size) does are shown in Table 13. While the birth weight of the kids in both groups was the same, kids from elite dams were heavier at 10, 20 and 30 weeks. The study also showed male kids were heavier at birth and all subsequent weighings and kids from single births weighed significantly more at birth and subsequent weighing than twins. In terms of mortality, the data was not comprehensively evaluated but a few interesting patterns were observed with different breeding combinations. In joinings of elite bucks and does there was only a 14.3% mortality, compared with 46.4% from control buck and doe joining (Kugonza 2014).

Table 13: Weight of kids at birth then 10, 20 and 30 weeks for elite and control does in Uganda

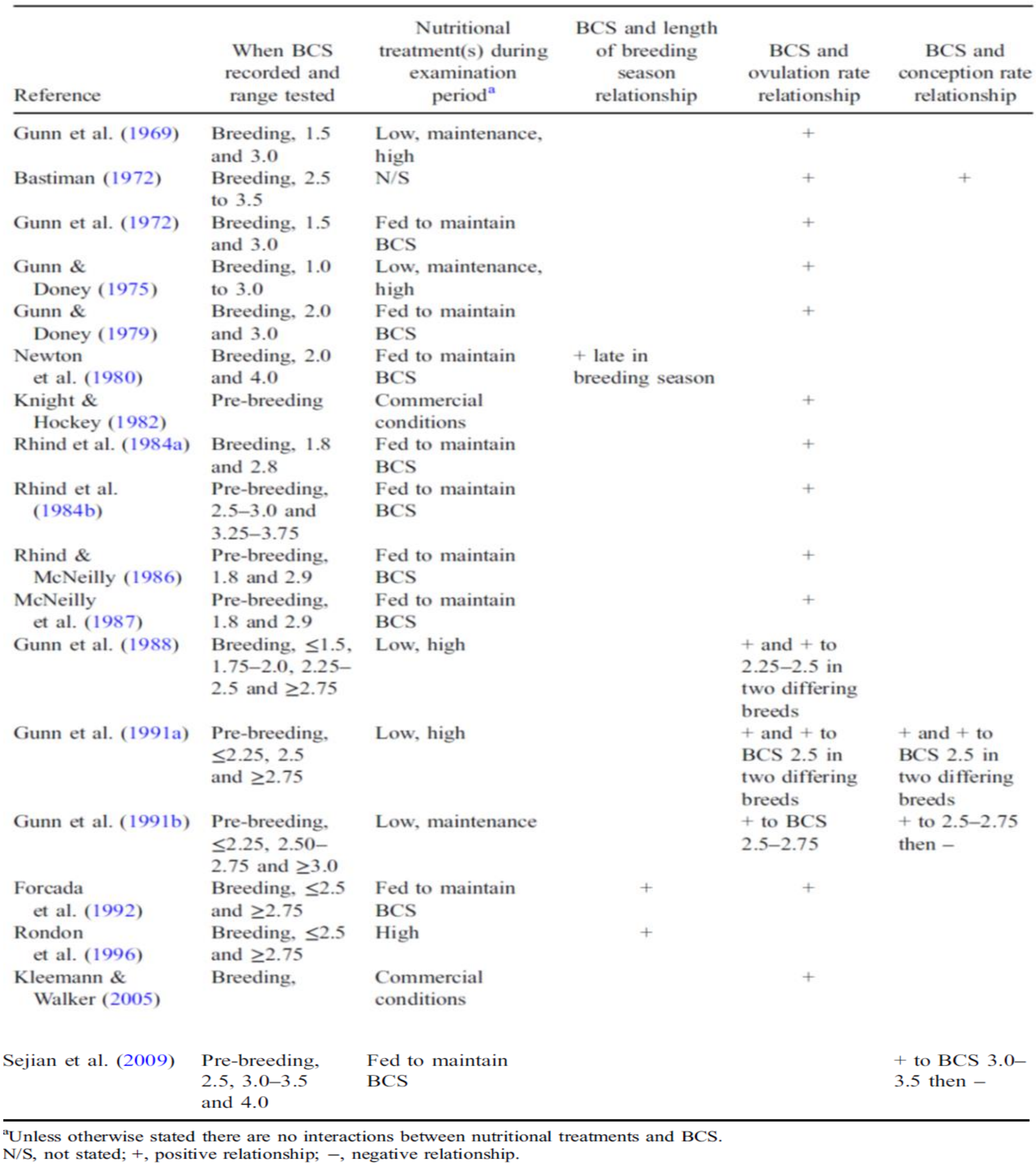
DOE SIZE	BIRTH	10 WEEKS	20 WEEKS	30 WEEKS
Elite	2.1 +/- 0.04	7.3 +/- 0.3	11.2 +/- 0.4	15.1 +/- 0.6
Control	2.1 +/- 0.03	6.6 +/- 0.2	9.7 +/- 0.5	13.2 +/- 0.7
	p>0.10	p<0.10	p<0.10	p<0.05

Source: (Kugonza 2014)

In sheep there have been numerous studies (thoroughly reviewed by Kenyon et al 2014) showing the relationship between BCS and various measurable reproductive traits including: length of breeding season, ovulation rate and conception rate (Table 14); number of embryos, number of lambs born and lamb survival (Table 15); and lamb birth and weaning weight and growth rate to weaning (Table 16). These studies have involved a variety of sheep breeds and while these are not included in the tables below they are included in the text of the review article. They are not included here as they are about sheep not goats specifically and thus the difference is thought not specifically relevant for this review. The studies indicate:

- Ewes of higher BCS have a longer breeding season, however this effect is relatively minor. Manipulation of BCS is unlikely to change the timing of the breeding season significantly.
- There is a positive relationship between BCS and ovulation rate. Ewes in high BCS are however likely to have a reduced response to improved nutrition than ewes of a lower condition score.
- The data suggests that there is a minimum BCS above which there is an increase in conception rate, and an upper BCS, beyond which the conception rate will decrease.
- Both high and low BCS can have a negative impact on embryo survival.
- The number of foetuses increases with BCS. However, BCS objectives might vary with the breed of sheep, where some sheep have a lower optimal BCS than others.
- There is a curvilinear relationship between BCS and number of lambs born, with a possible BCS beyond which there is a negative impact on the lambing rate.
- In most studies (but not all) the BCS of the ewe had no effect on the birth weight of lambs (although much variation was noted). This may be due to a difference in the timing of the condition scoring, number of foetuses and nutrition of ewe.
- Improving BCS could be used as a management tool to improve lamb survival.
- The lamb survival of ewes in BCS 2 was the same as for ewes in the BCS 3 group, for unknown reasons.
- There is a positive relationship between ewe BCS and lamb growth, however this is thought to reach a point where beyond no further gains are made.

Table 14: Summary of studies in sheep showing the relationship between BCS, breeding season, ovulation rate and conception rate



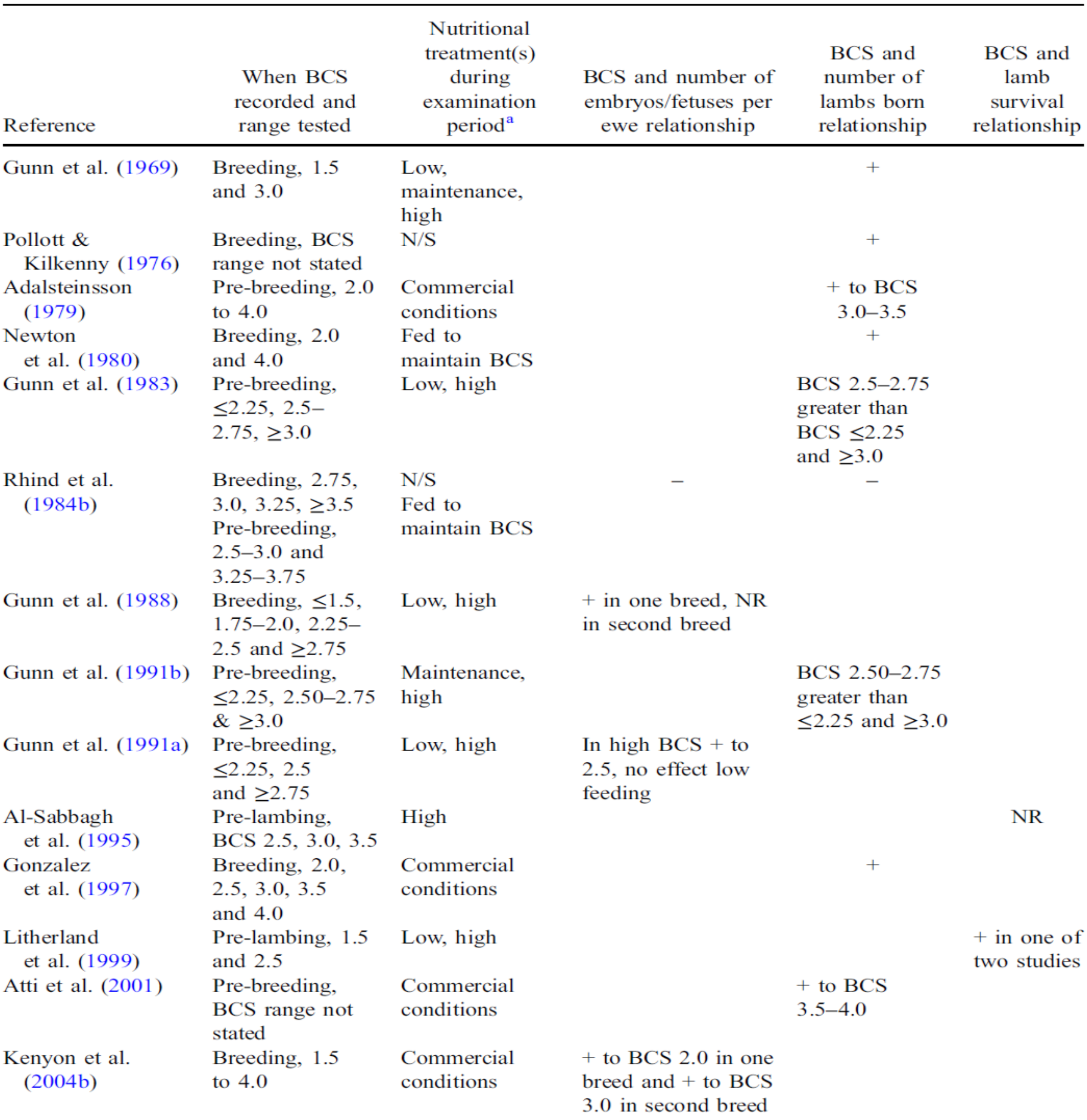
Reference	When BCS recorded and range tested	Nutritional treatment(s) during examination period[a]	BCS and length of breeding season relationship	BCS and ovulation rate relationship	BCS and conception rate relationship
Gunn et al. (1969)	Breeding, 1.5 and 3.0	Low, maintenance, high		+	
Bastiman (1972)	Breeding, 2.5 to 3.5	N/S		+	+
Gunn et al. (1972)	Breeding, 1.5 and 3.0	Fed to maintain BCS		+	
Gunn & Doney (1975)	Breeding, 1.0 to 3.0	Low, maintenance, high		+	
Gunn & Doney (1979)	Breeding, 2.0 and 3.0	Fed to maintain BCS		+	
Newton et al. (1980)	Breeding, 2.0 and 4.0	Fed to maintain BCS	+ late in breeding season		
Knight & Hockey (1982)	Pre-breeding	Commercial conditions		+	
Rhind et al. (1984a)	Breeding, 1.8 and 2.8	Fed to maintain BCS		+	
Rhind et al. (1984b)	Pre-breeding, 2.5–3.0 and 3.25–3.75	Fed to maintain BCS		+	
Rhind & McNeilly (1986)	Pre-breeding, 1.8 and 2.9	Fed to maintain BCS		+	
McNeilly et al. (1987)	Pre-breeding, 1.8 and 2.9	Fed to maintain BCS		+	
Gunn et al. (1988)	Breeding, ≤1.5, 1.75–2.0, 2.25–2.5 and ≥2.75	Low, high		+ and + to 2.25–2.5 in two differing breeds	
Gunn et al. (1991a)	Pre-breeding, ≤2.25, 2.5 and ≥2.75	Low, high		+ and + to BCS 2.5 in two differing breeds	+ and + to BCS 2.5 in two differing breeds
Gunn et al. (1991b)	Pre-breeding, ≤2.25, 2.50–2.75 and ≥3.0	Low, maintenance		+ to BCS 2.5–2.75	+ to 2.5–2.75 then –
Forcada et al. (1992)	Breeding, ≤2.5 and ≥2.75	Fed to maintain BCS	+	+	
Rondon et al. (1996)	Breeding, ≤2.5 and ≥2.75	High	+		
Kleemann & Walker (2005)	Breeding,	Commercial conditions		+	
Sejian et al. (2009)	Pre-breeding, 2.5, 3.0–3.5 and 4.0	Fed to maintain BCS			+ to BCS 3.0–3.5 then –

[a] Unless otherwise stated there are no interactions between nutritional treatments and BCS.
N/S, not stated; +, positive relationship; –, negative relationship.

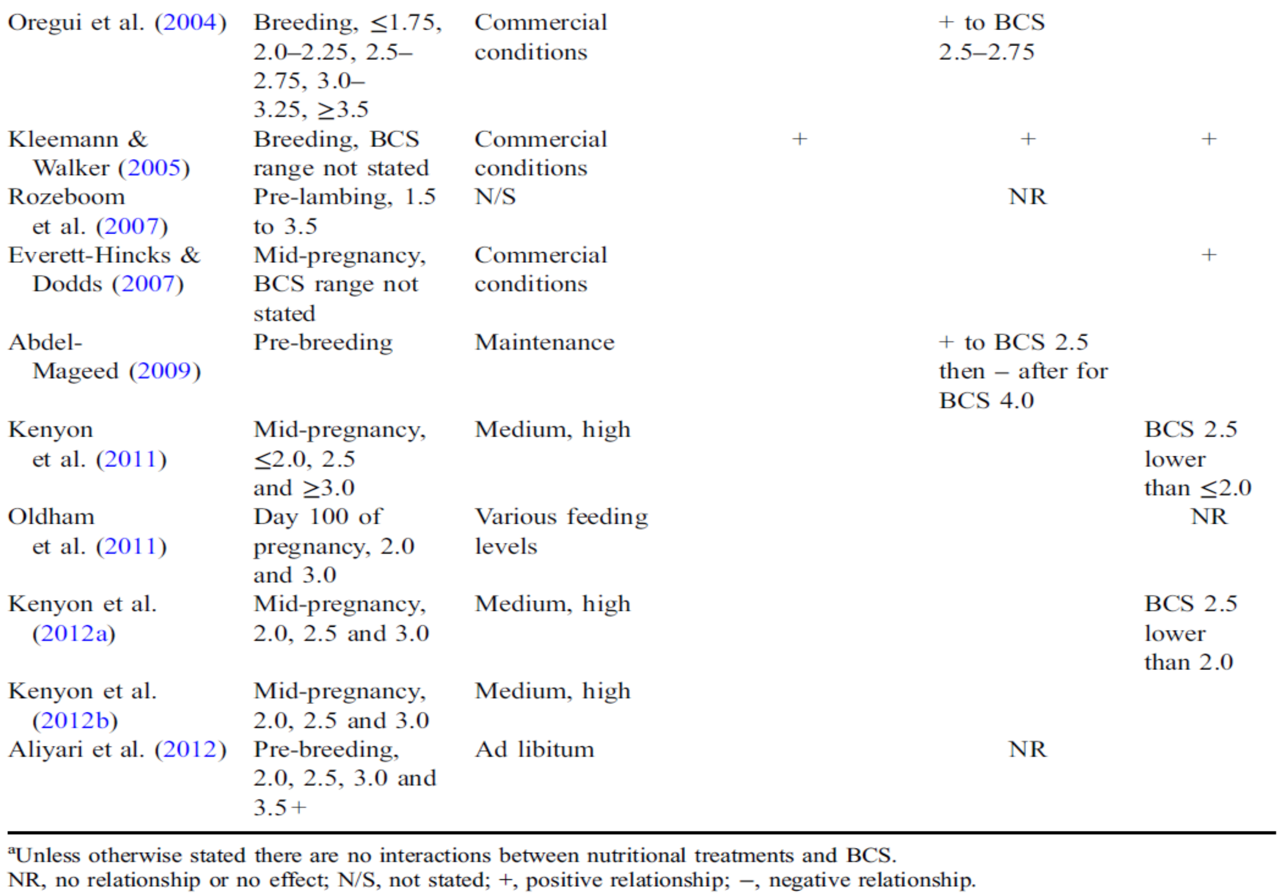
Source: Compiled by (Kenyon et al. 2014) from various sources as listed in the table.

(Gunn et al. 1969, Bastiman 1972, Gunn et al. 1972, Gunn and Doney 1975, Gunn and Doney 1979, Newton et al. 1980, Knight and Hockey 1982, Rhind et al. 1984a, Rhind et al. 1984b, Rhind and McNeilly 1986, McNeilly et al. 1987, Gunn et al. 1988, Gunn et al. 1991a, Gunn et al. 1991b, Forcada et al. 1992, Rondon et al. 1996, Kleemann and Walker 2005, Sejian et al. 2010)

Table 15: Summary of studies in sheep showing the relationship between BCS and number of embryos/foetuses and lambs born and lamb survival



Reference	When BCS recorded and range tested	Nutritional treatment(s) during examination period[a]	BCS and number of embryos/fetuses per ewe relationship	BCS and number of lambs born relationship	BCS and lamb survival relationship
Gunn et al. (1969)	Breeding, 1.5 and 3.0	Low, maintenance, high		+	
Pollott & Kilkenny (1976)	Breeding, BCS range not stated	N/S		+	
Adalsteinsson (1979)	Pre-breeding, 2.0 to 4.0	Commercial conditions		+ to BCS 3.0–3.5	
Newton et al. (1980)	Breeding, 2.0 and 4.0	Fed to maintain BCS		+	
Gunn et al. (1983)	Pre-breeding, ≤2.25, 2.5–2.75, ≥3.0	Low, high		BCS 2.5–2.75 greater than BCS ≤2.25 and ≥3.0	
Rhind et al. (1984b)	Breeding, 2.75, 3.0, 3.25, ≥3.5 Pre-breeding, 2.5–3.0 and 3.25–3.75	N/S Fed to maintain BCS	–	–	
Gunn et al. (1988)	Breeding, ≤1.5, 1.75–2.0, 2.25–2.5 and ≥2.75	Low, high	+ in one breed, NR in second breed		
Gunn et al. (1991b)	Pre-breeding, ≤2.25, 2.50–2.75 & ≥3.0	Maintenance, high		BCS 2.50–2.75 greater than ≤2.25 and ≥3.0	
Gunn et al. (1991a)	Pre-breeding, ≤2.25, 2.5 and ≥2.75	Low, high	In high BCS + to 2.5, no effect low feeding		
Al-Sabbagh et al. (1995)	Pre-lambing, BCS 2.5, 3.0, 3.5	High			NR
Gonzalez et al. (1997)	Breeding, 2.0, 2.5, 3.0, 3.5 and 4.0	Commercial conditions		+	
Litherland et al. (1999)	Pre-lambing, 1.5 and 2.5	Low, high			+ in one of two studies
Atti et al. (2001)	Pre-breeding, BCS range not stated	Commercial conditions		+ to BCS 3.5–4.0	
Kenyon et al. (2004b)	Breeding, 1.5 to 4.0	Commercial conditions	+ to BCS 2.0 in one breed and + to BCS 3.0 in second breed		



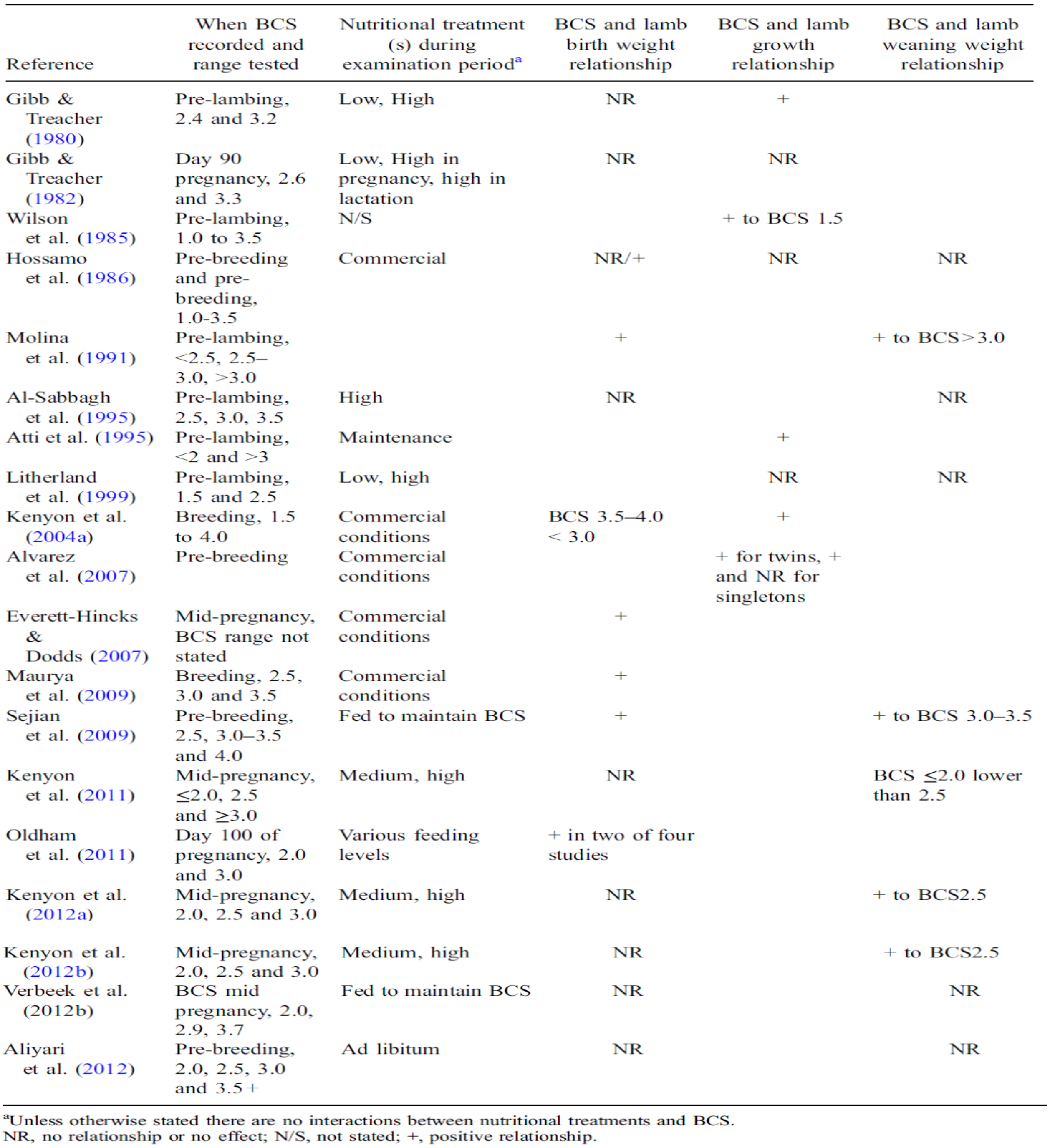
Oregui et al. (2004)	Breeding, ≤1.75, 2.0–2.25, 2.5–2.75, 3.0–3.25, ≥3.5	Commercial conditions		+ to BCS 2.5–2.75	
Kleemann & Walker (2005)	Breeding, BCS range not stated	Commercial conditions	+	+	+
Rozeboom et al. (2007)	Pre-lambing, 1.5 to 3.5	N/S		NR	
Everett-Hincks & Dodds (2007)	Mid-pregnancy, BCS range not stated	Commercial conditions			+
Abdel-Mageed (2009)	Pre-breeding	Maintenance		+ to BCS 2.5 then – after for BCS 4.0	
Kenyon et al. (2011)	Mid-pregnancy, ≤2.0, 2.5 and ≥3.0	Medium, high			BCS 2.5 lower than ≤2.0
Oldham et al. (2011)	Day 100 of pregnancy, 2.0 and 3.0	Various feeding levels			NR
Kenyon et al. (2012a)	Mid-pregnancy, 2.0, 2.5 and 3.0	Medium, high			BCS 2.5 lower than 2.0
Kenyon et al. (2012b)	Mid-pregnancy, 2.0, 2.5 and 3.0	Medium, high			
Aliyari et al. (2012)	Pre-breeding, 2.0, 2.5, 3.0 and 3.5+	Ad libitum		NR	

[a] Unless otherwise stated there are no interactions between nutritional treatments and BCS.
NR, no relationship or no effect; N/S, not stated; +, positive relationship; –, negative relationship.

Source: Complied by (Kenyon et al. 2014) from various sources as listed in the table.

(Gunn et al. 1969, Pollott and Kilkenny 1976, Adalsteinsson 1979, Newton et al. 1980, Gunn et al. 1983, Rhind et al. 1984b, Gunn et al. 1988, Gunn et al. 1991a, Gunn et al. 1991b, Al-Sabbagh et al. 1995, Gonzalez et al. 1997, MG et al. 1999, Atti et al. 2001, Kenyon et al. 2004, Oregui 2004, Kleemann and Walker 2005, Rozeboom 2007, Everett-Hincks and Dodds 2008, Abdel-Mageed 2009, Kenyon et al. 2011, Oldham et al. 2011, Aliyari et al. 2012, Kenyon et al. 2012a, Kenyon et al. 2012b)

Table 16: Summary of studies showing the relationship between BCS and lamb birth and weaning weight and lamb growth to weaning.



Reference	When BCS recorded and range tested	Nutritional treatment (s) during examination period[a]	BCS and lamb birth weight relationship	BCS and lamb growth relationship	BCS and lamb weaning weight relationship
Gibb & Treacher (1980)	Pre-lambing, 2.4 and 3.2	Low, High	NR	+	
Gibb & Treacher (1982)	Day 90 pregnancy, 2.6 and 3.3	Low, High in pregnancy, high in lactation	NR	NR	
Wilson et al. (1985)	Pre-lambing, 1.0 to 3.5	N/S		+ to BCS 1.5	
Hossamo et al. (1986)	Pre-breeding and pre-breeding, 1.0-3.5	Commercial	NR/+	NR	NR
Molina et al. (1991)	Pre-lambing, <2.5, 2.5–3.0, >3.0		+		+ to BCS>3.0
Al-Sabbagh et al. (1995)	Pre-lambing, 2.5, 3.0, 3.5	High	NR		NR
Atti et al. (1995)	Pre-lambing, <2 and >3	Maintenance		+	
Litherland et al. (1999)	Pre-lambing, 1.5 and 2.5	Low, high		NR	NR
Kenyon et al. (2004a)	Breeding, 1.5 to 4.0	Commercial conditions	BCS 3.5–4.0 < 3.0	+	
Alvarez et al. (2007)	Pre-breeding	Commercial conditions		+ for twins, + and NR for singletons	
Everett-Hincks & Dodds (2007)	Mid-pregnancy, BCS range not stated	Commercial conditions	+		
Maurya et al. (2009)	Breeding, 2.5, 3.0 and 3.5	Commercial conditions	+		
Sejian et al. (2009)	Pre-breeding, 2.5, 3.0–3.5 and 4.0	Fed to maintain BCS	+		+ to BCS 3.0–3.5
Kenyon et al. (2011)	Mid-pregnancy, ≤2.0, 2.5 and ≥3.0	Medium, high	NR		BCS ≤2.0 lower than 2.5
Oldham et al. (2011)	Day 100 of pregnancy, 2.0 and 3.0	Various feeding levels	+ in two of four studies		
Kenyon et al. (2012a)	Mid-pregnancy, 2.0, 2.5 and 3.0	Medium, high	NR		+ to BCS2.5
Kenyon et al. (2012b)	Mid-pregnancy, 2.0, 2.5 and 3.0	Medium, high	NR		+ to BCS2.5
Verbeek et al. (2012b)	BCS mid pregnancy, 2.0, 2.9, 3.7	Fed to maintain BCS	NR		NR
Aliyari et al. (2012)	Pre-breeding, 2.0, 2.5, 3.0 and 3.5+	Ad libitum	NR		NR

[a] Unless otherwise stated there are no interactions between nutritional treatments and BCS.
NR, no relationship or no effect; N/S, not stated; +, positive relationship.

Source: Compiled by (Kenyon et al. 2014) from various sources as listed in the table.

(Gibb and T. Treache 1980, Gibb and Treacher 1982, Wilson et al. 1985, Hossamo et al. 1986, Molina et al. 1991, Al-Sabbagh et al. 1995, Atti et al. 1995, MG et al. 1999, Kenyon et al. 2004, Alvarez et al. 2007, Everett-Hincks and Dodds 2008, Maurya et al. 2009, Sejian et al. 2010, Kenyon et al. 2011, Oldham et al. 2011, Aliyari et al. 2012, Kenyon et al. 2012a, Kenyon et al. 2012b, Verbeek et al. 2012)

Whilst not a peer-reviewed paper, a report by the Glenthompson (Vic) Best Wool Best Lamb group (2011) of lamb survival provides some interesting findings about the relationship between the condition score of maiden and adult crossbred ewes and lamb survivability. On one farm, an increase in the condition score of maiden ewes on the point of lambing from 2.6 to 3.2 resulted an increase in twin lamb survival of 13 percentage points (an extra 26% lambs marked). On another farm, an increase in condition score of adult crossbred ewes from 2.5 to 3 resulted in a 10-percentage-point increase in lamb survival (Table 17 and Table 18) (BWBL 2011).

Table 17: Effect of condition score of maiden crossbred ewes on lamb survivability

LAMBING CONDITION SCORE	AVERAGE LAMBING CONDITION SCORE	EWES IN MOB	LAMB MARKING %	LAMB SURVIVAL %
Low	2.6	188	118.1	59.0
Med	2.9	213	130.5	65.3
High	3.2	197	144.2	72.1

Source: (BWBL 2011)

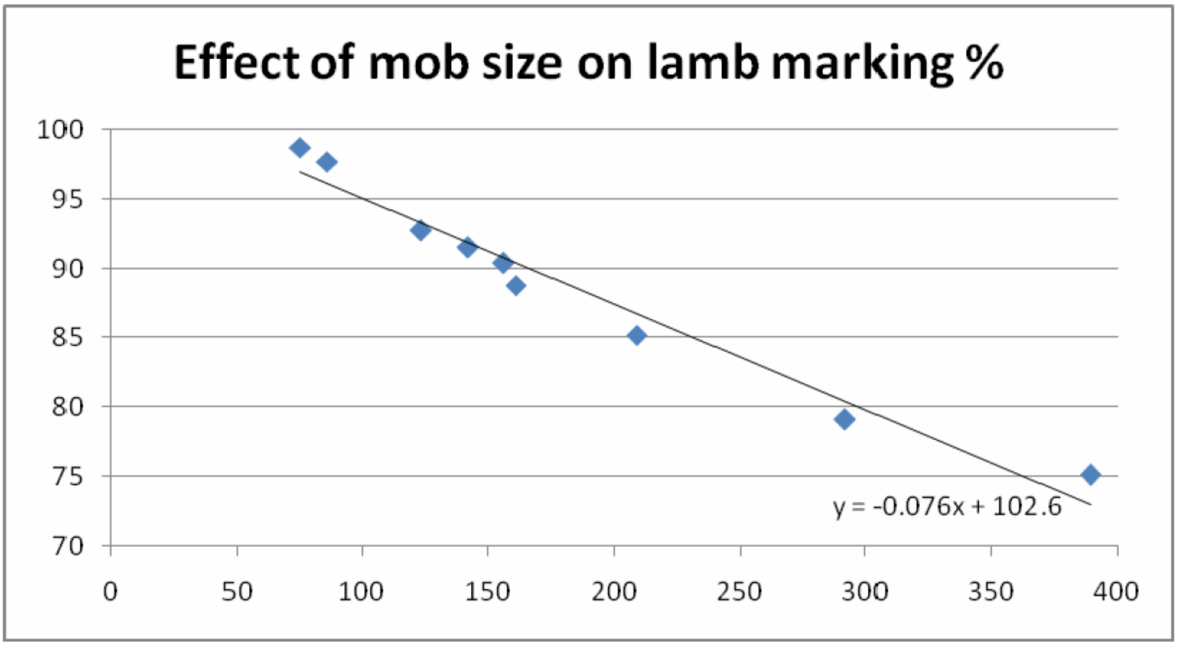
Table 18: Effect of condition score of adult crossbred ewes on lamb survivability

LAMBING CONDITION SCORE	EWES JOINED	SCANNING %	LAMB MARKING %	LAMB SURVIVAL %
2.5	6220	140.0	112.6	80.4
3	6180	149.0	135.4	90.9

Source: (BWBL 2011)

6.6 INFLUENCE OF THE ENVIRONMENT

The Glenthompson (Vic) Best Wool Best Lamb group (2011) report includes data on the relationship between the size of the ewe mob at the time of lambing and survival of lambs born to Merino ewes on one farm (Figure 10). With mobs of more than 200, there was an average lambing percentage of 79.8% while for mobs less than 200 the average lambing percentage was 93.3%. The authors reported that this pattern was consistent across all trials undertaken regardless of ewe type (BWBL 2011).



Source: (BWBL 2011)

Figure 10: Effect of mob size at lambing (horizontal axis) on marking percentage (vertical axis) in Merino ewes

The same group also described an increase in survival of crossbred and Merino twin lambs when provided with shelter compared those that were not (different properties) (Table 20 and Table 20).

Table 19: Effect of shelter on survival of crossbred twin lambs

	NO. OF EWES SCANNED IN LAMB	NO. OF FOETUSES	NO. OF LAMBS MARKED	LAMB MARKING %	LAMB SURVIVAL %
Sheltered	505	1010	915	181.2	90.6
Unsheltered	503	1006	813	161.6	80.8

Source: (BWBL 2011)

Table 20: Effect of shelter on survival of Merino twin lambs

		NO. OF EWES SCANNED IN LAMB	NO. OF FOETUSES	NO. OF LAMBS MARKED	LAMB MARKING %	LAMB SURVIVAL %
Sheltered	Twins	582	1164	821	141.1	70.5
	Singles	225	225	215	95.6	95.6
	Total	807				
Unsheltered	Twins	217	434	252	116.1	58.1
	Singles	573	573	502	87.6	87.6
	Total	790				

Source: (BWBL 2011)

6.7 INFLUENCE OF LACTATION

The influence of lactation on cycling has been discussed in depth in section 4.6.

In a study in the arid rangelands of Mexico, goats that were lactating whilst pregnant during the ‘dry season’ had dramatically poorer reproductive outcomes. There was no major weight loss but pregnancy rate and kidding rate were reduced and there was a huge increase in prenatal wastage (Mellado et al. 2005b). A summary of these findings is shown in Table 21.

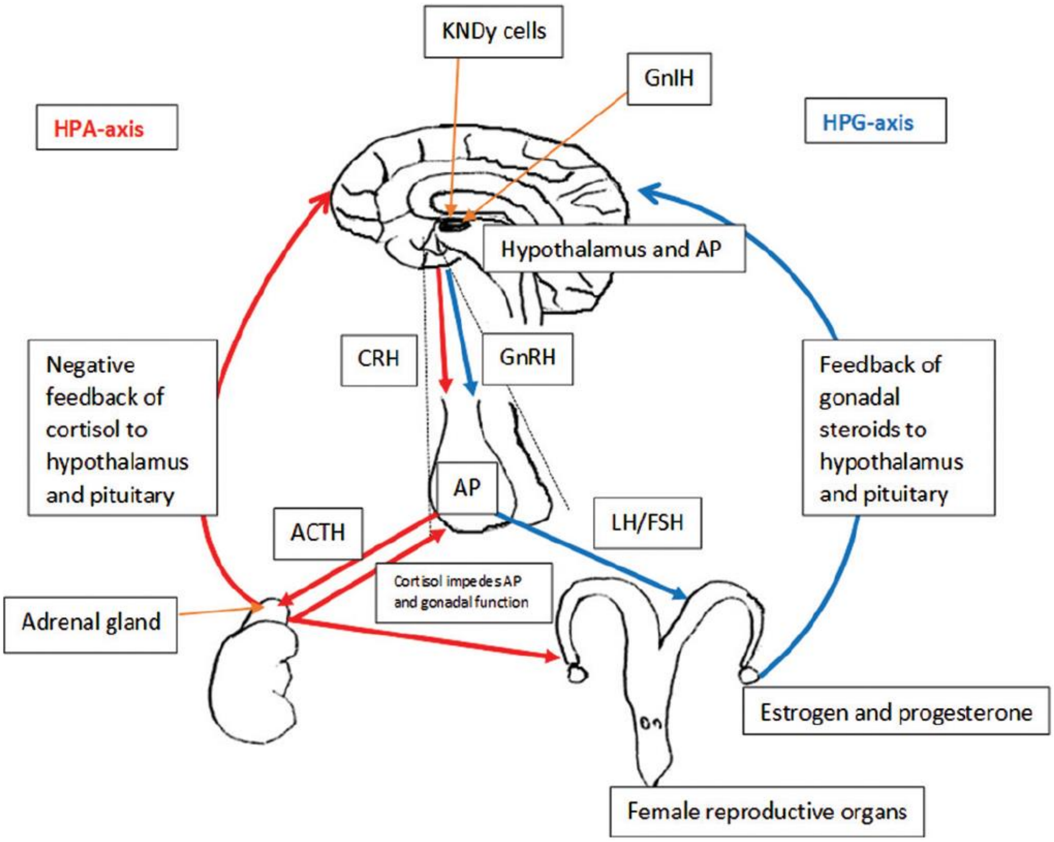
Table 21: Comparison of various reproductive measure in lactating vs dry does

REPRODUCTIVE MEASURE	LACTATING DOES	DRY DOES
Pregnancy rate	60%	92%
Kidding rate	14%	88%
Prenatal wastage	77%	4%

Source: (Mellado et al. 2005b)

6.8 INFLUENCE OF STRESS

The impact of stress on the reproductive performance in ewes has been well documented (Dobson 2012). There are various causes of stress in ewes including the stress caused by management procedures like transport or shearing ((Parr et al. 1989), as cited by (Dobson 2012)), poor body condition, sudden changes in diet or temperature extremes. Figure 11 shows the interactions and feedback between the hormones and organs in the pathways of female animals. Positive and negative feedback via oestrogen and progesterone occur on the hypothalamus in the hypothalamus-pituitary-gonad (HPG) axis, while cortisol provides negative feedback in the hypothalamus–pituitary–adrenal (HPA) axis. Cortisol impedes reproductive function by acting on the anterior pituitary and the reproductive organs (Narayan and Parisella 2017).



Source: (Narayan and Parisella 2017)

Figure 11: Diagram of the hypothalamus-pituitary-adrenal (HPA) axis and the hypothalamus-pituitary-gonad (HPG) axis of the female animal

Stress causes an increase in activity along the HPA axis. This can subsequently interact and modulate the HPG axis and interfere with reproductive function. Specifically, stress may impede fecundity, fertility, ovulation rate and ovum quality and birth weight of offspring. It may also lead to an increase in embryo and offspring mortality. Stress acts firstly to decrease the synthesis and secretion of GnRH, then reduces the pituitary response to GnRH at the anterior pituitary gland. The exact process by which the axis interacts with reproductive function is complex and thought to involve a number of hormones (Narayan and Parisella 2017).

Stress can also be divided into acute and chronic stress. Acute stress tends to only cause a short term negative impact on reproduction ((Coburn et al. 2010), as cited by (Narayan and Parisella 2017)). Chronic stress in ewes causes supression of the pituitary rsponse to GnRH in the HPG axis (Pierce et al. 2008).

Environmental stress during the oestrus period reduced the ovulation rate in ewes ((Doney et al. 1976a), as cited by (Dobson 2012) and (Doney et al. 1973), as cited by (Bretzlaff and Romano 2001)). Stress including daily transportation, rough flocking by dogs or handling by strangers in the time immediately following mating was also associated with increased embryonic loss ((Doney et al. 1976b) as cited by (Dobson 2012)). Environmental stresses have been found to interfere with the endocrine interactions that coordinate follicle development in ovaries, ovulation and hormone production. The hormones prepare the uterus for the conceptus and trigger pheromone release to attract the ram to match with ovum release (Dobson 2012). The reproductive consequences of ewes being exposed to stress reflect the ewe's ability to respond to the environment in which she has become accustomed. Not breeding in a time of stress reduces the ewe's exposure to unnecessary risk and delays genetic transfer to a time that is more suitable.

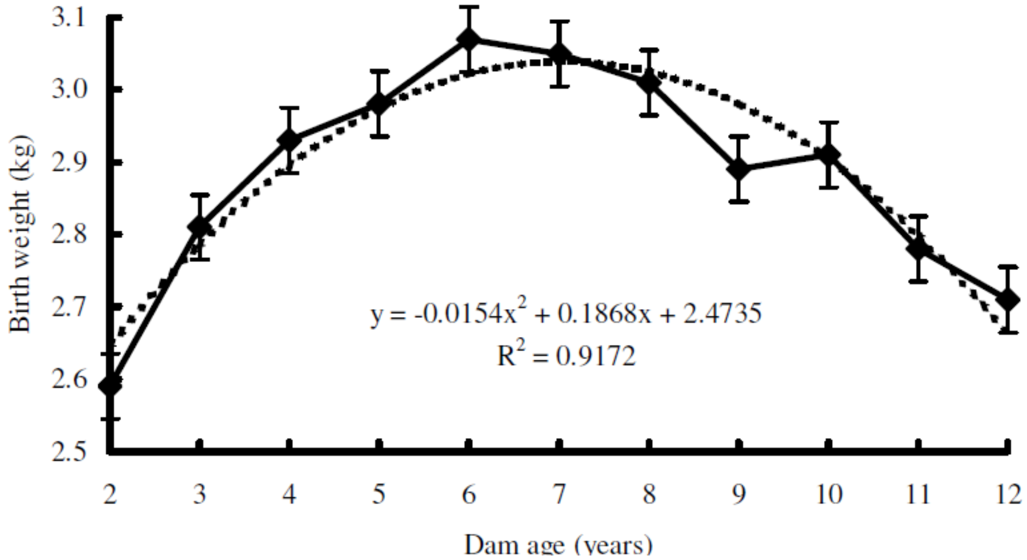
One specific stress is variation in temperature. This is an important influence on the reproductive performance of goats, especially those grazing arid and semi-arid areas where there are high temperatures and significant fluctuations in temperature.

The stress caused by high temperatures (40 degrees for 6 hours a day) caused a decrease in overt sexual behaviour and a failure to mate and conceive in Bharat Merino ewes in sub-tropical India (latitude 26^{O}N) (Maurya et al. 2005). This occurred in ewes that had otherwise had normal ovarian development. Ewes also experienced a delay in the onset of oestrus, thought to be due to abnormal ovarian function associated with alterations in hormone secretions including LH, oestrogens and GnRH (Maurya et al. 2005). In addition, these ewes produced poorer quality embryos (Naqvi et al. 2004).

Ali and Hayder (2008) found that ewes joined in late spring had higher pregnancy and lambing rates than those joined in the winter. However, there was a temporary reduction in growth rate of the foetus in the heat of summer in the late-spring-mated ewes. The time of mating in this study had no impact on the foetal loss or incidence of twinning ((Ali and Hayder 2008), as cited by (Dobson 2012)).

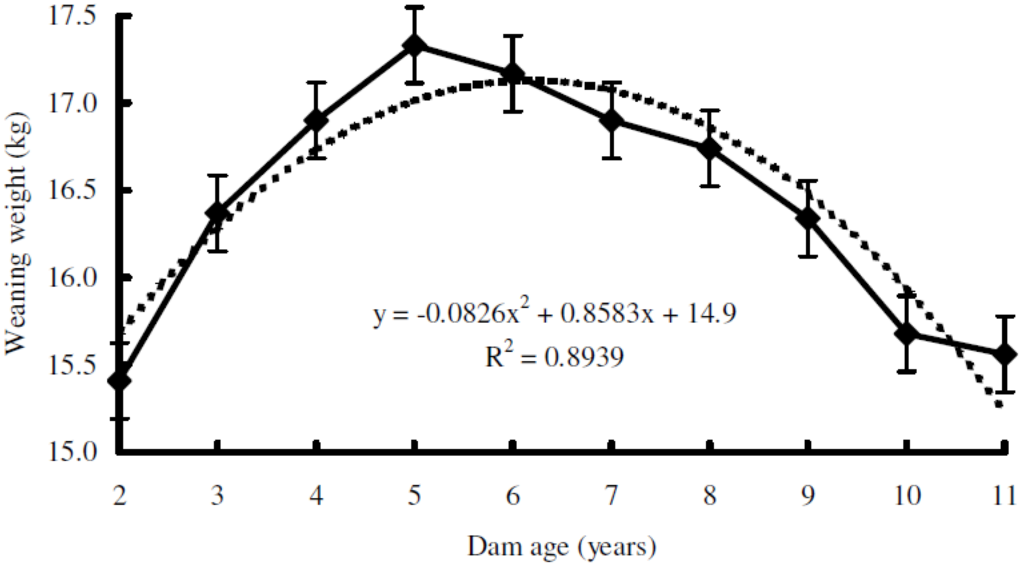
6.9 INFLUENCE OF AGE

Figure 12 and Figure 13 show the association between age of the dam and weight of the kid at birth and at weaning in a study of South African goats in South Africa. It shows that birth weights and weaning weights peaked when the doe was 5-6 years old (Snyman 2009). Whether the same relationships would apply to Australian goat meat breeds under Australian conditions is difficult to say.



Source: (Snyman 2009)

Figure 12: Relationship between age of dam and birth weight of kids in Angora goats in South Africa



Source: (Snyman 2009)

Figure 13: Relationship between age of dam and weaning weight of kids in Angora goats in South Africa

6.10 INFLUENCE OF THE BUCK EFFECT

The buck effect is described in detail in section in section 7.3.5.

7. IMPROVING REPRODUCTIVE PERFORMANCE

7.1 OVERVIEW

Section 4 has provided some general information about goat reproductive processes and how management and environmental factors can influence the reproductive success of does, both positively and negatively.

The potential of a doe to perform reproductively is dependent on the genetic and environmental factors and how they interact. Where nutrition varies seasonally it can impact significantly on a doe's performance ((Riera 1982), as cited by (Greyling 2000)).

The reproductive efficiency of a doe is dependent on various factors including:

- Cyclic activity;
- Ovulation rate;
- Fertilisation rate;
- Length of breeding season;
- Anoestrus period post-partum; and
- Viability and growth rate of offspring ((Greyling 1988), as cited by (Greyling 2000)).

This section provides details of management tools and processes that can be implemented to maximise reproductive outcomes for does. These interventions can be broadly divided into two groups:

1. Manipulation by natural means

This includes capitalising on what the doe is already capable of, without chemical or invasive intervention. Measures include improving doe health, providing targeted nutritional supplementation to maximise outcomes at various stages in the reproductive cycle, and improving management to promote better kid health at birth through until they are sexually active.

2. Manipulation by non-natural means

This includes the use of chemical intervention to synchronise does for artificial insemination (AI) and embryo transfer (ET), or for the induction of cycling during periods of anoestrus. Accelerated breeding programs involving kidding three times in two years or five times in three years are also included here as in the most part they require hormonal intervention to facilitate cycling and successful mating in the non-breeding season.

7.2 MEASURING AND RECORDING

As part of the process of implementing change to improve reproductive outcome, enterprises should measure and record various reproductive parameters so they can monitor changes over time. Without accurate measurement and recording subtle improvements in reproductive capacity may be missed.

The parameters that can be measured include:

- Pregnancy rate;
- Kidding rate;
- Weaning rate;

- Length of reproductive cycle;
- Liveweight of kids at birth;
- Liveweight of kids at weaning;
- Kidding interval ((Greyling 1988) as cited by (Greyling 2000)); and
- Doe condition score.

7.3 MANIPULATION BY NATURAL MEANS

7.3.1 DOE HEALTH

In extension material prepared at the University of Arkansas, it is recommended that producers monitor the body condition of their does by palpation along the backbone and the ribs. Excessive or insufficient condition of the doe can affect productivity. Early detection of nutritional and health conditions can be made with frequent observations (Jones and Powell 2019) and allow for timely treatment and response.

Error! Reference source not found. provides a brief summary of the management approaches to assist in ptimising reproductive potential in the ewe, from the abstract from (Fthenakis et al. 2012). The table is directly translatable to does.

The condition of the udder is critical to ensure that the doe has every opportunity to produce adequate milk for her offspring. Injuries, deformities and disease (both acute and chronic) can interfere with the health of the doe and also affect her ability to produce sufficient milk to raise her offspring. This becomes more critical as the number of offspring per doe increases.

In ewes, udder management includes the resolution of any existing infections and the prevention of any new ones while the female is dry (not lactating). Examination of the udder of all ewes at the end of lactation identifies females that have poor udder health and these animals may need to be culled. If abnormalities are detected a more detailed examination may be required. Abnormalities commonly identified in ewes include nodules, hardness and abscesses ((Saratsis et al. 1998), as cited by (Fthenakis et al. 2012)).

Criteria for culling ewes may include recurring or ongoing mastitis, lack of a complete response to treatment or permanent damage to one or more of the mammary glands. There are benefits from culling affected individuals for the whole mob/herd including the improvement of overall herd health by decreasing the source of infections, reducing bulk cell count1 (for dairies) and decreasing the use and cost of veterinarians ((Mavrogianni et al. 2011), as cited by (Fthenakis et al. 2012)) and pharmaceutical products.

Lambs that are born as one of multiple births, to a mother with mammary lesions, tend not to grow well and may require supplementation ((Fthenakis and Jones 1990), as cited by (Fthenakis et al. 2012)).

Intramammary treatments have been used to decrease the bulk cell count in in dairy ewes (Gonzalo et al. 2004) and dairy goats ((Poutrel et al. 1997), as cited by (Fthenakis et al. 2012)). They may also be effective in

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[1] The concentration of body (somatic) cells in milk from a mob/herd of dairy animals, which indicates the likelihood of subclinical mastitis

ewes in mutton systems ((Hendy et al. 1981), as cited by (Fthenakis et al. 2012)). The important factors for success with intramammary treatment are to ensure that both mammary glands of all ewes are treated hygienically, and that treatment is used when there is complete cessation of lactation. Injectable antibiotics may also be used to help reduce post-partum mastitis in ewes (Croft et al. 2000). Ideally, the choice of product would be based on susceptibility testing of the causative bacteria (Mavrogianni et al. 2011).

7.3.2 BUCK HEALTH

While buck health is strictly outside the scope of this project, it is an essential consideration for a successful small ruminant reproductive program. Males require year-round health monitoring and management, not just during the breeding season, to ensure their optimal productivity and longevity. A pre-mating soundness examination is recommended as well as careful selection of males for joining and use of the appropriate ratio of males to females (Ridler et al. 2012). Various buck: doe ratios are described in the literature and they vary significantly. No systematic review or study of buck: doe ratios was found. The ratio selected needs to consider buck availability, length of mating period, age of bucks, size of the joining paddock, use of the buck effect and the importance of a tight kidding (most does joined successfully on the first cycle). Module 6 of ‘Going into Goats’ recommends 5% bucks in extensive systems, and 1.5-2.0% in intensive systems, and higher ratios where young bucks are being used (or if does have been synchronised). Nothing was found in the literature to suggest that these recommendations were inappropriate.

7.3.3 MANAGEMENT OF PRE-PUBERTAL DOES AND AGE AT FIRST KIDDING

Careful and considered selection of replacement males and females will assist to optimise reproductive performance and should form part of an overall breeding strategy. The selection process varies but is commonly based on each animal’s productivity, potential reproductive capacity and structural integrity. The productive life of a small ruminant is largely determined by the timing of onset of puberty, as this determines the first time that an animal can kid/lamb. Other factors to be considered are the seasonality of breeding, the variation between breeds and the season in which animals are born. Good management of pre-pubertal goats is crucial to improving reproductive performance on farm (Valasi et al. 2012).

The processes that determine the timing of the onset of puberty are complicated and influenced by both internal and external factors. In temperate areas, the photoperiod is one of the more important factors that influence the onset of puberty (Malpaux et al. 1989). The three main factors that control successful breeding in maiden animals are:

1. Age of the animal (6-12 months, but dependent on breed and month of birth);
2. Time of year – whether breeding season or not (this varies between breeds); and
3. Bodyweight (65% of total adult weight) (Foster et al. 1985).

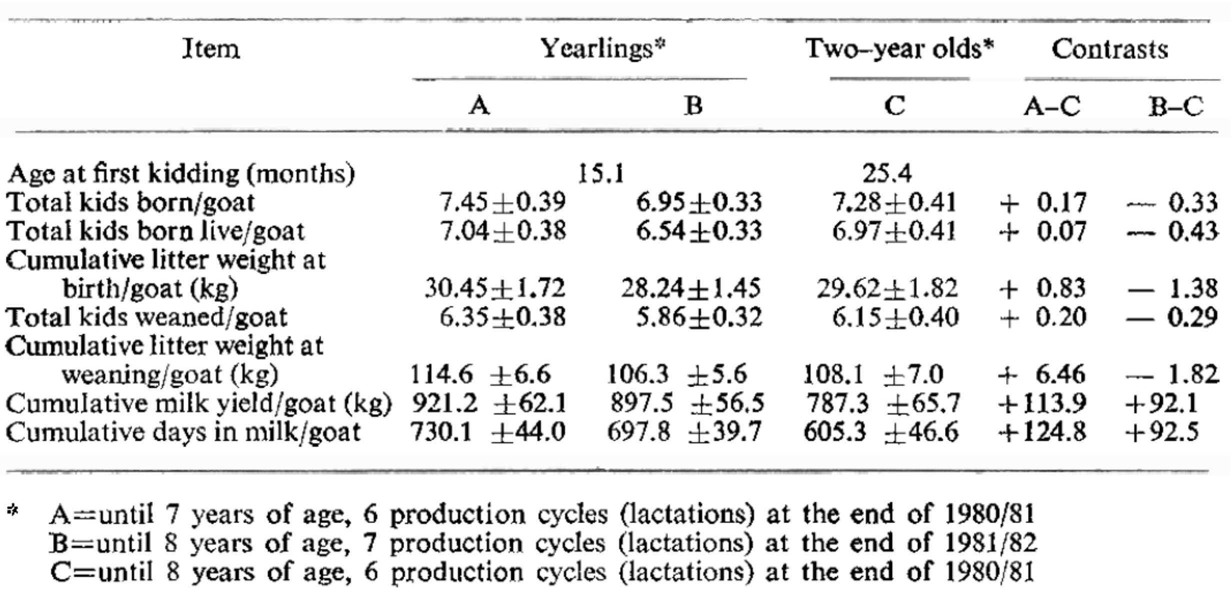
In most production systems the aim is to minimise the time between birth and mating for potential replacement females. Time without breeding means an increase in costs including feed, management procedures, veterinary drugs and labour. Animals that fail to reach the appropriate body weight within the breeding season should not be bred. Reaching sexual maturity marks a time when the female is of adequate condition to maintain a successful pregnancy and deliver offspring successfully. There is thus a limit to which puberty can be hastened (Valasi et al. 2012).

Providing sufficient nutrition to allow for normal growth is essential. Puberty may be delayed by underfeeding and advanced by a high plain of nutrition (Valasi et al. 2012). Lambs that grow faster are more likely to exhibit oestrus earlier and to conceive at a younger age than those lambs that grow more slowly ((Dýrmundsson 1981), as cited by (Valasi et al. 2012)). In another study, heavier ewe lambs had an increased ovulation rate compared to those that were lighter at the same age. This effect carried on into the next breeding period ((Bizelis et al. 1990), as cited by (Valasi et al. 2012)). Nutrition of ewe lambs late in pregnancy is more critical than that of adult ewes (Dýrmundsson 1981).

In kids/lambs that are the minimum age and weight for joining, the use of hormones can induce oestrus and ovulation when used at a time close to the beginning of the breeding season ((Stellflug et al. 2001), as cited by (Valasi et al. 2012)).

A study by Mavrogenis and Constantinou (1983) compared the performance of 84 goats first bred as yearlings, and 75 goats bred for the first time at two years, at Akhelia, Cyprus. All goats were provided with the same management and nutrition. The does all kidded for the first time in the experiment in the same year and were monitored from 1975 to 1982. Major reproductive measures for the two groups are shown in Table 22. The study concluded that neither overall production nor the duration of production was affected by joining at 12 months for the first time. It should be noted, however, that age and number of production cycles differed between the two groups making it difficult to directly compare the results (Mavrogenis 1983).

Table 22: Lifetime performance of goats bred at one and two years old in Cyprus



Item	Yearlings*		Two–year olds*	Contrasts	
	A	B	C	A–C	B–C
Age at first kidding (months)	15.1		25.4		
Total kids born/goat	7.45±0.39	6.95±0.33	7.28±0.41	+ 0.17	— 0.33
Total kids born live/goat	7.04±0.38	6.54±0.33	6.97±0.41	+ 0.07	— 0.43
Cumulative litter weight at birth/goat (kg)	30.45±1.72	28.24±1.45	29.62±1.82	+ 0.83	— 1.38
Total kids weaned/goat	6.35±0.38	5.86±0.32	6.15±0.40	+ 0.20	— 0.29
Cumulative litter weight at weaning/goat (kg)	114.6 ±6.6	106.3 ±5.6	108.1 ±7.0	+ 6.46	— 1.82
Cumulative milk yield/goat (kg)	921.2 ±62.1	897.5 ±56.5	787.3 ±65.7	+113.9	+92.1
Cumulative days in milk/goat	730.1 ±44.0	697.8 ±39.7	605.3 ±46.6	+124.8	+92.5

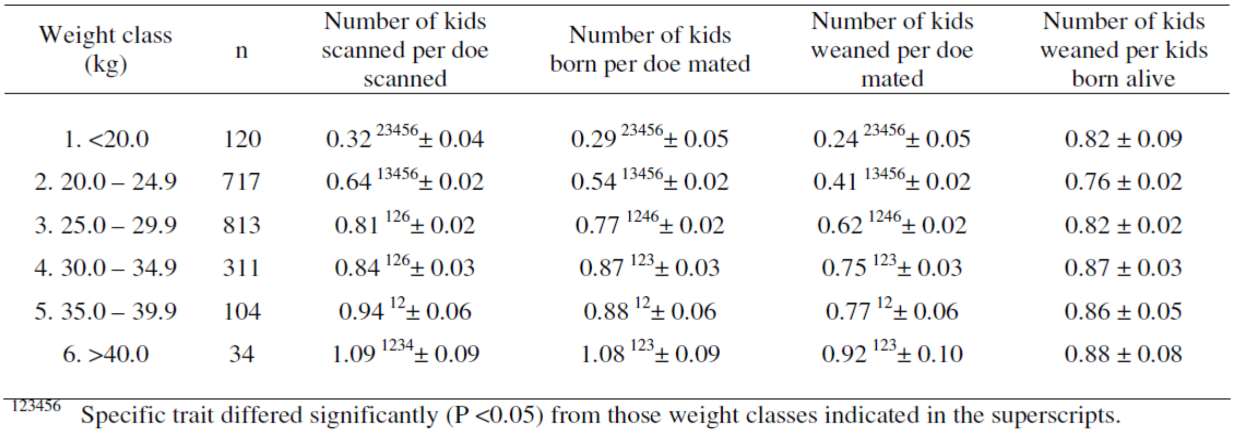
* A=until 7 years of age, 6 production cycles (lactations) at the end of 1980/81
B=until 8 years of age, 7 production cycles (lactations) at the end of 1981/82
C=until 8 years of age, 6 production cycles (lactations) at the end of 1980/81

Source: (Mavrogenis 1983)

A large study involving 12 Angora goat studs and 6271 Angora does in South Africa examined the influence of bodyweight, age and management system on reproductive performance. The management systems varied in the type of feed provided to the does and kids, including access to pasture, veld (grasslands), supplementation with grain or pellets. The study showed that age and bodyweight of the doe and the management system impacted on the reproductive outcome. The bodyweight at joining and number of kids weaned per doe mated was significantly greater for maidens raised on pasture compared to those on veld.

Table 23 shows the effect of bodyweight at first joining on various reproduction performance measures across the study (Snyman 2009).

Table 23: Effect of body weight of Angora does at first mating on reproductive performance



Weight class (kg)	n	Number of kids scanned per doe scanned	Number of kids born per doe mated	Number of kids weaned per doe mated	Number of kids weaned per kids born alive
1. <20.0	120	0.32 ^{23456}± 0.04	0.29 ^{23456}± 0.05	0.24 ^{23456}± 0.05	0.82 ± 0.09
2. 20.0 – 24.9	717	0.64 ^{13456}± 0.02	0.54 ^{13456}± 0.02	0.41 ^{13456}± 0.02	0.76 ± 0.02
3. 25.0 – 29.9	813	0.81 ^{126}± 0.02	0.77 ^{1246}± 0.02	0.62 ^{1246}± 0.02	0.82 ± 0.02
4. 30.0 – 34.9	311	0.84 ^{126}± 0.03	0.87 ^{123}± 0.03	0.75 ^{123}± 0.03	0.87 ± 0.03
5. 35.0 – 39.9	104	0.94 ^{12}± 0.06	0.88 ^{12}± 0.06	0.77 ^{12}± 0.06	0.86 ± 0.05
6. >40.0	34	1.09 ^{1234}± 0.09	1.08 ^{123}± 0.09	0.92 ^{123}± 0.10	0.88 ± 0.08

^{123456} Specific trait differed significantly ($P < 0.05$) from those weight classes indicated in the superscripts.

Source: (Snyman 2009)

In another study, five different dairy goat breeds (n=476) on a commercial farm in Mexico (26º06' N), were studied to evaluate any association between reproductive performance at the first kidding and later in life. It was concluded that weight and development in early life had no impact on lifetime fertility. It was suggested that selecting does producing more than one kid and those with high litter weight could lead to improved lifetime productivity of the flock (Mellado et al. 2005a).

McGregor (2007) cites US data on the effect of kid doe body weight at first mating on first kidding and lifetime kidding performance (Table 24). The same table appears in MLA's Bred Well Fed Well material. Note that the original source of this data is not identified in either of these resources, so no statement is made in the present review as to their veracity.

Table 24: Effect of kid doe body weight at first mating on lifetime kidding performance

KID DOE BODY WEIGHT AT MATING (KG)	FIRST KIDDING %	AVERAGE LIFETIME KIDDING %
Below 18	2	48
18-20	21	70
20-23	32	72
23-25	55	79
25-27	78	82

KID DOE BODY WEIGHT AT MATING (KG)	FIRST KIDDING %	AVERAGE LIFETIME KIDDING %
27-32	81	86
Above 32	88	89

Source: (McGregor 2007)

7.3.4 PREGNANCY DIAGNOSIS

OVERVIEW OF TECHNIQUES

Accurate diagnosis of pregnancy early in gestation allows for improved management of stock according to their reproductive state, including the number of offspring they are expected to deliver. It also is paramount to the assessment of kid loss and management of multiple births. The identification of empty animals allows them to be culled from the production system altogether or drafted away from the pregnant animals for differential treatment. The method of pregnancy diagnosis will be determined by the producer and must take into consideration the facilities, equipment available, skill of the tester and the stage of pregnancy at which testing is conducted. The evaluation of an individual's technique includes consideration of:

- Speed of testing;
- Sensitivity of the method (the likelihood of calling a pregnant animal 'pregnant');
- Specificity of the method (the likelihood of calling a non-pregnant animal 'non-pregnant'); and
- Cost ((Tamasia 2007), as cited by (Fthenakis et al. 2012)).

Table 25 outlines various pregnancy diagnosis methods that can be used in sheep at various stages of pregnancy. In commercial sheep production systems, the most commonly used techniques include identifying ewes that do not return to oestrus after mating, udder examination, palpation of the abdomen and ultrasound ((Tamasia 2007), as cited by (Fthenakis et al. 2012)).

Table 25: Methods available for diagnosing pregnancy in ewes

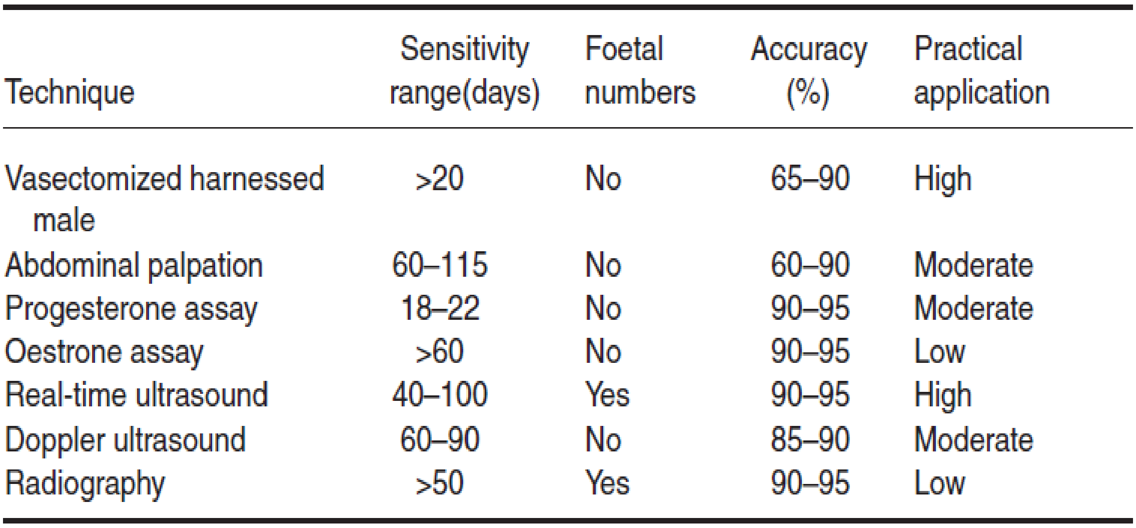
METHOD	RECOMMENDED STAGE OF PREGNANCY
Measurement of early pregnancy factor concentration in blood	1st day
Measurement of progesterone concentration in blood or milk	15th-19th day
Measurement of ovine pregnancy-associated glycoprotein in blood	18th day
Observation of ewes for oestrus signs	16th-18th day
Laparoscopy	17th-28th day
Measurement of pregnancy-specific protein B concentration in blood	>18th day

METHOD	RECOMMENDED STAGE OF PREGNANCY
Transrectal ultrasonographic examination for pregnancy diagnosis	25th-30th day
Measurement of oestrone sulphate concentration in blood	>28th (best: 40th–50th) day, >70th day
Transcutaneous ultrasonographic examination for pregnancy diagnosis	>35th day
Transcutaneous ultrasonographic examination for number of foetuses	45th–100th day
Rectal-abdominal palpation	49th–109th day
Palpation of the vaginal artery	>60th day
X-ray examination	>65th–70th day
Udder development	>110th day
Increase in abdominal size	>130th day

Source: (Fthenakis et al. 2012), citing (Noakes 2003, Tamasia 2007, Taverne and Noakes 2009)

Table 26 shows some of the more commonly used techniques to diagnose pregnancy. It includes information on the sensitivity, accuracy, practicality and ability or not to identify the number of foetuses for each of the techniques listed. Real time ultrasound had an accuracy of 90-95%, sensitivity of 40-60 days and a high practical application which would make it the most useful tool on the list (Rekik et al. 2012). As this technique requires an expert (in most cases) to perform, the cost of travel may be a limiting factor for remote properties with smaller number of animals to scan.

Table 26: Comparison of techniques for diagnosing pregnancy in the doe



Technique	Sensitivity range(days)	Foetal numbers	Accuracy (%)	Practical application
Vasectomized harnessed male	>20	No	65–90	High
Abdominal palpation	60–115	No	60–90	Moderate
Progesterone assay	18–22	No	90–95	Moderate
Oestrone assay	>60	No	90–95	Low
Real-time ultrasound	40–100	Yes	90–95	High
Doppler ultrasound	60–90	No	85–90	Moderate
Radiography	>50	Yes	90–95	Low

Source: (Rekik et al. 2012)

ULTRASONOGRAPHY

Ultrasonography, the application of ultrasound pulses to differentiate areas of different density within the body and commonly referred to simply as ‘ultrasound’, has been established as an effective tool to assess the reproductive tract of small ruminants (Bretzlaff and Romano 2001).

The accuracy and efficiency of ultrasound can vary with:

- Operator experience and expertise;
- Size and body condition of the goat;
- Livestock handling facilities and equipment;
- Stage of gestation; and
- The type of transducer on the ultrasound machine (Bretzlaff and Romano 2001).

Recognised techniques in goats include transabdominal and transrectal ultrasound. Bretzlaff and Romano (2001) reported that performing ultrasound in a standing position is preferred in goats due to their strong resistance to being tipped. However, early pregnancy diagnosis, and evaluation of the uterus and ovaries are more reliably completed with the goat in dorsal recumbency. Pregnancy can be detected by transabdominal ultrasound from 30-35 days gestation. Transrectally it can be performed as early as 18 days after breeding. It is recommended that positive scans are repeated at 40-45 days of gestation. Scanning to assess the number of foetuses can be performed from 40-70 days transabdominally, while transrectally an estimation of the number of embryos can be found at 25-30 days of gestation. Clipping of the hair on the target area can improve images, although experienced scanners can achieve good results without the need for this. Precision is improved when the joining time is known and pregnancies are within the middle trimester (Bretzlaff and Romano 2001).

Martin et al (2004) endorse the use of ultrasound to improve reproductive capability in small ruminants as part of their ‘clean green and ethical’ model, describing it as non-hormonal and non-invasive. They advocate the use of ultrasound to differentiate between single and multiple birth allowing for accurate implementation of specific feeding strategies to meet the different needs of females during pregnancy and lactation. They also suggest that estimation of the foetus age (to within 5 days (Greenwood et al. 2002), as cited by (Martin et al. 2004a)) allows for more timely nutritional support.

The accuracy of quantification of the number of foetuses drops as the number exceeds two ((Taverne et al. 1985), as cited by (Bretzlaff and Romano 2001)). Bretzlaff and Romano (2001) advocate the classification of pregnancy in goats as either ‘single’ or ‘multiple’ rather than attempting to provide a precise estimation of the number of foetuses. If scanning is to be used to identify three or more foetuses this is most accurate when completed at seven weeks’ gestation. Producers who choose to use ultrasound to determine the number of foetuses should be advised of the variation in accuracy and that spontaneous embryo mortality can occur post-scanning (Bretzlaff and Romano 2001).

In ewes, ultrasound has been conducted both transcutaneously and transrectally. The choice of technique is determined by the availability of equipment, skill of the scanner and the stage of pregnancy. The transrectal technique is more accurate prior to the 35th day but both approaches are equally accurate between 35-70 days of pregnancy. Diagnosis in the second half of pregnancy is best completed using the transcutaneous method. The most accurate way to estimate the number of foetuses in ewes is to use transcutaneous examination between the 45th and 100th days ((Kähn 2004, Meinecke-Tillmann and Meinecke 2007), as cited by (Fthenakis et al. 2012)).

In one study, two transrectal ultrasonic devices were found to be considerably more accurate at diagnosing pregnancy than transrectal Doppler[2] ultrasound or rectoabdominal palpation in ewes. However, seven ewes died from peritonitis following rectal probe use and another six aborted (Trapp and Slyter 1983).

Ultrasound is rarely used for examination of the ovaries of sheep and goats, but it is used more commonly in cattle reproductive investigations (Scott 2012). Ultrasound can also be used as a diagnostic aid for a number of other reproductive problems (Table 27).

Table 27: Other uses of ultrasound in small ruminant reproductive diagnostics

PROBLEM	INDICATIONS FOR ULTRASOUND USE	REFERENCE
Retained foetus in utero after delivery of a lamb	⌖ Transabdominal ballottement suggests foetus in utero ⌖ Cervix contraction prevents manual palpation ⌖ When delivered, lamb number is less than that detected in earlier pregnancy scanning	(Scott and Gessert 2000)

---

[2] Doppler is a type of ultrasonography used to estimate blood flow by bouncing ultrasound waves off circulating red blood cells

PROBLEM	INDICATIONS FOR ULTRASOUND USE	REFERENCE
Delayed uterine involution post-partum (sheep)	⌖ Dystocia or Caesarean section which are likely to cause delayed involution	(Hauser and Bostedt 2002)
Uterine torsion	⌖ Narrow reproductive tract restricts vaginal examination (sheep)* ⌖ Torsion may be proximal to cervix and thus cannot be detected vaginally (sheep)** ⌖ Early identification may allow for early intervention and the potential for better outcomes**	*(Wehrend et al. 2002) **(Scott 1989)
Vaginal prolapse	⌖ A vaginal prolapse may contain a urinary bladder, uterine horns or both. These can be identified by ultrasound	(Scott 2012)

Source: references in table cited by (Scott 2012)

In addition, ultrasound can be used in investigating abnormalities of the reproductive tract of rams, including scrotal atrophy and infection, epididymitis and orchitis (Scott 2012).

OESTRONE SULFATE

Pregnant does produce detectable levels of oestrone sulphate after 45-50 days of pregnancy. Oestrone sulphate can be detected in urine, milk and blood (McArthur and Geary 1986). Commercial tests for oestrogen are adequate indicators of oestrone sulphate. In a study by McArthur and Geary (1986), milk from 66 pregnant dairy goats was tested for oestrone sulphate using a direct immunoassay. Levels of oestrone sulphate were low until 35 days after which time the rise was rapid. As well as diagnosing pregnancy with an accuracy of 95.6% the test could distinguish pseudopregnancies from real pregnancies (McArthur and Geary 1986). This type of testing is more suited to dairy than goat meat enterprises.

ECONOMICS OF PREGNANCY TESTING

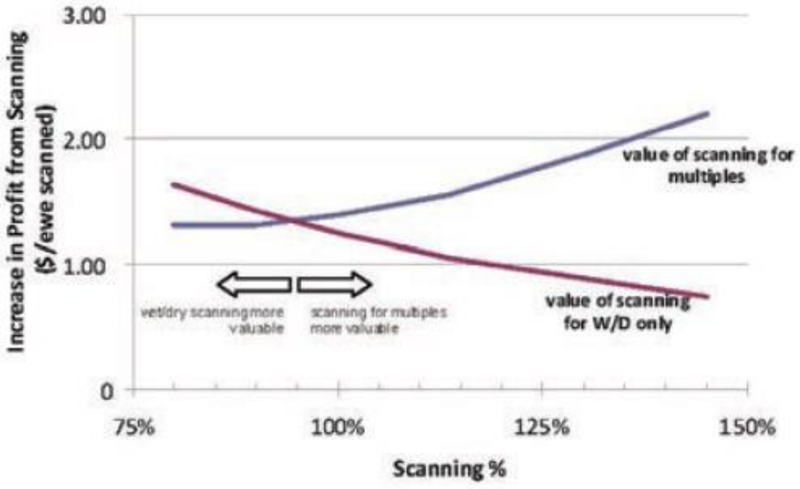
Pregnancy testing is used in enterprises that use AI and ET and in more intensive systems. In extensive production systems based on natural mating it less likely to be advantageous because there is less scope to make management changes based on the test results (Rekik et al. 2012).

The Cooperative Research Centre for Sheep Industry Innovation (Sheep CRC) has undertaken a useful assessment of the value of pregnancy scanning in sheep. It states that the main benefits from pregnancy scanning are gained in situations where one or more of the following applies:

- The season is poor and feed shortage during pregnancy is likely;
- There are likely to be many dry ewes; and
- There are likely to be many sets of twins, which can be managed separately (CRC 2019).

Pregnancy scanning can be used to determine if an animal is pregnant or not or to differentiate between singles and multiple lambs. Scanning just for pregnant or empty allows the producer to remove the non-pregnant ewes from the breeding flock and allow for differentiated feeding, allowing savings in feed costs. Differentiating between single and multiple pregnancies allows for even more specific allocation of feed to those animals with higher requirements and estimation of breeding value (CRC 2019).

Figure 14 shows the increase in profit compared to the scanning percentage when scanning either for pregnant/empty or multiples. The profit calculations take account of the impact of culling empty ewes on the overall flock structure. As the number of foetuses per 100 ewes increases, there is an increased benefit of scanning for multiples. The take-home messages from the article were to consider not scanning for preg/empty if there are less than 5% empty ewes, and to consider not scanning for multiples if the twinning rate is less than 15% (CRC 2019).



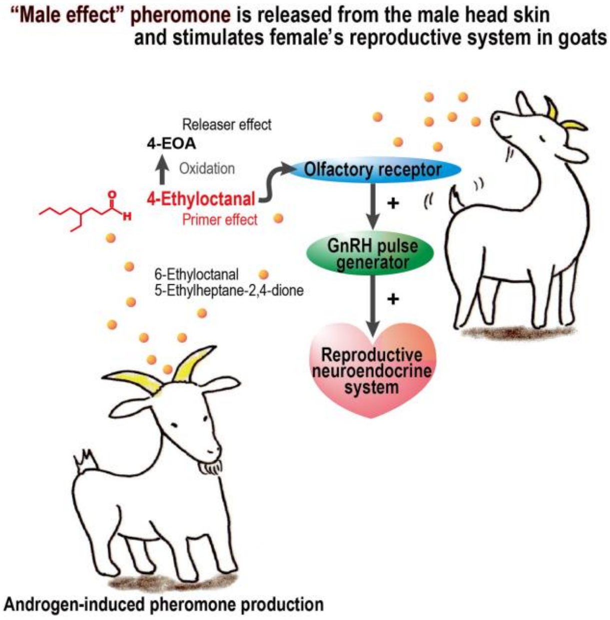
Source: (CRC 2019)

Figure 14: The impact on profit per ewe with scanning when the impact of culling dry ewes is considered

7.3.5 THE BUCK (MALE) EFFECT

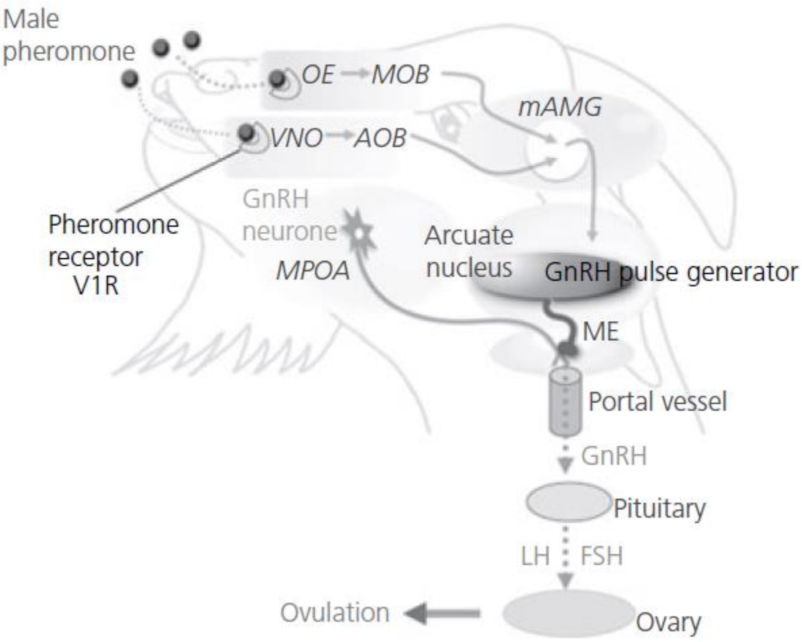
The male effect can also be called the buck effect (Flores et al. 2000), the ram effect (Martin et al. 1986, Walkden-Brown et al. 1999) and the stag effect ((Haigh and Hudson 1993), as cited by (Tuckwell 2003)) for goats, sheep and Wapiti / elk deer respectively. The process involves the introduction of a male to a group of females after a period of separation between the two.

Figure 15 summarises how the buck effect works overall, while Figure 16 shows how the male pheromones work in the doe to promote ovarian activity (Murata et al. 2014)



Source:(Murata et al. 2014)

Figure 15: Interaction of the buck, doe and relevant hormones in the buck effect



Source: (Murata et al. 2009)

Figure 16: Schematic diagram of how male pheromones alter reproductive activity in does in the 'buck effect'

The period of separation must be at least one month at a distance of no less than one kilometre. The initial contact with the males helps to stimulate the females to cycle (A.W.I. and M.L.A. 2008, MLA 2008). This approach can be used to synchronise the females, leading to a much tighter birthing period. The 'male effect' provides a 'clean, green and ethical' method of inducing puberty and synchronisation of first oestrus (Scaramuzzi and Martin 2008). It has also been described as a cost-effective management tool that considers human health, the environment and animal welfare (Valasi et al. 2012).

However, not all breeds of sheep (Bartlewski et al. 2002) and goats respond to the ram/buck sufficiently to provide a management advantage (Martin et al. 2004a). The response of ewes to the ram effect varies depending on the breed, length of time since the last lambing, body condition, physiological state and season. The best effect is seen when the rams are introduced 4-8 weeks before the breeding season is due to begin. The ram effect is only effective when used as a sudden and short exposure. With long periods of exposure the affect does not persist (Notter 2012).

The overall benefit of the male effect is influenced by the degree of seasonality of the breed and the location (latitude) of the goats. Goats that normally display only moderate seasonality are more likely to respond positively to the introduction of a male (Walkden-Brown et al. 1999). Where goats are highly seasonally dependent, however, the effect of the male may only bring forward the beginning of the breeding season by a few weeks. Used alone, the buck effect cannot induce full sexual activity in highly seasonal goats in the middle of the anoestrus period (Walkden-Brown et al. 1999). However, ovulation can be induced in sheep and goats by the sudden introduction of novel males to females that are anoestrous due to lactation or the time of year (Martin et al. 1986, Walkden-Brown et al. 1999).

Pre-treatment using photoperiod manipulation of females and/or males may be used to optimise the response to the male/buck effect ((Flores et al. 2000), cited by (Fatet et al. 2011)). Goats located in alpine areas have been shown to require artificial photoperiod treatment of both males and females to obtain a good male effect (Maria-Teresa et al. 2007). In a study in subtropical Mexico, the sexual activity of the male was critical for a successful effect. Bucks received photoperiod treatment of long days followed by melatonin / natural days to maximise the stimulation of ovulation and oestrus behaviour in female goats. The result from the male effect was greater using treated rather than untreated males (Flores et al. 2000).

Other studies have shown that the male effect was greatest in does that were provided with nutritional supplementation compared to those that were not. The benefits included more female goats displaying oestrus behaviour, ovulating and becoming pregnant ((De Santiago-Miramontes et al. 2008, Fitz-Rodriguez et al. 2009) as cited by (Fatet et al. 2011)).

In parts of the United States, the male effect has been used to achieve almost year-round breeding and kidding. This involves the introduction of a buck, which has been isolated for no less than 2-3 weeks, to 'transitional' females (moving between the breeding and non-breeding season). Most females ovulated in response to the buck effect. In herds where females born out of season were selected, these were more likely to be transitional most of the year and the buck effect was more successful. The buck effect also had the advantage of enhancing oestrus behaviours in does and improving reproductive efficiency (Bretzlaff and Romano 2001).

The male effect may advance the first cycle of young ewes by up to two weeks ((Amoah and Bryant 1984), as cited by (Valasi et al. 2012)), although further research is required to confirm this (Martin et al. 2004b).

Artificial insemination can be used in females that have been induced to ovulate using the male effect as they will be adequately synchronised ((Lindsay et al. 1984) and (Corke 1980), both cited by (Martin et al. 2004a). It is thought that the synchronisation induced by the male effect would also allow for focussed feeding for litter size, foetal programming and survival of neonates (Martin et al. 2004a).

7.3.6 THE FEMALE EFFECT

Some anovulatory does will be stimulated to ovulate by the presence of female goats in oestrus (Restall et al. 1995).

7.3.7 NUTRITION, BODY WEIGHT AND BODY CONDITION SCORING

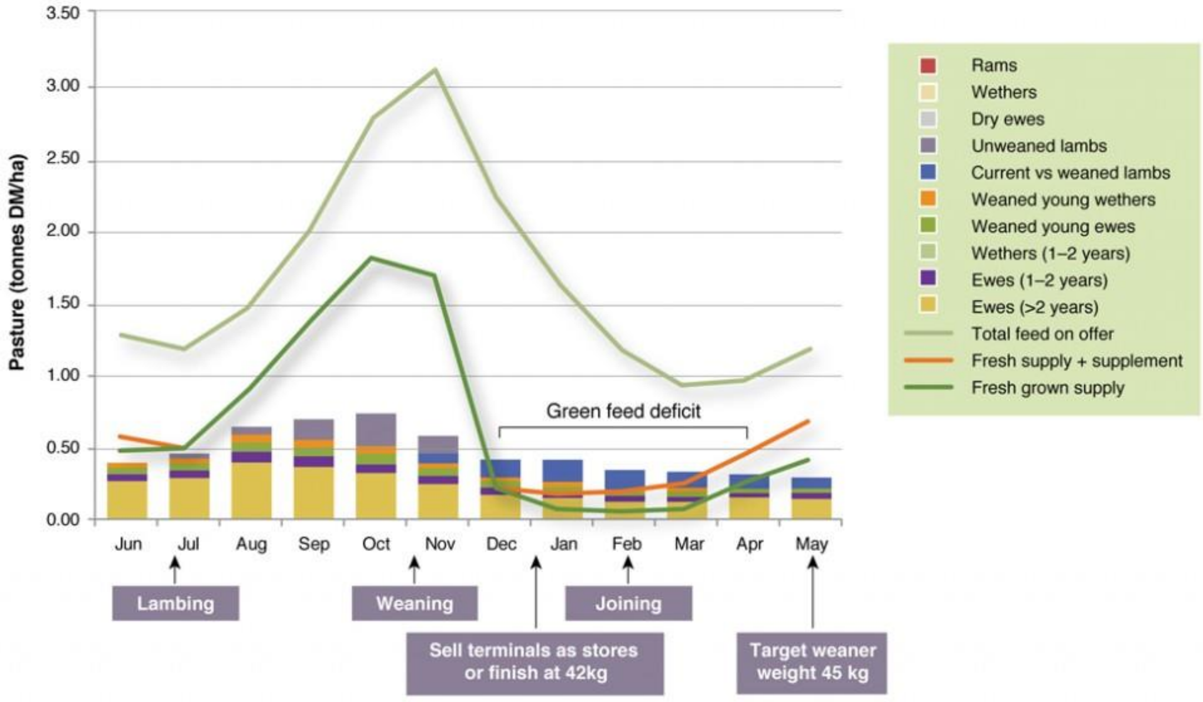
OverviewA literature review of goat nutrition in Australia for MLA by Jolly (2013) provides a comprehensive and detailed report into the nutritional requirements of goats and how they vary between some of the main goat breeds farmed in Australia. The review also describes how animals respond to a variety of feeding regimes.

The influence of nutrition on reproductive success in goats and sheep has been long established and is summarised in section 6.5. This link has been critical in the survival of species in their natural environment, ensuring that animals do not expend resources reproducing unless there is sufficient nutrition available for the survival of the dam and her offspring. The phases of lactation and neonatal growth particularly pose a high energy demand on the female. This dependence of reproductive function on nutrition, however, creates physiological barriers for commercial production systems of sheep and goats where it might be preferable to breed at other times of the year (Scaramuzzi et al. 2006).

PRODUCTION TO MATCH PASTURE

In livestock enterprises, productivity relies upon effective matching of nutritional demands against feed availability. Knowing how the quality and quantity of feed available varies on a property is critical in planning reproductive management to best utilise this feed. Ideally, periods of maximum demand and supply will occur at the same time. If not, then the degree and duration of deficit in supply should be minimised. Inadequate pasture availability requires supplementation to avoid detrimental effect on stock production and welfare, which can be costly.

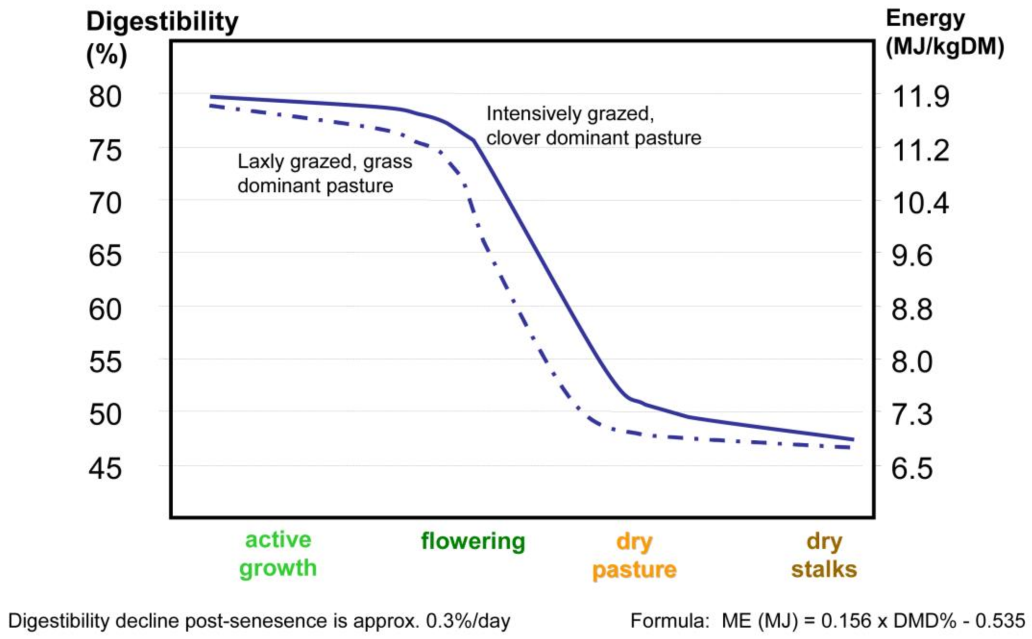
The majority of the literature on pasture availability and meeting demand in small ruminants comes from sheep enterprises. The EverGraze program, in which MLA is a partner, has produced very detailed information on the growth of different pasture types at different locations across Australia (Saul 2013a). Figure 17 shows an example of a sheep enterprise on a property in Western Australia. It shows the pasture availability and relevant reproductive milestones throughout a year. It allows ready identification of the times of the year when deficiencies are likely to occur.



Source: EverGraze (Saul 2013b)

Figure 17: Example of a sheep enterprise in Western Australia showing feed demand and supply throughout the year

The following two figures show the digestibility of pasture in a Mediterranean climate (Figure 18) and in Hamilton, Victoria (Figure 19). It shows the dramatic reduction in energy and digestibility of pasture as it matures and dries off.

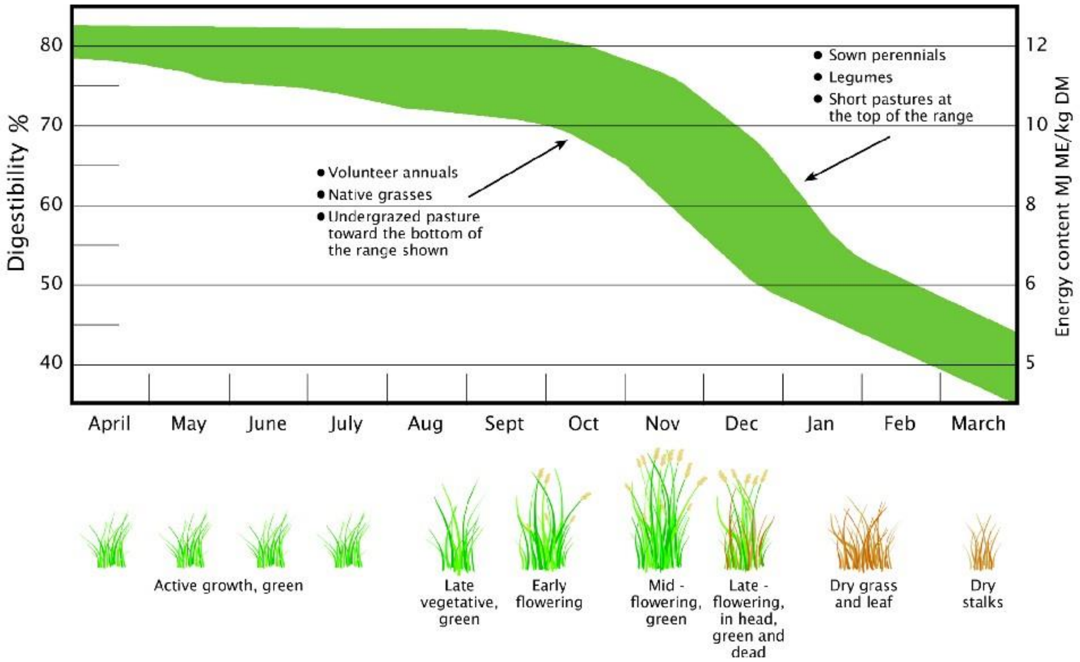


Digestibility decline post-senesence is approx. 0.3%/day

Formula: ME (MJ) = 0.156 x DMD% - 0.535

Source: (Hyder 2018)

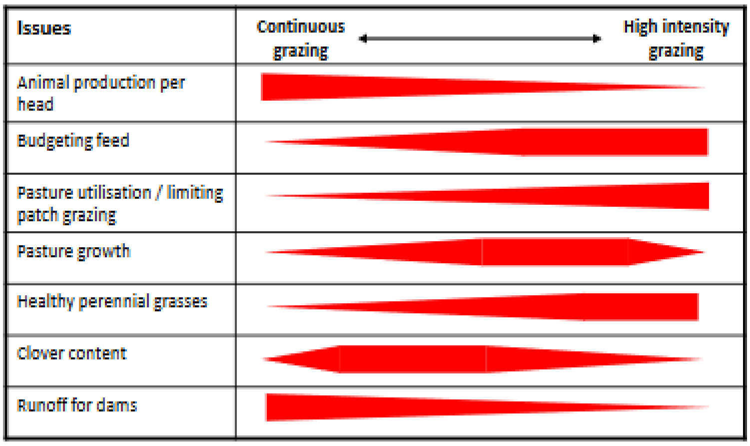
Figure 18: The digestibility of annual plants in a Mediterranean climate



Source: (Nie 2006)

Figure 19: The energy and digestibility of various pasture types in Hamilton (Vic)

The stocking rate and extension of stock rotation through paddocks can also impact on the pasture, productivity and the environment. Figure 20 shows how these impacts vary with the grazing intensity from continuous grazing thought to high intensity rotational grazing.



Issues	Continuous grazing ↔ High intensity grazing
Animal production per head	
Budgeting feed	
Pasture utilisation / limiting patch grazing	
Pasture growth	
Healthy perennial grasses	
Clover content	
Runoff for dams	

Source: EverGraze (Badgery 2009)

Figure 20: The impact of grazing intensity on pasture and productivity

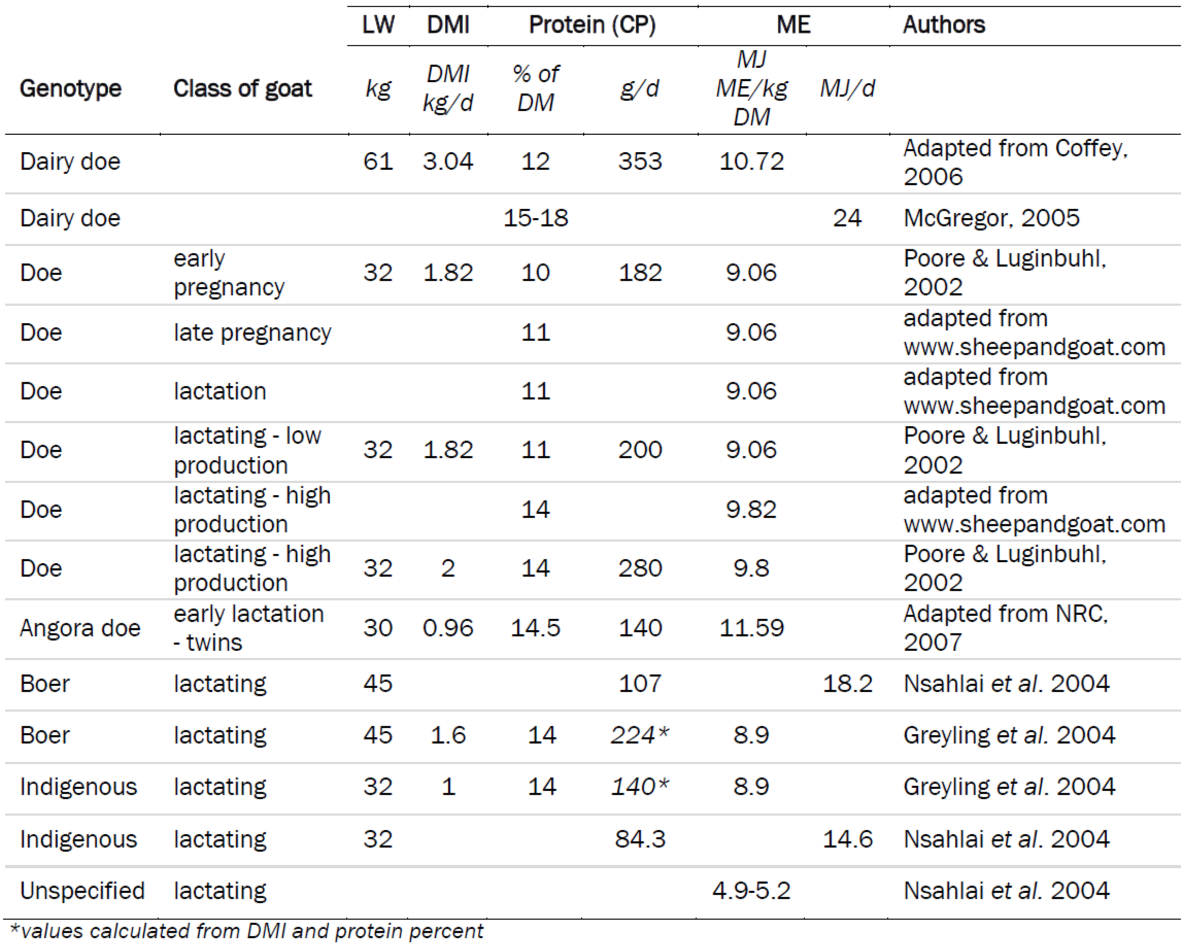
These figures show clearly how pasture availability and digestibility varies within a year. There is also considerable between-year variation that has become more apparent with climate change. This adds complexity to the ability for producers to plan their reproductive calendar and to consider more complex advanced breeding programs.

MAINTENANCE REQUIREMENTS

In 2013, San Jolly completed a comprehensive literature review on ‘Goat nutrition in Australia’ for MLA. The review concluded that the guidelines for nutrient requirements for goats varied considerably, and it was uncertain which source was ‘correct’. In addition, the significant variation in environments where goats exist in Australia and the variation in genotypes makes determination of nutrient requirements complex. Two significant recommendations from the review were the clarification of the dry matter, protein and mineral requirements for the various classes of goats in several genotypes; and validation of the nutritional requirements for the reproductive does in non-experimental situations.

Table 28 provides a summary of studies of the nutritional requirements of several goats breeds in various physiological states within the reproductive cycle. The table shows that suggested dry matter intake for goats varies from 3.04 kg/day in dairy goats to 1kg/day in a lactating indigenous breeds, while estimated protein requirements as a percentage of dry matter ranged between 12% and 15-18% (Jolly 2013).

Table 28: Estimates of liveweight (LW), dry matter intake (DMI), crude protein (CP) and metabolisable energy (ME) requirements of does (from various sources)



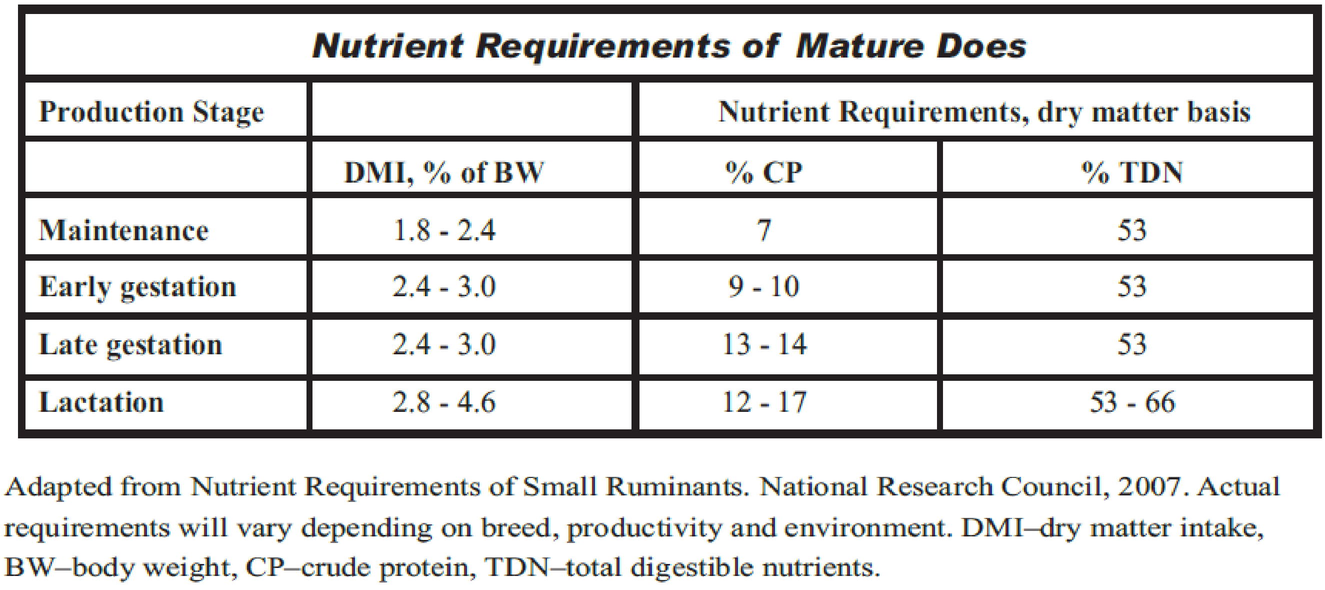
		LW	DMI	Protein (CP)		ME		Authors
Genotype	**Class of goat**	*kg*	*DMI kg/d*	*% of DM*	*g/d*	*MJ ME/kg DM*	*MJ/d*	
Dairy doe		61	3.04	12	353	10.72		Adapted from Coffey, 2006
Dairy doe				15-18			24	McGregor, 2005
Doe	early pregnancy	32	1.82	10	182	9.06		Poore & Luginbuhl, 2002
Doe	late pregnancy			11		9.06		adapted from www.sheepandgoat.com
Doe	lactation			11		9.06		adapted from www.sheepandgoat.com
Doe	lactating - low production	32	1.82	11	200	9.06		Poore & Luginbuhl, 2002
Doe	lactating - high production			14		9.82		adapted from www.sheepandgoat.com
Doe	lactating - high production	32	2	14	280	9.8		Poore & Luginbuhl, 2002
Angora doe	early lactation - twins	30	0.96	14.5	140	11.59		Adapted from NRC, 2007
Boer	lactating	45			107		18.2	Nsahlai *et al*. 2004
Boer	lactating	45	1.6	14	*224**	8.9		Greyling *et al*. 2004
Indigenous	lactating	32	1	14	*140**	8.9		Greyling *et al*. 2004
Indigenous	lactating	32			84.3		14.6	Nsahlai *et al*. 2004
Unspecified	lactating					4.9-5.2		Nsahlai *et al*. 2004

**values calculated from DMI and protein percent*

Source: adapted by (Jolly 2013) from various sources as identified in the table. (Poore and Luginbuhl 2002, Greyling et al. 2004, Nsahlai et al. 2004, McGregor 2005, Coffey 2006, NRC 2007)

The National Research Council (NRC) of the United States publishes nutritional requirements for small ruminants. There are two editions of these figures, released in 1981 and 2007. The earlier figures (1981) were based on a few studies that did not involve goat breeds commonly found in Australia. The later figures (2007, requirements for does shown in Table 29) were based on goats that were confined and thus adjustments would be required to allow for paddock conditions (Jolly 2013). Some adjustment may also be required for variation in quality and quantity of feed available, as some suggest goats may be able to alter their energy requirements based on available feed. In situations where there is a reduction in available feed, Bedouin goats (desert goats) are able to reduce their energy requirements by up to 65% (Silanikove 1997).

Table 29: Nutritional requirements for goats



Nutrient Requirements of Mature Does

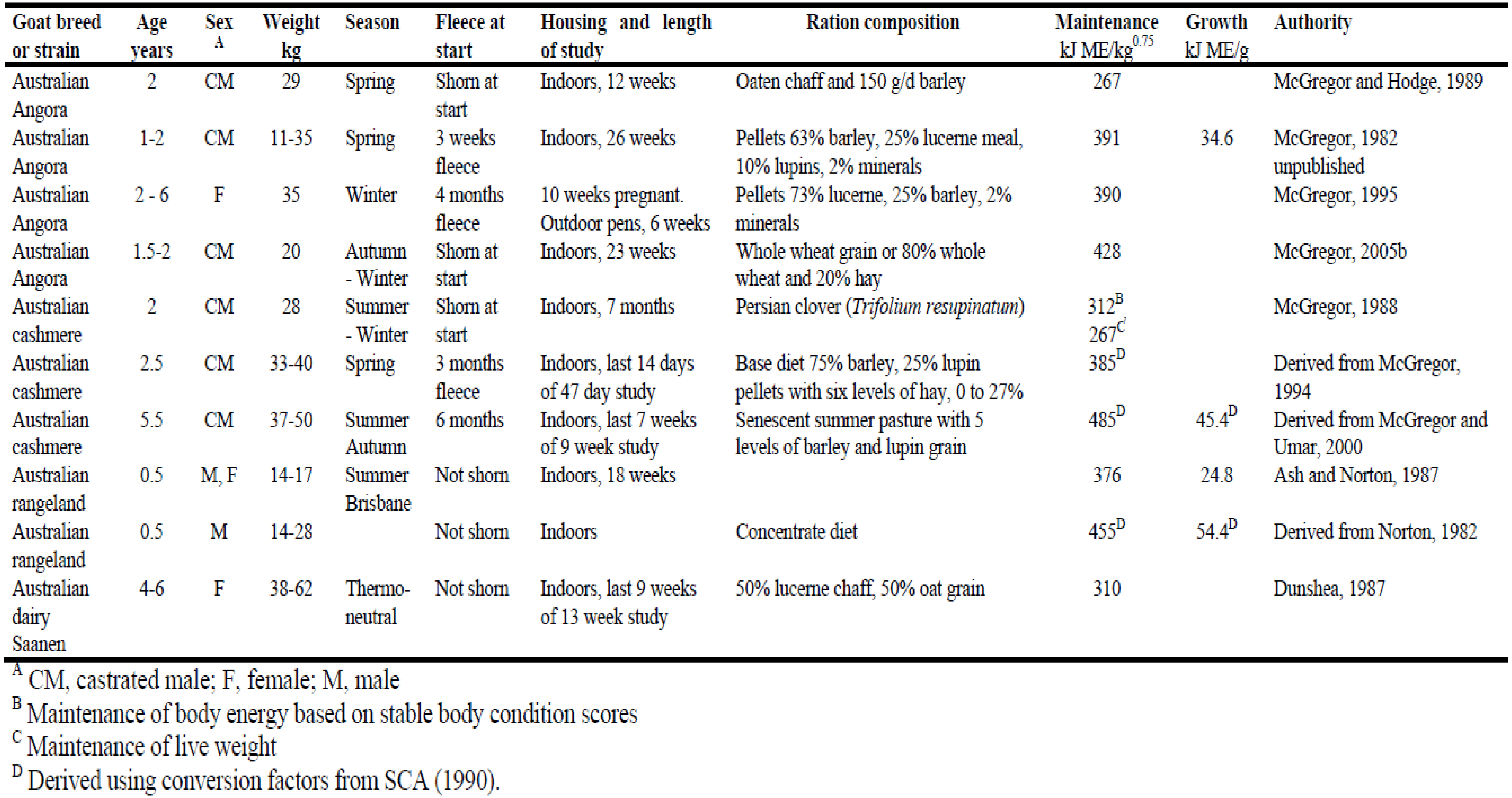
Production Stage		Nutrient Requirements, dry matter basis	
	DMI, % of BW	% CP	% TDN
Maintenance	1.8 - 2.4	7	53
Early gestation	2.4 - 3.0	9 - 10	53
Late gestation	2.4 - 3.0	13 - 14	53
Lactation	2.8 - 4.6	12 - 17	53 - 66

Adapted from Nutrient Requirements of Small Ruminants. National Research Council, 2007. Actual requirements will vary depending on breed, productivity and environment. DMI–dry matter intake, BW–body weight, CP–crude protein, TDN–total digestible nutrients.

Source (Rashid 2008), adapted from (NRC 2007)

A report entitled ‘Nutrition and management of goats in drought’ by McGregor (2005), published by the Rural Industries Research and Development Corporation, provides a very comprehensive guide to feeding goats in a drought. Its estimations of nutritional requirements could provide a useful base for normal season conditions. Table 30 is a summary from (McGregor 2005) of the energy requirements for Angora, Cashmere, dairy and Angora goats, most of which are different to those provided in the table by Jolly (2013) above (Table 28). McGregor uses various Australian research resources, the NRC (1981) figures and ‘Feeding standards for Australian livestock – ruminants’ produced by the Standing Committee on Agriculture (SCA 1990) – a total of 22 sources – to derive average estimates of energy requirements. His calculated figure for maintenance in goats is 404.7 kJ ME/kg$^{0.75}$. This is assuming minimal activity of the goats (McGregor 2005).

Table 30: Some estimates of energy requirements for various goat breeds from selected sources



Goat breed or strain	Age years	Sex [A]	Weight kg	Season	Fleece at start	Housing and length of study	Ration composition	Maintenance kJ ME/kg$^{0.75}$	Growth kJ ME/g	Authority
Australian Angora	2	CM	29	Spring	Shorn at start	Indoors, 12 weeks	Oaten chaff and 150 g/d barley	267		McGregor and Hodge, 1989
Australian Angora	1-2	CM	11-35	Spring	3 weeks fleece	Indoors, 26 weeks	Pellets 63% barley, 25% lucerne meal, 10% lupins, 2% minerals	391	34.6	McGregor, 1982 unpublished
Australian Angora	2 - 6	F	35	Winter	4 months fleece	10 weeks pregnant. Outdoor pens, 6 weeks	Pellets 73% lucerne, 25% barley, 2% minerals	390		McGregor, 1995
Australian Angora	1.5-2	CM	20	Autumn - Winter	Shorn at start	Indoors, 23 weeks	Whole wheat grain or 80% whole wheat and 20% hay	428		McGregor, 2005b
Australian cashmere	2	CM	28	Summer - Winter	Shorn at start	Indoors, 7 months	Persian clover (*Trifolium resupinatum*)	312[B] 267[C]		McGregor, 1988
Australian cashmere	2.5	CM	33-40	Spring	3 months fleece	Indoors, last 14 days of 47 day study	Base diet 75% barley, 25% lupin pellets with six levels of hay, 0 to 27%	385[D]		Derived from McGregor, 1994
Australian cashmere	5.5	CM	37-50	Summer Autumn	6 months	Indoors, last 7 weeks of 9 week study	Senescent summer pasture with 5 levels of barley and lupin grain	485[D]	45.4[D]	Derived from McGregor and Umar, 2000
Australian rangeland	0.5	M, F	14-17	Summer Brisbane	Not shorn	Indoors, 18 weeks		376	24.8	Ash and Norton, 1987
Australian rangeland	0.5	M	14-28		Not shorn	Indoors	Concentrate diet	455[D]	54.4[D]	Derived from Norton, 1982
Australian dairy Saanen	4-6	F	38-62	Thermo-neutral	Not shorn	Indoors, last 9 weeks of 13 week study	50% lucerne chaff, 50% oat grain	310		Dunshea, 1987

[A] CM, castrated male; F, female; M, male

[B] Maintenance of body energy based on stable body condition scores

[C] Maintenance of live weight

[D] Derived using conversion factors from SCA (1990).

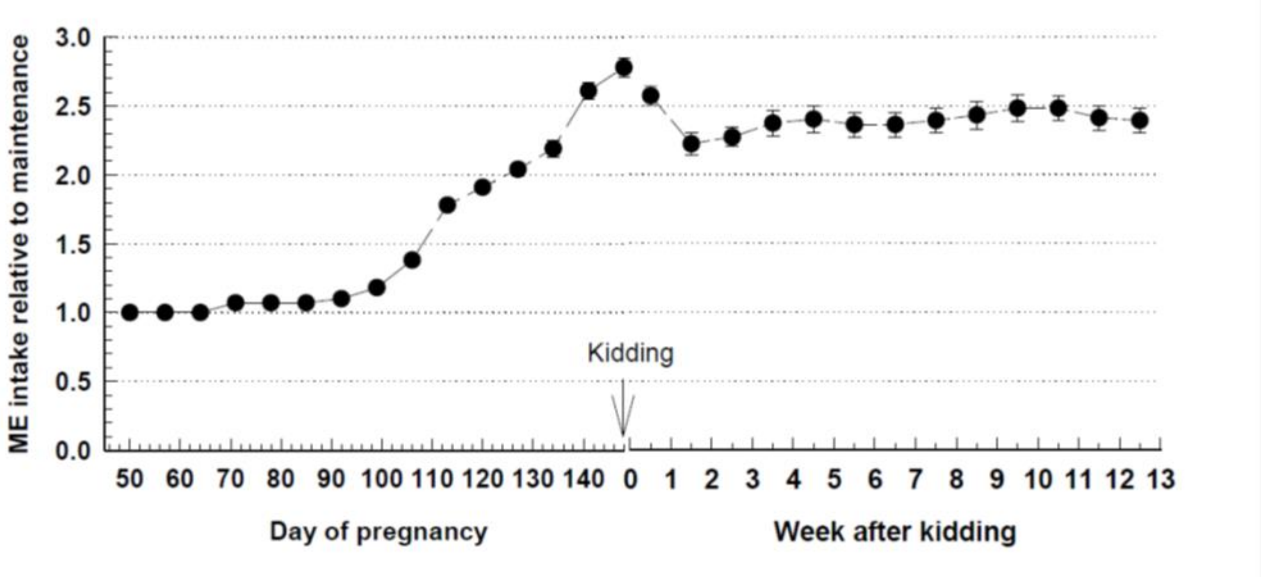
Source: Compiled by (McGregor 2005) from various sources as listed in the table {(Norton 1982, Ash and Norton 1987, Dunshea 1987, McGregor and Hodge 1989, McGregor 2006)(listed as 2005b) (McGregor 1988, McGregor 1994, McGregor and Umar 2000)}

REQUIREMENTS DURING PREGNANCY

In calculating nutritional requirements for pregnancy, the NRC allows for a 20% twinning rate and advises maintenance to 85 days (NRC 1981). The SCA provides data based on that available in sheep assuming a birth weight of 4kg and suggests feeding maintenance to 66 days of pregnancy (SCA 1990).

McGregor (1995) measured the energy requirements for pregnant and lactating Angora does kept in pens indoors with only minimal activity (McGregor 1995). Using the data from this study and the SCA (1990) recommendations, McGregor (2005) developed the graph in Figure 21 of energy requirements for pregnant and lactating does in drought conditions. The assumptions in the development of this graph included that the animals are in a drought, average liveweight of does is 35kg, maintenance is provided in early pregnancy, supplementation is increased from 66 days and is given ad lib from 120 days of pregnancy.

The fact that these studies involved Angora goats should be considered in interpreting the results for goat meat production systems in Australia. For example, the study assumed that 20% of does are carrying twins, which is lower than might be expected for meat breeds. McGregor states that, as a rule of thumb, from 140 days of gestation and during lactation does should be fed 2.5 times maintenance (McGregor 2005).



Source: (McGregor 2005)

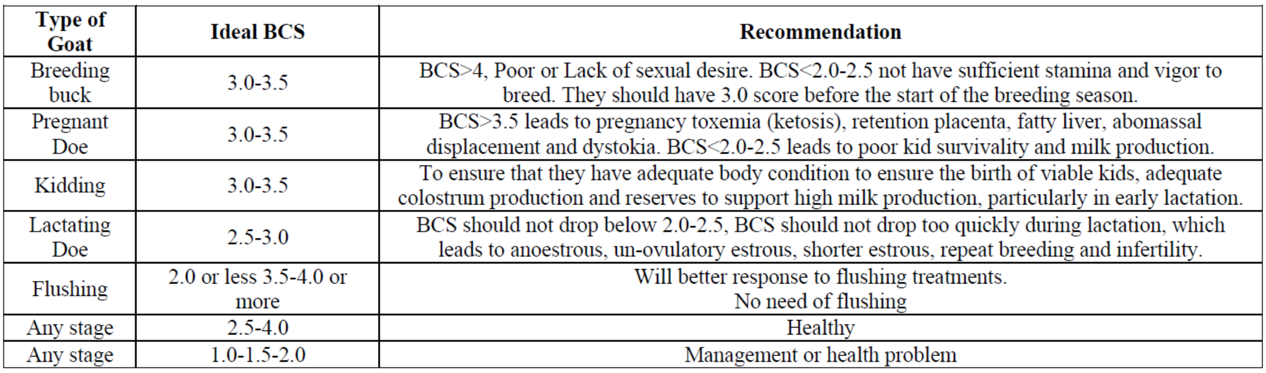
Figure 21: Suggested drought energy feeding regime for pregnant and lactating does

BODY CONDITION SCORING

The American Institute for Goat Research has produced a very detailed description of body condition scoring of goats including pictures from different angles of the animals in the various condition scores. The document emphasises the importance of 'touching', not just looking at, animals to condition score them accurately (Villaquiran et al. 2019).

Ghosh et al (2019) reviewed the impact and significance of body condition scoring in goats. The article emphasises the importance of condition scoring in order to optimise the reproductive potential of goats in both milk and meat enterprises. Table 31 was included in this paper and shows the 'ideal' body condition for goats in various physiological states (Ghosh et al. 2019).

Table 31: Recommended BCS in various physiological states



Type of Goat	Ideal BCS	Recommendation
Breeding buck	3.0-3.5	BCS>4, Poor or Lack of sexual desire. BCS<2.0-2.5 not have sufficient stamina and vigor to breed. They should have 3.0 score before the start of the breeding season.
Pregnant Doe	3.0-3.5	BCS>3.5 leads to pregnancy toxemia (ketosis), retention placenta, fatty liver, abomassal displacement and dystokia. BCS<2.0-2.5 leads to poor kid survivality and milk production.
Kidding	3.0-3.5	To ensure that they have adequate body condition to ensure the birth of viable kids, adequate colostrum production and reserves to support high milk production, particularly in early lactation.
Lactating Doe	2.5-3.0	BCS should not drop below 2.0-2.5, BCS should not drop too quickly during lactation, which leads to anoestrous, un-ovulatory estrous, shorter estrous, repeat breeding and infertility.
Flushing	2.0 or less 3.5-4.0 or more	Will better response to flushing treatments. No need of flushing
Any stage	2.5-4.0	Healthy
Any stage	1.0-1.5-2.0	Management or health problem

Source: (Ghosh et al. 2019)

In a review of body condition score and its relation to production characteristics in sheep, Kenyon et al (2014) note that finding a single optimal BCS is unlikely from either an economic or biological perspective. Some of the variables that influence the target BCS are the age and breed of the animal, the number of lambs it is feeding or bearing, the quality and quantity of the food on offer and the type of production system. The authors suggested ranges of desirable BCS at the various stages of reproduction shown in Table 32 (Kenyon et al. 2014).

Table 32: Recommended body condition scores of ewes at various stage in the reproductive cycle

REPRODUCTIVE STAGE	BCS	COMMENT
Breeding	2.5-3.5	
Early pregnancy	2.5-3.5	
Late pregnancy	Variable	Weight loss is likely during this stage
Lambing	2.5-3.0	Absolute minimum BCS 2
Lactation	?	
Weaning	2.0	No more than 1 unit BCS loss from lambing BCS

Source: (Kenyon et al. 2014) using the studies included in the various tables above

PROVIDING ADEQUATE NUTRITION

Poor reproductive success has been observed in both sheep and goats when there is a limit to nutrition available ((Lindsay et al. 1993), as cited by (Blache and Martin 2009b)). Equally, improved reproductive performance in sheep and goats has been observed through ‘focused feeding’ ((Martin et al. 2004c), as cited by (Blache and Martin 2009b)).

The brain controls most reproductive responses to the environment. Both internal and external factors influence the release of hormones that in turn determine sexual activity. However, the reproductive organs (gonads, mammary gland and uterus) can also respond directly to blood-borne nutritional factors independent of the brain. These various influences on the reproductive activity of the female provide opportunities to manage reproductive efficiency. Nutritional manipulation is a preferred option for management of reproduction in small ruminants for many as it is seen as ‘clean green and ethical’ and avoids the use of exogenous hormones (Martin et al. 2004a).

Adapted nutrition can be used to modulate most aspects of the reproductive cycle (Fatet et al. 2011). Small ruminants live in environments that are continuously changing and this requires them to adapt. Although these processes of adaptation have changed over time with controlled breeding, some persist – for example, there are genotypes that respond quite markedly to external stimuli such as improved litter size with an increase in nutrition ((Martin et al. 2004c), as cited by (Blache and Martin 2009b)).

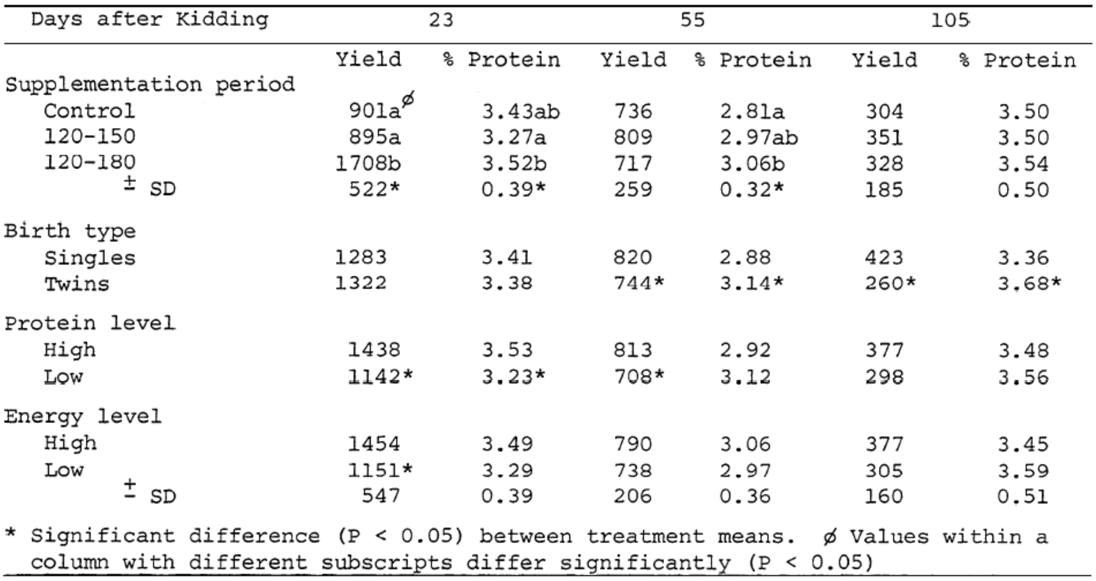
The deleterious effect of inadequate nutrition is more significant in females than males. The consequence of failing to meet their requirements can be fatal for both offspring and mother. Reproductively, the ewe responds to available nutrition in various ways, firstly whether to reproduce or not, and secondly whether to have one or two lambs (Scaramuzzi et al. 2006). It is known in sheep that folliculogenesis and ovulation rate can be increased by providing targeted nutrition. This may include the provision of extra nutrition to ewes in the last few days of the oestrus cycle to increase the number of twin ovulations. This is an effective way to improve ovulation rate and litter size in extensive, low-cost production systems in semi-arid environments (Martin et al. 2004a).

The energy demand of females varies throughout the reproductive cycle. Ovulation does not increase the energy requirements of the ewe and the first three months of gestation increases the energy used by just three per cent. Over the last two months of gestation, however, pregnancy accounts for 20% of energy expenditure (Fierro and Bryant 1990). In order to achieve the best reproductive outcomes, the animal’s nutrition must match the stage of its reproductive cycle (Blache and Martin 2009a)

If a positive energy balance is ongoing there will be weight gain. The positive effect on folliculogenesis will occur before there is a notable change in bodyweight. Nutrition is likely to be a ‘metabolic signalling mechanism’ for folliculogenesis and spermatogenesis (Scaramuzzi et al. 2006).

Norton (1984) compared the milk yield and protein percentage of 72 Rangeland goats fed on various diets. Some goats were supplemented between 120-150 days and others between 120-180 days after mating. Supplementation included a pelleted ration of cotton seed meal, barley straw and sorghum grain. The study then further compared does fed a high (20.6%) and low (12.2%) protein diet and those fed ad lib and 70% ad lib. The results of the study are shown in Table 33. The study concluded that improved nutrition in early lactation increased milk production considerably in feral goats. The impact of this increased milk production on kid growth, however, was not reported (Norton 1984).

Table 33: Influence of the duration, type and amount of supplementation on milk yield and protein content for twin and single bearing does



Days after Kidding	23		55		105	
	Yield	% Protein	Yield	% Protein	Yield	% Protein
Supplementation period						
Control	901a$^{\varnothing}$	3.43ab	736	2.81a	304	3.50
120-150	895a	3.27a	809	2.97ab	351	3.50
120-180	1708b	3.52b	717	3.06b	328	3.54
± SD	522*	0.39*	259	0.32*	185	0.50
Birth type						
Singles	1283	3.41	820	2.88	423	3.36
Twins	1322	3.38	744*	3.14*	260*	3.68*
Protein level						
High	1438	3.53	813	2.92	377	3.48
Low	1142*	3.23*	708*	3.12	298	3.56
Energy level						
High	1454	3.49	790	3.06	377	3.45
Low	1151*	3.29	738	2.97	305	3.59
± SD	547	0.39	206	0.36	160	0.51

* Significant difference ($P < 0.05$) between treatment means. $\varnothing$ Values within a column with different subscripts differ significantly ($P < 0.05$)

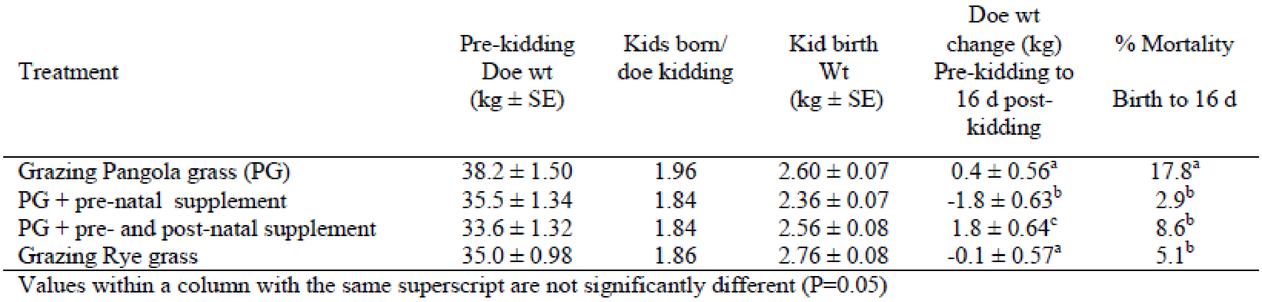
Source: (Norton 1984)

In a later study, Goodwin and Norton (2006) compared the milk production and consequential survivability of kids born to Australian Cashmere does at Mount Cotton in Queensland fed a variety of diets. The diets were:

- Pangola grass;
- Pangola grass and 360g/day supplement for 2 weeks pre-kidding;
- Pangola grass and 360g/day supplement for 2 weeks before and one month after kidding; and
- Irrigated ryegrass.

Does receiving supplementation before and after kidding gained weight, those on pasture alone maintained weight and those only receiving supplementation prior to kidding lost weight. There was no impact on birth weight of kids. There was a significant reduction in mortality of kids up to 16 days of age in all supplemented groups including the group on irrigated ryegrass pasture when compared to Pangola grass-fed does. The results are summarised in Table 34 (Goodwin 2004).

Table 34: The effect of doe nutrition on kid birth weight and survival to 16 days of age

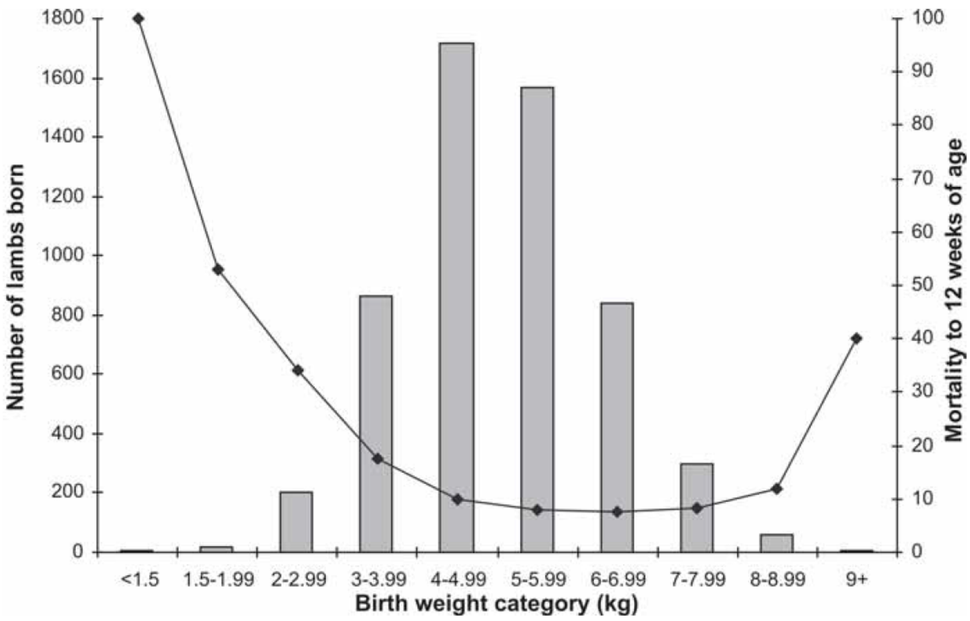


Treatment	Pre-kidding Doe wt (kg ± SE)	Kids born/ doe kidding	Kid birth Wt (kg ± SE)	Doe wt change (kg) Pre-kidding to 16 d post-kidding	% Mortality Birth to 16 d
Grazing Pangola grass (PG)	38.2 ± 1.50	1.96	2.60 ± 0.07	0.4 ± 0.56^{a}	17.8^{a}
PG + pre-natal supplement	35.5 ± 1.34	1.84	2.36 ± 0.07	-1.8 ± 0.63^{b}	2.9^{b}
PG + pre- and post-natal supplement	33.6 ± 1.32	1.84	2.56 ± 0.08	1.8 ± 0.64^{c}	8.6^{b}
Grazing Rye grass	35.0 ± 0.98	1.86	2.76 ± 0.08	-0.1 ± 0.57^{a}	5.1^{b}

Values within a column with the same superscript are not significantly different (P=0.05)

Source: (Goodwin 2004)

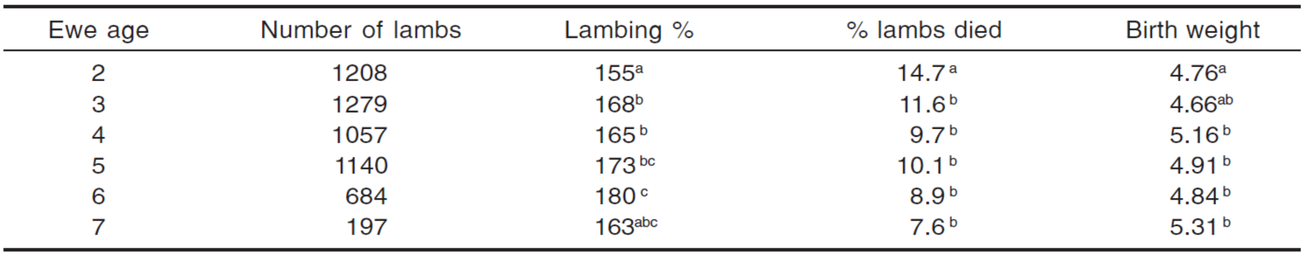
A large study conducted over six years in New Zealand examined litter size, lamb mortality, birth weight and growth rate to 12 weeks in several types of crossbred ewe. Data was collected on 5571 lambs from Romney, Finn x Romney, East Frisian x Romney and Poll Dorset x Romney sheep. Figure 22 shows the number of lambs born in each birth weight group and the mortality of lambs to 12 weeks of age. It shows that the majority of the lambs were born weighing between 4-6kgs and that at birth weights of less than 3kg there was a sharp rise in lamb deaths (lambs born less than 1.5kg did not survive). There was also a sharp rise in deaths among lambs more than 8kg probably due to dystocia. Table 35 shows how the age of the doe influenced the lambing percentage, birth weight and mortality of lambs up to 12 weeks of age (Thompson et al. 2004).



Source: (Thompson et al. 2004)

Figure 22: The number of lambs born in each birth weight groups and the mortality of lambs to 12 weeks of age

Table 35: Effect of ewe age (in years) on the lambing percentage (lambs born/ewe lambing), lamb mortality up to 12 weeks of age and birth weight (kg)

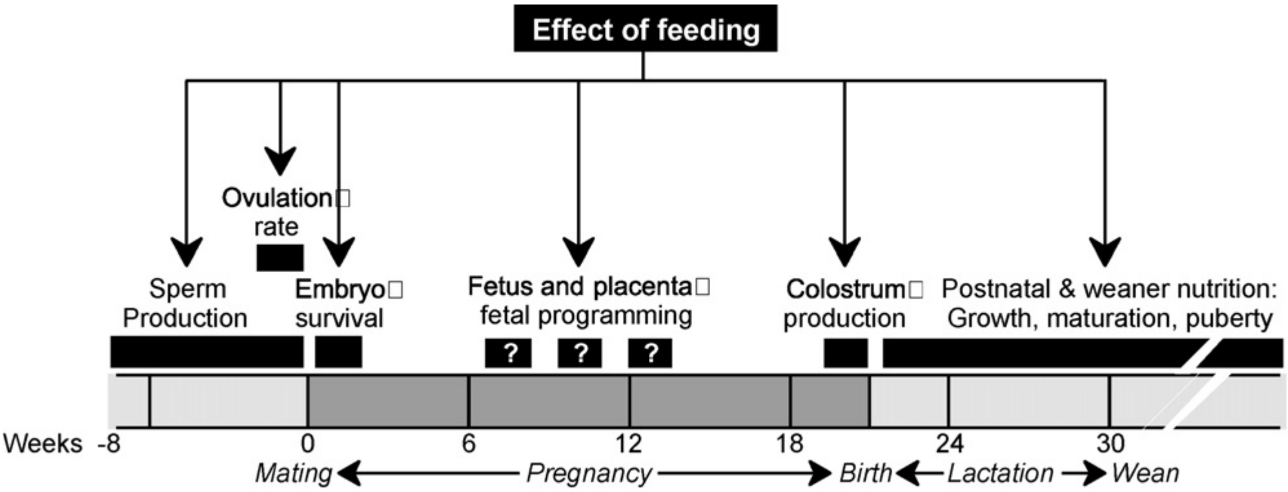


Ewe age	Number of lambs	Lambing %	% lambs died	Birth weight
2	1208	155^{a}	14.7^{a}	4.76^{a}
3	1279	168^{b}	11.6^{b}	4.66^{ab}
4	1057	165^{b}	9.7^{b}	5.16^{b}
5	1140	173^{bc}	10.1^{b}	4.91^{b}
6	684	180^{c}	8.9^{b}	4.84^{b}
7	197	163^{abc}	7.6^{b}	5.31^{b}

Source: (Thompson et al. 2004)

Focus feeding has been developed following much research over a long period into the interaction between nutrition and reproduction. Sperm production, ovulation rate and offspring survival can be improved by focus feeding. The success of focus feeding is dependent on many factors including the timing of the dietary stimulus, the quality of the dietary stimulus and the metabolic history of the animal (Blache and Martin 2009b).

Figure 23 shows strategic points in the reproductive cycle where targeted feeding can boost performance.



Source: (Martin et al. 2004c), modified by (Blache et al. 2008)

Figure 23: Effective feeding for reproductive success

The choice of nutritional supplementation needs to take into consideration the reproductive stage of the animals as well as their functional and physical capacity. Does in late pregnancy, especially those having multiple kids, have less abdominal space, which in turn reduces the space available to the rumen for expansion. During late pregnancy the density of feed needs to increase to allow the doe to increase her intake to meet her dietary requirements (Jolly 2013).

SPECIFIC INTERVENTIONS

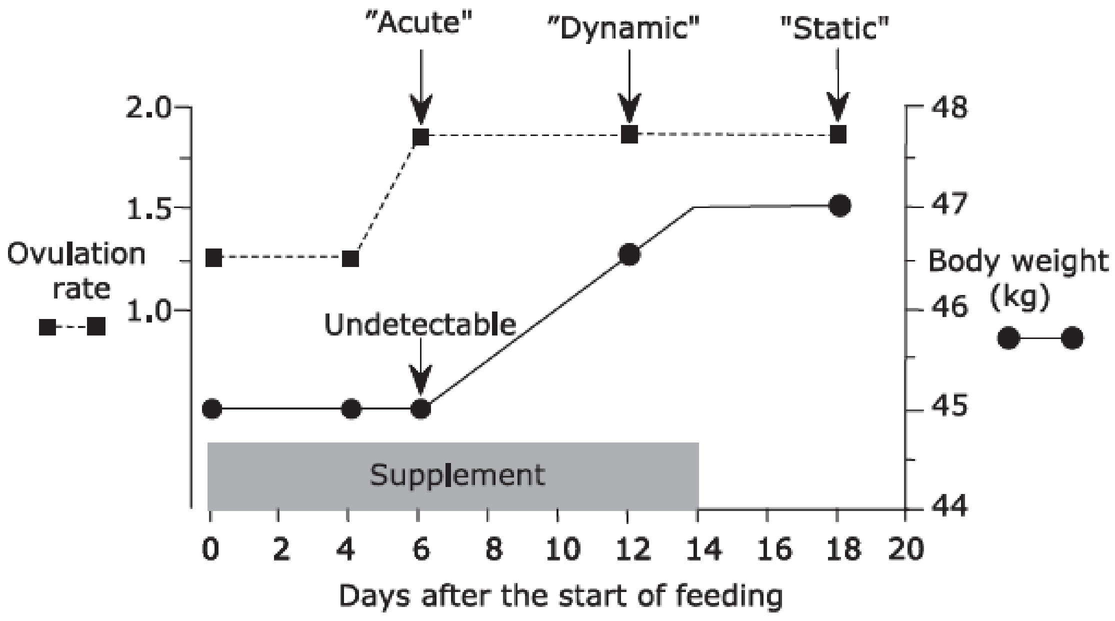
Maximising ovulation

The ovulation rate of small ruminants can be manipulated by managing their diet. 'Flushing' is a term that has been used to describe the process whereby breeding does are provided with supplementary feed around 30 days prior to and after bucks are introduced at joining time. The additional feed might comprise protein and /or energy. The effect on the doe will depend on the quality and the quality of the feed supplied as well as the time of the year (breeding season or not) and the condition of the doe at the time of flushing. The outcome from flushing can be improved fertility, increased pregnancy rates and/or a higher number of multiple births (Filley and Peters 2019).

Scaramuzzi et al (2006) have divided the effect of nutrition on ovulation rate into three influences:

- Acute – where there is no change in body weight;
- Dynamic – associated with increasing body weight; and
- Static – associated with an increased body weight (Scaramuzzi et al. 2006)

This is shown in Figure 24.



Source: (Scaramuzzi et al. 2006)

Figure 24: Acute, dynamic and static influences of nutrition on ovulation rate in sheep

(Stewart and Oldham 1986) found that feeding ewes lupins for four days in the last stages of oestrus improved the number of twin ovulations by 20-30%. Subsequent studies have found that achieving this response on-farm has been unreliable. It is proposed that there are other factors influencing the female's response ((Croker et al. 1985), as cited by (Martin et al. 2004a)).

Maximising embryonic survival

Embryo survival can be negatively impacted by both undernutrition ((Blockey et al. 1974), as cited by (Martin et al. 2004a)) and overfeeding of ewes ((Cumming et al. 1975), as cited by (Martin et al. 2004a)). Overfeeding in the first few days following fertilisation is thought to be associated with increased clearance of progesterone ((Cumming et al. 1975), as cited by (Martin et al. 2004a)). This means that supplementation for increased ovulation needs to be provided at specific times in order to not deleteriously affect embryo survival in the period shortly after fertilisation (Martin et al. 2004a). This research suggests that when flushing for improved reproductive outcomes at mating, supplementation should be modified or stopped during the immediate post-mating period. The precision of this modification post-mating remains unclear.

Improving future productivity of the foetus by programming

Foetal programming refers to the intrauterine impact of nutrition of the mother on the foetus. The implications of undernutrition may not be evident until after birth or after sexual maturity. Various mammalian models have shown that the peri-conceptual environment, which is mediated by maternal nutrition, can impact on development during gestation and can affect the physiological and metabolic health of adult offspring (Fleming et al. 2012).In the offspring of rats that have suffered nutritional restriction the impacts are varied and include:

- Altered glucose transporter expression;
- Reduced use of peripheral glucose in oxidative muscles;
- Changes in hepatic enzymes;
- Decrease in the size of islet cells, with decreased vascularisation and reduced secretory responses;
- Intolerance of glucose;
- Reduced growth; and
- Pancreatic content reduction (Holness 1996, Desai 1997) as cited by (Martin et al. 2004a).

Undernutrition of the ewe during pregnancy can affect lamb birth weight and cause permanent changes to the wool follicle population, which in turn causes a decrease in the wool production, of progeny. In addition, affected offspring had significantly broader wool. As the period of undernutrition continues (including into the post-natal period) , so does the impact on liveweight, wool follicle population and the production of clean wool (Kelly et al. 2006). The effect of undernutrition on the development of muscle fibres can also lead to long term impacts on growth and carcase quality (Greenwood et al. 2000). The effect on the reproductive axis includes a delay in the follicular development of ovaries in foetal ewes, thus reducing the overall lifetime reproductive potential of the ewe. Development of Sertoli cells, essential for testis formation and spermatogenesis, in newborn males may also be reduced (Alejandro et al. 2002).

Increasing colostrum production and kid / lamb survival

The provision of adequate colostrum is very important to survival of the newborn. Work by (Goursaud and Nowak 1999) has shown that the distension of the gut of a lamb after the initial feed of colostrum markedly improved its ability to recognise its mother and to form a ewe-lamb bond. This is likely to result in improved lamb survival (Goursaud and Nowak 1999).

Targeted supplementation of ewes prior to lambing hastened the decrease in progesterone and increased the lactose concentration in the colostrum (Banchero et al. 2002). Both of these changes hasten lactogenesis ((Hartmann et al. 1973), as cited by (Martin et al. 2004a)).

Ewes fed lupins during the last week of pregnancy have been shown to produce more colostrum even when they are already being provided with good quality pasture (Murphy et al. 1996). In another study, maize supplementation was even more effective at increasing colostrum production than lupins, more than doubling the volume of colostrum available to the lamb. Twin-bearing ewes responded more than ewes bearing single lambs, while unsupplemented ewes bearing twins were found to be unlikely to provide sufficient energy in their colostrum for their newborn lambs (Banchero et al. 2002).

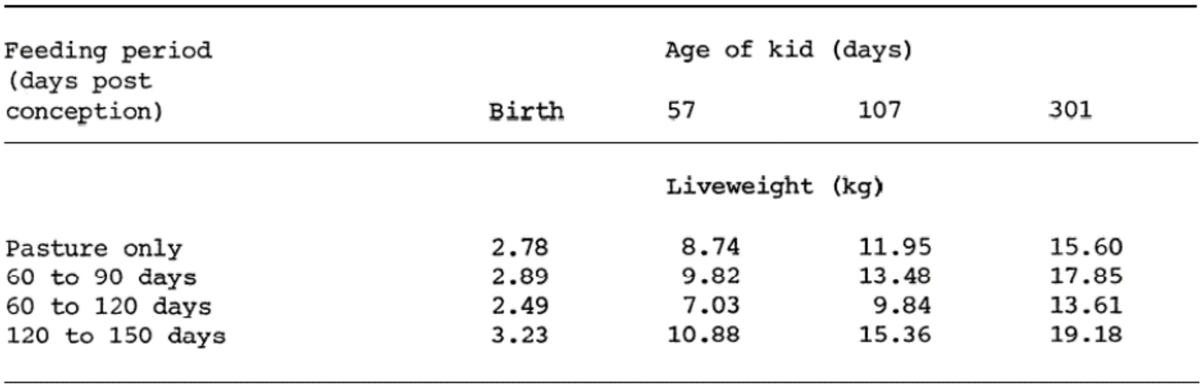
A later study found that barley could also be used to improve production of colostrum in ewes, especially those producing twins (Banchero et al. 2007). In late pregnancy there is little room in the rumen of ewes, especially those bearing twins, and this reduces roughage intake. Grain provides glucose from the starch (Martin et al. 2004a).

This short burst of increased nutrition does not impact significantly on the birth weight of the lambs nor therefore the risk of dystocia. The accuracy in timing of this supplementation is important as well as the quantity and quality of the feed.

In a study at the Wollongbar Research Centre (Norton 1985), a mixture of single- and twin-bearing does were placed into several groups. The does were fed a pelleted ration for variable periods post conception: 60-90 days, 90-120 days, 120-150 days and 120-180 days. Diets were either high or low protein and were fed ad libitum or 70% ad libitum. The report states that it was beyond the scope of the project to measure all the interactions and so only birth weight and the growth of the kids was recorded.

Table 36 shows the weight of kids at birth, 57, 107 and 301 days, at the four different feeding regimes. Does that were supplemented in the last month of pregnancy delivered kids that were heavier at birth and remained heavier up to ten months of age compared to those of ewes just fed earlier in gestation or in the control group. It was thought that energy was more important in establishing this response than protein (Norton 1985). This study has some inconsistencies and is without statistical analysis of the data, however. It be a useful experiment to repeat.

Table 36: The effects of the feeding period of does on kid weight at birth and subsequent growth to shearing.



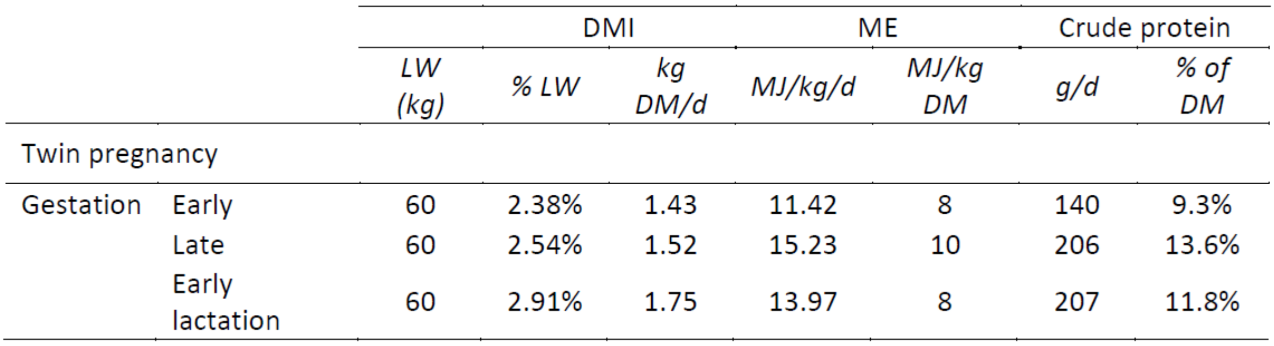
Feeding period (days post conception)		Age of kid (days)		
	Birth	57	107	301
		Liveweight (kg)		
Pasture only	2.78	8.74	11.95	15.60
60 to 90 days	2.89	9.82	13.48	17.85
60 to 120 days	2.49	7.03	9.84	13.61
120 to 150 days	3.23	10.88	15.36	19.18

Source: (Norton 1985)

Feeding does pregnant with more than one kid

The majority of knowledge of feeding does having twins or more comes from research in sheep. The National Research Council NRC) (NRC 2007) however, provides estimates for the daily dry matter intake and energy requirements for a 60kg twin bearing (non dairy) doe in early and late pregnancy and lactation. These are shown in Table 37. Jolly (2013), however notes that this information fails to account for does that might have access to high-quality pasture (high in ME and protein) where less is required (Jolly 2013). Again, the NRC figures should be used with caution.

Table 37: Energy and protein requirements for twin-bearing does



			DMI		ME		Crude protein	
		LW (kg)	*% LW*	*kg DM/d*	*MJ/kg/d*	*MJ/kg DM*	*g/d*	*% of DM*
Twin pregnancy								
Gestation	Early	60	2.38%	1.43	11.42	8	140	9.3%
	Late	60	2.54%	1.52	15.23	10	206	13.6%
	Early lactation	60	2.91%	1.75	13.97	8	207	11.8%

Source: (NRC 2007), adapted by (Jolly 2013)

There is a large amount of literature covering the impacts of ewe weight and condition score on lamb survivability. The Lifetimewool content includes very specific detail about different BCS of does bearing twins and the recommended feed on offer (FOO) they require at different stages of pregnancy (LTW 2008).

During the last six weeks of pregnancy the feed demand of ewes increases. At 100 days of pregnancy the ewe with a single requires 10MJ ME per days and 13MJ ME at lambing. Ewes with twins need 11.5MJ ME at 100 days and 16MJ ME at lambing (DPIRD 2018).

ALTERNATIVE FEED RESOURCES

Blache et al 2008 have reviewed potential 'alternative feed resources' (AFR) that could be used instead of traditional supplementary feeds, which may be restricted in use by their cost. Some of these resources include alternative pasture species, feed blocks and willow cuttings.

While these AFR may provide the required energy and protein for reproduction, caution should be shown as they can contain compounds such as plant or fungal toxins that may adversely impact on the reproductive cycle (Blache et al. 2008). The negative impacts may be because they are toxic or because they interfere with the reproductive system ((Ben Salem et al. 2001), as cited by (Blache et al. 2008)). How plant toxins interfere with ruminant reproductive capacity is largely not understood (Blache et al. 2008). Some plants contain phytoestrogens whose effect on reproduction is mediated via oestrogen receptors ((Usui et al. 2002), as cited by (Blache et al. 2008)). Legumes consumed in high quantities have also been documented to have negative impacts on reproductive health ((Adams 1998), as cited by (Blache et al. 2008)).

Some types of pasture, trees and shrubs contain tannins. In low concentrations tannins can be beneficial to reproduction but in high quantities they can reduce feed intake ((Barry and Forss 1983), as cited by (Blache et al. 2008)). Another consideration is the mineral and vitamin content of AFR. Some of these food types may be deficient in minerals, with detrimental effects on reproduction in both males and females (Blache et al. 2008).

7.3.8 GENETICS

Breeding goats for meat production has been reviewed at the global level by (Shrestha and Fahmy 2005, Shrestha and Fahmy 2007a, Shrestha and Fahmy 2007b). The review notes that the potential for genetic (or indeed husbandry or nutrition) improvement from scientific advances has not been realised to the same extent in goats as in other livestock species. The body of literature on the genetics of reproduction is far larger and more thoroughly reviewed in sheep than it is in goats, although the expectation is that the mechanisms will be similar between the two species (Notter 2012).

The goat genetic literature, with a focus on Australian conditions, has been reviewed by Aldridge (2017). He notes that the greatest gaps are in genetic parameters for carcase, reproductive and health traits and concludes that the greatest opportunity for improvement in reproductive efficiency is in kid survival (see below).

Genetic potential for reproductive performance in livestock can be improved by exploiting:

- Between-breed variation, through crossbreeding, which also exploits hybrid vigour;
- Within-breed variation; and
- Within-herd variation.

Reproductive traits generally have low heritability, which limits the opportunity to improve reproductive performance in goats and sheep by selecting within a breed (Notter 2012). Crossbreeding using established breeds with known performance measures of genetic merit can achieve improved productivity by specific crosses and back crosses (Shrestha and Fahmy 2007a). However, progress can be made within breeds and within herds, as described below.

Crossbreeding in Australia has mainly been effected since the early 1990s through the introduction of the Boer goat, which provided a major impetus to genetic improvement (Blackburn 2004) and stimulated interest in genetic improvement of the Australian goat herd, including the introduction of KIDPLAN (Aldridge 2017). KIDPLAN is a national performance recording scheme database for goats and was established in 1997 ((Ball et al. 2001), as cited in (Aldridge 2014)). KIDPLAN is made available by Sheep Genetics. It provides estimated breeding values (EBVs) for important traits, and selection indexes combining several EBVs, calculated from phenotypic and pedigree data recorded by producers on almost 20,000 Boer goats (Aldridge 2017). EBVs and indexes allow producers to assess an animal’s genetic merit in respect to the breeding objectives of the herd (MLA 2014a).

KIDPLAN has three EBVs concerned directly with fertility:

- Number of kids born (NKB);
- Number of kids weaned (NKW); and
- Scrotal circumference (yearling and hogget measurements).

Bucks with a higher positive EBV for NKB or NKW can be expected to sire daughters that will give birth to or wean (respectively) a higher percentage of kids than the average. Bucks with a higher positive EBV for scrotal circumference can be expected to produce sons with higher scrotal circumference and therefore fertility.

In addition to these EBVs are several concerned with live weight traits, including maternal weaning weight (an estimate of the doe's potential for milk production and ability to provide a better maternal environment), birth weight and weaning weight (MLA 2014b).

A situation analysis of performance recording of Australia meat goats through KIDPLAN was reported in 2014 (Aldridge 2014). The analysis found that carcase traits and growth were commonly recorded, but less so reproductive and parasite resistance trait data. There was some small movement in the average EBV for NKB, with a trend to fewer kids, either as a producer preference or due to correlation with other traits. Low phenotypic variance and low EBV accuracy hinder progress (Aldridge 2014).

In Michael Aldridge's thesis (2017), he recommends industry develop a new index based on goat parameter estimates and economic values rather than those currently modified from sheep values. In addition, Aldridge recommends that traits such as kid survival be included as this would improve the gain in reproductive rate. He estimates that this could result in an increase in financial return of $6.75 per doe per year (Aldridge 2017).

Recent overseas studies of the genetics of reproduction place significant emphasis on the role of genetics in optimising accelerated breeding systems (described in section 7.4.2). In a review of the genetic improvement of reproductive efficiency of sheep and goats, (Notter 2012) at Virginia Tech in the United States focuses on two critical aspects of the reproductive cycle: seasonality and ovulation rate / litter size.

Seasonality refers to the extent to which breeding within a herd is confined to a particular time of the year, and is described above in section 6.1. Highly seasonal breeds of goats and sheep are less suitable for accelerated breeding systems where joining occurs more than once per year and therefore sometimes falls outside the usual breeding season.

It is possible to improve seasonality of breeding and litter size by crossbreeding and/or selection within the breed (Notter 2012). For example, in a five-year study by (Al-Shorepy and Notter 1997) of autumn-lambing crossbred ewes, selection for fertility led to an increase in litter size and EBV for fertility (which has been linked to improved future fertility). Over an 11-year trial of selection in another study, ewes in the selected line had a lambing rate of 87%, 17% higher than the control group (Notter 2008b).

In a study of Rideau Arcott sheep in a commercial accelerated breeding system of five lambings in three years in Canada, it was found that there was sufficient genetic variation in fertility outside of the usual breeding season to offer the potential to improve out-of-season breeding by selection (Tosh et al. 2002).

The genetics of Polypay sheep in an accelerated lambing system were studied by (Vanimisetti and Notter 2012). The reproductive traits of ewe lamb fertility, the age of the ewe at first, second and third lambing, first and second lambing interval and the number of lambings per ewe by the age of 38 months were estimated. Heritabilities for ewe lamb fertility (0.14), age at first and second lambing (0.39, 0.28) and number of lambs by 38 months (0.27) were high enough to improve performance in accelerated lambing systems. Genetic correlation estimates suggested that selecting for ewe lamb fertility might impact negatively on growth potential, so a carefully-designed breeding program incorporating multiple trait selection objectives is important (Vanimisetti and Notter 2012).

According to (Vanimisetti and Notter 2012), 'success in accelerated lambing depends on the ability of ewes to conceive during spring and summer and is best achieved by screening large numbers of ewes in these seasons to identify useful genetic variation in fertility among individuals or families'. One option is to establish a nucleus flock with the purpose of selecting animals that can breed in spring and summer. Rams and ewes bred from this nucleus flock can then be introduced into the commercial flock. Earlier studies have found selection improves out-of-season breeding ability (Notter 2008a) and increases the length of the breeding season (Vincent et al. 2000).

The second key area of reproductive efficiency addressed by (Notter 2012) is ovulation rate / litter size. There are large differences between breeds in the mean ovulation rates of adult ewes or does, from around one to over three. Control of ovulation rate is polygenic. A number of mutations with a large effect on ovulation (such as those found in the Booroola Merino) have been identified in sheep but not in goats (Notter 2012). The heritabilities of ovulation rate (0.15), litter size (0.13) and lambs weaned (0.05) are low (Safari et al. 2005). Within-breed selection will therefore yield an increase in litter unlikely to exceed 0.02 lambs per year (0.01 in the more likely case that there are multiple traits in the selection objective) (Notter 2012).

This means that in goats, in the absence of major ovulation rate mutations, the best opportunity to achieve at least modest progress in litter size is through crossbreeding with more prolific breeds such as Nubians. (Notter 2012) notes that in sheep, the existence of a wide range of prolific breeds gives producers options for finding a breed well-suited to their environment, and advises that 'with polygenic control of prolificacy, anticipated increases in ovulation rate and litter size can be titrated to desired levels by varying the contribution of a prolific breed to descendant populations.'

Any crossbreeding or selection program to increase litter size should also carefully monitor weaning rate, to ensure that kid / lamb survivability matches the increase in litter size at birth. The genetic correlation between litter size at birth and weaning can be low ((Vanimisetti et al. 2007) as cited by (Notter 2012)). A herd or flock's genetic potential for prolificacy should match the environmental conditions, especially feed resources, so the objective should be optimisation rather than maximisation of reproductive capacity (Notter 2012).

Indeed, in Australia, Aldridge et al 2015 note that kid survival is a priority for the Australian goat industry, as goats are already moderately fertile and highly fecund. Analysis of KIDPLAN data indicated a heritability for birth weight of 0.32 and for kid survival of 0.29 – the latter higher than expected – with a high genetic correlation between the two traits of 0.54 and positive phenotypic correlation. The authors concluded that survival could be achieved by either direct selection or indirect selection on birth weight (Aldridge et al. 2015).

7.3.9 MANIPULATION OF PHOTOPERIOD

Photoperiod treatment involves exposing goats to alternating long and short days. Animals are first exposed to long days, which may be provided naturally in the spring or summer, or by artificial lighting in the winter. They are then exposed to short days, for example by the use of melatonin implants ((Malpaux et al. 1989), as cited by (Fatet et al. 2011)). If animals are simply exposed to long periods of shortening days they may have a decrease in cyclic activity (Fatet et al. 2011).

Photoperiod manipulation is an effective way to allow out of season breeding in goats located in temperate and subtropical regions (Chemineau et al. 1992a, Delgadillo 2004). Photoperiod treatment, similarly to hormonal treatment, can initiate sexual activity in males and females (Chemineau et al. 1999). In females, photoperiod treatment is not effective at synchronising ovulation sufficiently for the purposes of artificial insemination but can induce ovulation over several weeks. If photoperiod treatment is combined with hormonal treatment or the buck effect it can be effective at synchronising ovulations (Fatet et al. 2011).

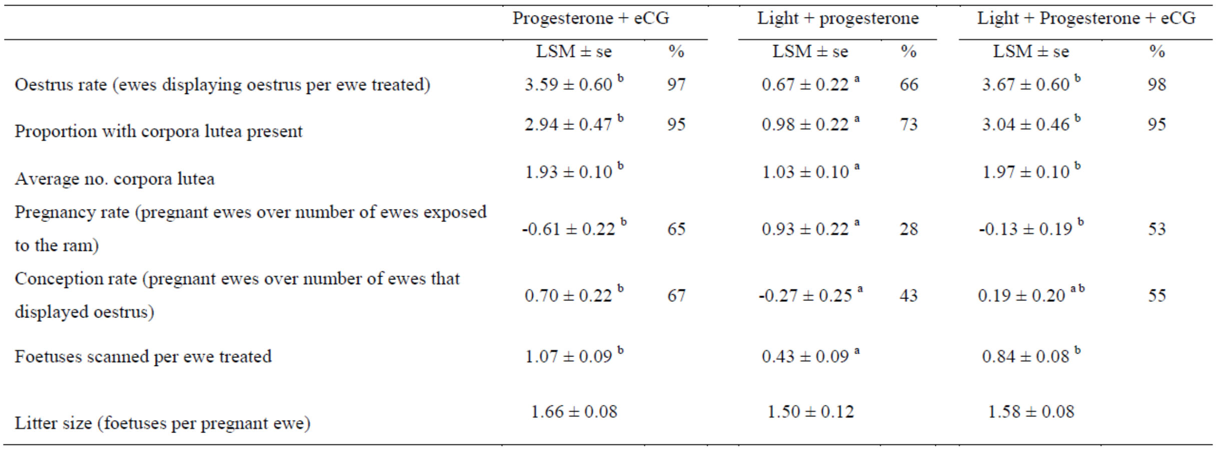
In goats, long-day treatment (involving pulse of light during the dark period) followed by melatonin (short-day therapy) was effective at inducing and maintaining oestrous in the spring (Chemineau et al. 1992b). In dairy goats that were anovulatory in the non-breeding season both extra light (long days) and melatonin were required to stimulate oestrous and ovulation. The introduction of males further enhanced the stimulation. Administration of melatonin soon after kidding, however, decreased milk production (Chemineau et al. 1988).

In a study at Massey University, New Zealand (30^{o}S), mixed-age Romney ewes (n=302) were treated with one of three programs and the impact on inducing oestrous activity was measured. The treatment groups were:

- Progesterone and eCG;
- Light and progesterone; and
- Light, progesterone and eCG.

Exposure of ewes to artificially long days did not increase reproductive performance compared to the ewes in the other group where light was not used. The group receiving just light and progesterone had the poorest reproductive performance with only 25% pregnancy rate (Table 38) (deNicolo 2007).

Table 38: Comparison of the treatment groups on various reproductive measures



	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 ^{ab}	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)

Source: (deNicolo 2007)

7.3.10 MAXIMISING GROWTH AND SURVIVAL POST-BIRTH

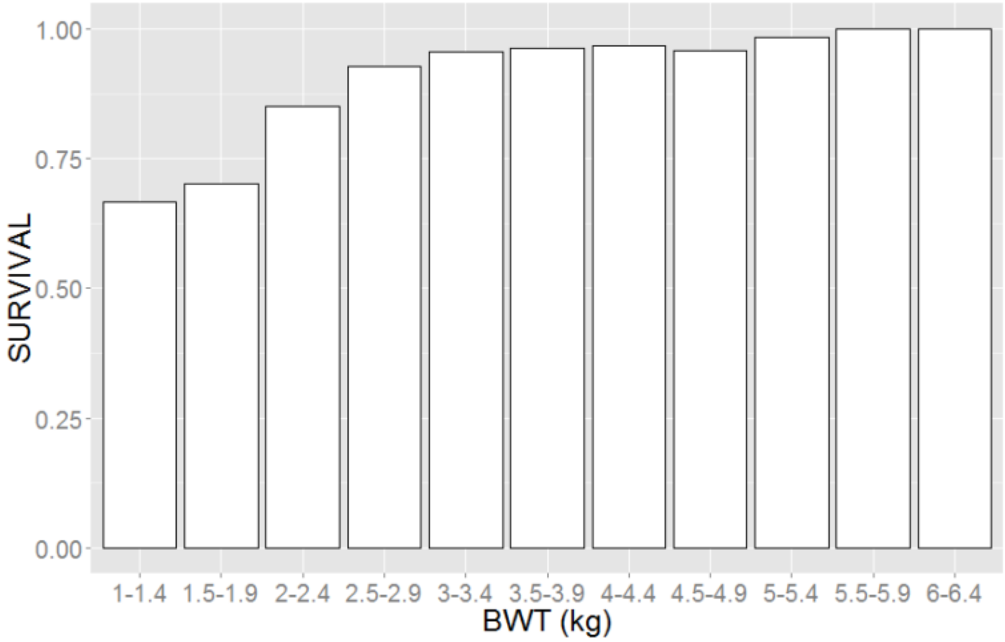
Kid mortality is an important and significant cause of reduced productivity in many enterprises. Improving survival of kids born significantly contributes to an improved reproductive rate and thus improved productivity and profitability. Kid mortality is subject to a separate project commissioned by MLA and so this issue will be only covered briefly here.

PERINATAL SURVIVAL

The vigour of kids shortly after birth, their birth weight and survival rate are significantly impacted by the nutrition of the doe during pregnancy (Aregheore and Lungu 1997). This has been covered in more detail in section 7.3.7.

The ability to maximise reproductive potential in any livestock enterprise relies upon ensuring that the maximum number of stock born are successfully weaned. Multiple births in goats are commonly associated with a high mortality rate ((Devendra 1983), as cited by (Greyling 2000)). The biological reasons why this should occur in production systems with adequate nutrition and management are not known. Naude and Hofmeyr (1981) state that when intensively managed, twins and triplets can be raised by Boer goats, while the first few days are crucial for triplets ((Naude and Hofmeyr 1981) as cited by (Greyling 2000)).

A trend of decreasing survival rates with lower birth weights was demonstrated in a review of KIDPLAN data by (Aldridge et al. 2015) (Figure 25). Interestingly, high birth weights were not associated with higher losses (due to the likelihood of dystocia), as is seen with some other species ((Brown et al. 2014) as cited by (Aldridge et al. 2015)).

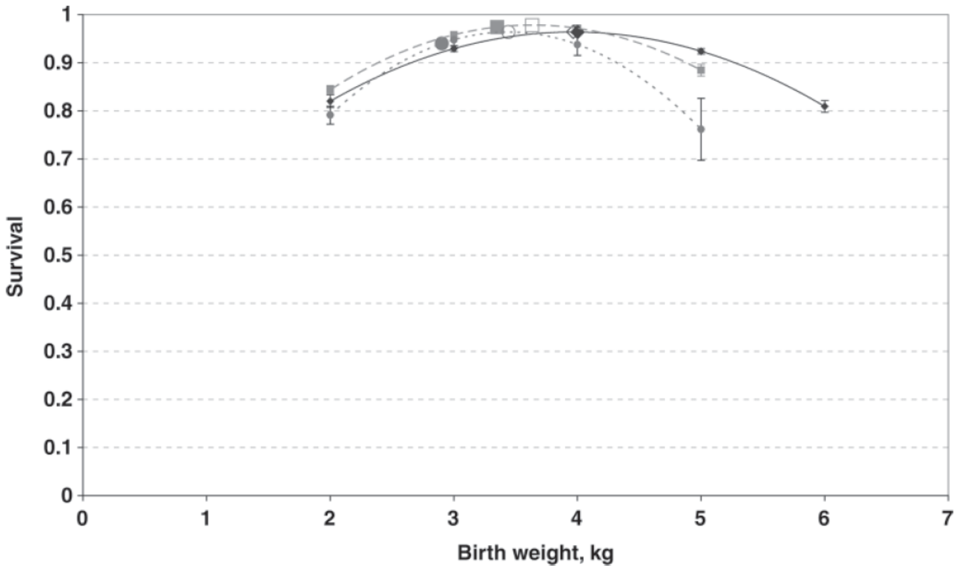


Source: (Aldridge et al. 2015)

Figure 25: Survival of goat kids plotted against their birth weight

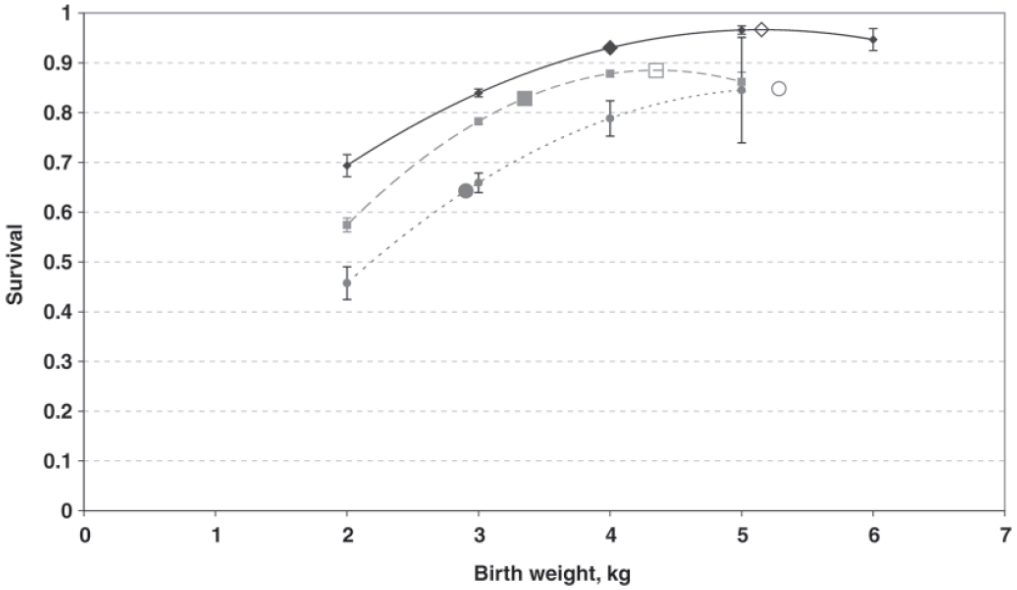
In this study, there was no difference in the survivability of single and twin kids (83 and 82% respectively), but kids in litters of greater than two kids had a survival rate of 71%. Heritability for birth weight was 0.32, similar to previous published figures, while the heritability of kid survival was 0.29, higher than previously reported. Genetic and phenotypic correlations between birth weight and kid survival were 0.54 and 0.16 respectively. The high heritability of kid survival suggests that significant progress could be made on kid survival if data was recorded and survival prioritised in the breeding program. The authors also suggested that litter size contributes to kid survival and birth weight although this required further investigation (Aldridge et al. 2015).

A very large analysis of lamb survival reviewed data from 14,142 Australian Merino lambs born between 1975 and 1983. The following three graphs (Figure 26, Figure 27 and Figure 28) show lamb survival at birth, in the first week and up to weaning (110 days) respectively. In contrast to kid mortality, the lamb survival graphs show a reduction in survival of single lambs at birth. This is likely to be due to dystocia (Hatcher et al. 2009).



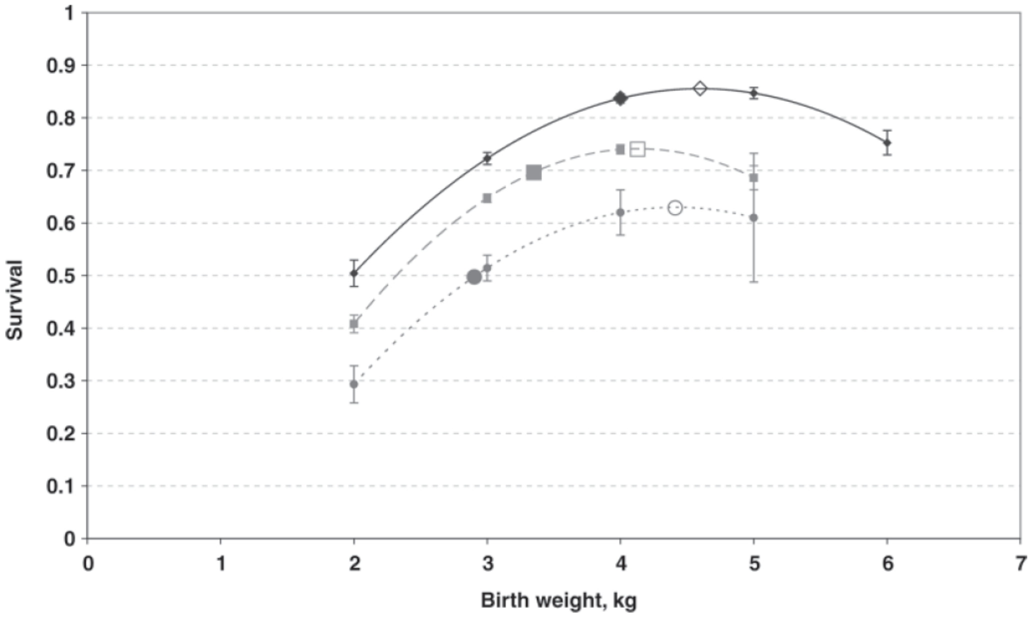
Source: (Hatcher et al. 2009). Single (solid line), twin (dashed line) and multiple (dotted line), The large closed symbol is the average birth weight and the open symbol is optimal birth weight for survival to weaning

Figure 26: Birth weight vs survival at birth of Merino lambs



Source: (Hatcher et al. 2009). Single (solid line), twin (dashed line) and multiple (dotted line), The large closed symbol is the average birth weight and the open symbol is optimal birth weight for survival to weaning

Figure 27: Birth weight vs survival in the first week of Merino lambs

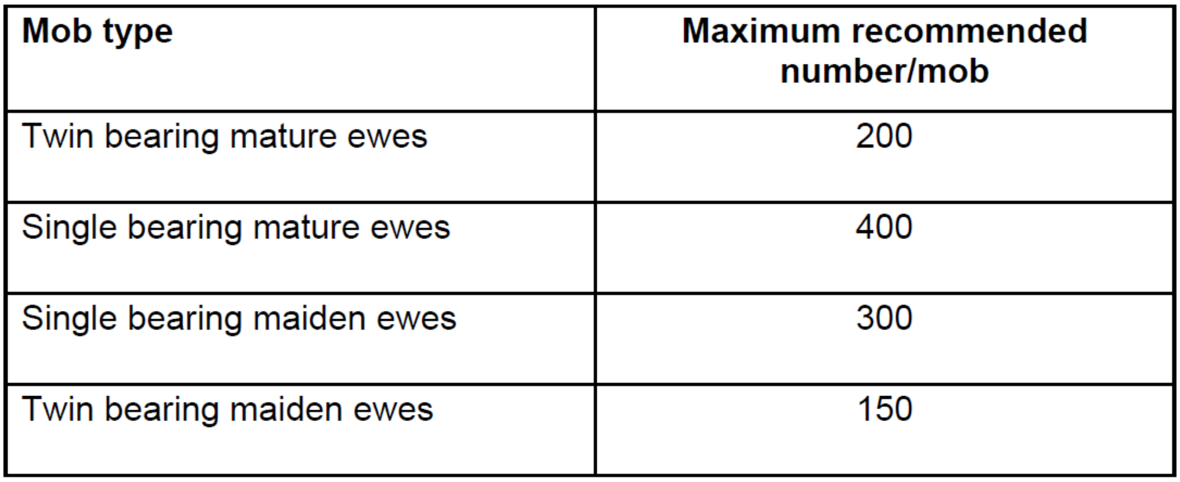


Source: (Hatcher et al. 2009). Single (solid line), twin (dashed line) and multiple (dotted line), The large closed symbol is the average birth weight and the open symbol is optimal birth weight for survival to weaning

Figure 28: Birth weight vs cumulative survival to weaning (110d) of Merino lambs

The Glenthompson Best Wool Best Lamb report (2011 – see section 6.5) advises that ewe mob size be restricted to gain the optimal reproductive outcomes, especially for twin-bearing ewes (Table 39).

Table 39: Recommended mob size for ewes of different birth type and parity



Mob type	Maximum recommended number/mob
Twin bearing mature ewes	200
Single bearing mature ewes	400
Single bearing maiden ewes	300
Twin bearing maiden ewes	150

Source: (BWBL 2011)

Maximising survival post-kidding can also include improving colostrum production, as described in section 7.3.7.

PRE-WEANING CARE

Raats et al (1983) measured lactation over a 12-week period in Boer goats between 2-6 years of age with 1-3 kids. Milk production increased with age of the ewe and litter size. Younger ewes showed a more marked response to increase in litter size than older ewes. The effect of age on the litter size was reduced as the litter size increased. The milk yield was found to increase in subsequent lactations until the fifth lactation (Raats et al. 1983).

A later study compared the lactation of Boer goat does that were either receiving or not receiving supplementation. On average, does that were supplemented produced 11.5% more milk over the 12-week trial, but there was no significant effect on the milk composition. The females that were supplemented lost less weight. The study showed that the time spent in a natural grazing area also impacted milk production regardless of supplementation (Raats 1988).

A study in humid subtropical Nashville evaluated the genetic influence on kid performance of Kiko, Boer and Spanish meat goats in a semi-intensively managed environment. It found that there was significant genetic variation between the three breeds for kid performance to weaning, with the Kiko goats showing better birth to weaning performance under the conditions of this study than the other two breeds. The effect of the maternal breed was greater than the direct breed effect. While this study emphasises the importance of doe breed selection to optimise kid performance to weaning, it should be considered that under different climatic conditions and with different management styles the relative breed rankings may differ (Browning 2011).

A number of studies have indicated that growth rate to weaning can be improved by genetic selection (Jolly 2013). Heritabilities of some growth indicators include the growth rate to weaning in Rangeland goats of 0.68 (Restall et al. 1984); mature weight at 18 months for Anglo- Nubians, 0.28 (Sousa et al. 2011); and weight of goats at 7 months, 0.69 (McDowell and Bove 1977) as cited by (Jolly 2013).

The success of weaning and the growth rate after weaning rely on adequate rumen development. The development of the rumen between birth and weaning determines the ability of the kid post-weaning to absorb nutrients as well as its potential dry matter intake (Jolly 2013). The rumen allows for the production of microbial proteins and for fermentation and absorption ((Beiranvand et al. 2014), as cited by (Nay Naing Htoo et al. 2018)). Age and body weight are good indicators of rumen growth, while the intake of solid food is also a good reflection of the rumen weight. Development of the rumen involves growth of the rumen papillae. Papilla length increases as the age of the kid increases (Amaral et al. 2005). Development of the rumen also involves tissue differentiation with papillary development and an increase in keratinisation along with an increase in volume, mass and surface area (Tamate et al. 1962).

The type and form of the nutrients consumed by the animal will affect cellular proliferation ((Norouzian et al. 2011), as cited by (Nay Naing Htoo et al. 2018)). A forage diet may not provide for optimal papilla development ((Norouzian et al. 2011), as cited by (Nay Naing Htoo et al. 2018)) while concentrates stimulate papillae development and cause keratinization of papillae in lambs and calves ((Beiranvand et al. 2014) as cited by (Nay Naing Htoo et al. 2018)). In a study of Boer-cross kids, those that received creep feed with or without roughage had significantly better papillary surface area and keratinization than those on milk alone. There was however no significant difference in development between those fed creep with or without the addition of roughage (Nay Naing Htoo et al. 2018). A similar study found that 48 Boer goat kids, supplemented with creep including alfalfa before weaning, measured better growth performance and weight gain than those on creep feed or milk alone (Nay et al. 2015). Saanen kids fed a pelleted diet had significantly increased papilla development (Amaral et al. 2005).

In calves, feeding of hay and grain have been associated with rapid development of the rumen while development is slow with a milk diet ((Kenny et al. 2009), as cited by (Nay Naing Htoo et al. 2018)).

A study compared various productive measures of 543 commercial meat goats' kids born in autumn (fall) to those born in spring in Kentucky. There was no significant difference in the death rate between the two kidding times. Autumn-born kids had a better growth rate and were a higher weight at 90 days. Triplets were less likely to survive than singles and twins. Male kids were heavier at birth and at 60 and 90 days. This study did not consider the difference in costs of kidding that may be associated with a difference in supplementary feed between the two kiddings. This needs to be considered along with the potential impact of winter stasis, against the potential financial gain of having stock to sell 'out of season' (Andries 2011).

Kid sex and litter size were found to impact on Taggar goat performance in Sudan. Male kids were generally bigger than female kids at birth and had a higher average weight gain. The pre-weaning daily gain was higher for singles then those born as twins or triplets. Single born kids also showed oestrus behaviour earlier than twin and triplet kids (Bushara et al. 2013).

WEANING

Weaning causes stress and a reduction in weight gain in kids and some suffer from weaning shock (weight loss post-weaning) (Lu and Potchoiba 1988). The decision about when to wean may be based on age and/or the weight of the kids. Studies have shown that the growth rate of kids decreases after weaning ((Morand-Fehr 1981), as cited by (Palma and Galina 1995)).

A review of milk feeding and weaning of dairy kids by Lu and Potchoiba (1988) suggests that kids can be weaned at any time providing they are consuming at least 30g/day of solid feed. This could occur at 9 kilograms of body weight or eight weeks of age. The authors reported that there was less weaning shock if this consumption target was followed. Decreasing milk feeding encouraged the consumption of solid feed (Lu and Potchoiba 1988). These findings should be considered with caution, given they were derived from a dairy enterprise where pre-weaning milk consumption is provided artificially and thus at considerable cost. There is reported to be some variation in the sensitivity of dairy breeds to weaning shock ((Teh et al. 1984), as cited by (Lu and Potchoiba 1988).

A study of dairy kids in Mexico compared early and late weaning. The early group was weaned at 10 kg (the usual weaning weight in Mexico dairy systems) while the later-weaned kids were provided milk for an additional 30 days. The rest of the diet was the same for both groups. Post-weaning growth reduction was noted in both groups, but faster growth was seen in the later weaned group, which reached the breeding target of 30 kg (60% of adult weight) a month earlier than the other group. The additional cost of rearing may have been recuperated if kids had been sold for meat, but in the case of retained females, both systems made animals available to breed by 8-9 months of age (Palma and Galina 1995).

Weaning by age

When kids were weaned at 4-6 weeks they suffered more from weaning shock and weight loss than those weaned at 8-10 weeks. The average daily weight gain of kids at 16 weeks of age, and bodyweight, were significantly higher for the later weaned group compared to those that were weaned earlier ((Teh et al. 1984), as cited by (Lu and Potchoiba 1988)).

The recommended age of weaning varies, some saying 8 weeks ((Teh et al. 1984) as cited by (Lu and Potchoiba 1988)). Other authors argue that weaning by 5 weeks is possible as long as kids are eating a minimum of 30g of solid feed daily prior to weaning ((Morand-Fehr 1981), as cited by (Lu and Potchoiba 1988)).

The Australian Industry Welfare Standards and Guidelines for Goats (2016) includes a standard (07.13) that '*Kids should not be weaned earlier than eight weeks of age to ensure adequate rumen development'*. (AHA 2016).

Weaning by weight

Weaning by weight helps to ensure that unhealthy and undernourished kids are not weaned too early. Some suggest that this might be when their weight reaches 2.5 times that of their birth weight ((Fehr 1975), as cited by (Lu and Potchoiba 1988)). Weaning shock was much less of a problem for kids weaned by weight compared to those that were weaned by age ((Teh et al. 1984), as cited by (Lu and Potchoiba 1988)).

POST-WEANING CARE

A study compared three groups of French Alpine weaner goats that were fed either a low or high amount of concentrate or were in the intermediate control group. The study continued through to 100 days into the goats' first lactation. Average daily gain of the kids on the low concentrate diet was considerably lower than that of the control and high group, by 23% and 33% respectively. Prolificacy was 30% higher in the control and high groups. However, milk yield in the first lactation was not impacted by the amount of supplement given to the weaned goats (Duvaux-Ponter and Dessauge 2018).

In another study, 32 Boer goat kids were weaned onto one of two pelleted diets, comprising either low or high metabolisable energy and provided ad libitum. There was no significant difference between the average daily gains of the goats on the two diets, fed for periods of either 28 or 56 days. The authors suggested the results indicated that Boer goats may be suitable to be finished in a feedlot situations (Sheridan et al. 2003).

7.4 NON-NATURAL INTERVENTION

For the purpose of this report the authors have included in this section management strategies that involve the use of pharmaceutical products such as hormones and melatonin, and invasive procedures such as artificial insemination and embryo transfer.

7.4.1 USE OF EXOGENOUS HORMONES

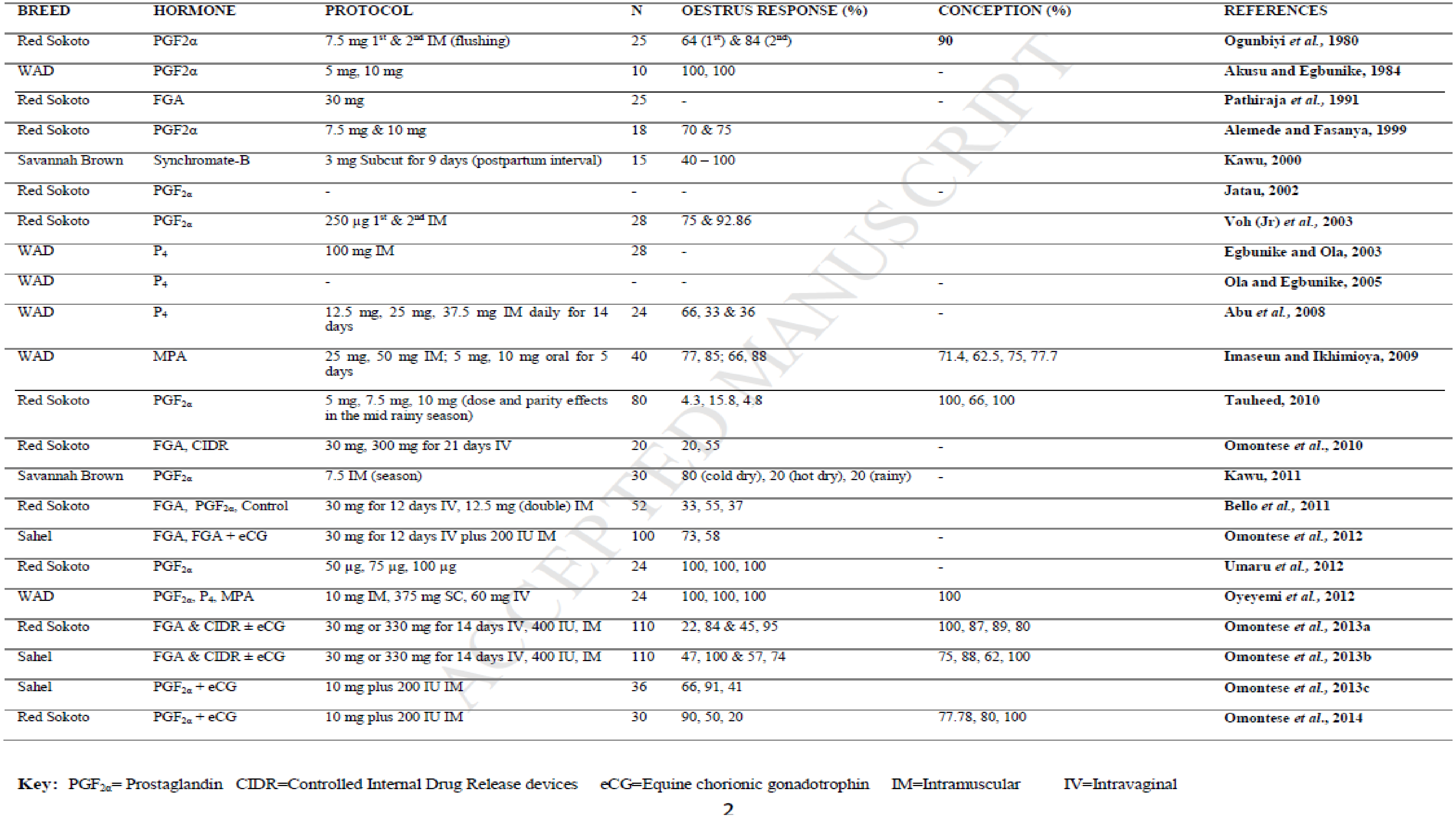
There is a vast quantity of literature on hormonal control of reproduction in small ruminants, and only the more recent papers are covered here, as protocols have evolved over time and older ones are now not relevant. The topic has been reviewed by (Abecia 2012). Three main groups of hormones are used:

- Progesterone and analogues (progestagens), with or without gonadotrophins;
- Prostaglandins and analogues; and
- Melatonin.

The first two of these act to modify the luteal phase of the cycle, while melatonin is used to change the animal’s perception of photoperiod (Abecia 2012). The type of insemination planned will determine how precise oestrus needs to be and therefore the most effective synchronisation technique. When goats are to be served naturally, there is a less critical requirement for precise ovulation (Bretzlaff and Romano 2001). Synchronisation can be effectively achieved using the buck effect (Flores et al. 2000). Timed artificial insemination requires precise synchronisation, and the timing of oestrus can be affected by a number of factors including the type of hormone used, the timing of administration and the buck effect. In a study of synchronised does, those that were exposed to a buck continuously at the end of the treatment came into oestrus sooner (Romano 1998).

Omontese et al (2016) recently reviewed oestrous synchronisation in goats in Nigeria. The paper provides a good overview of the options for synchronising goats (Table 40). The authors do not provide recommendations or preferred options. They do note, however, that when the reproductive status of the flock is unknown, the use of exogenous progesterone is preferred whereas prostaglandins and their analogues are easy to use but only effective in animals that are cycling.

Table 40: A summary of oestrous synchronisation of goats in Nigeria including protocols and oestrous response



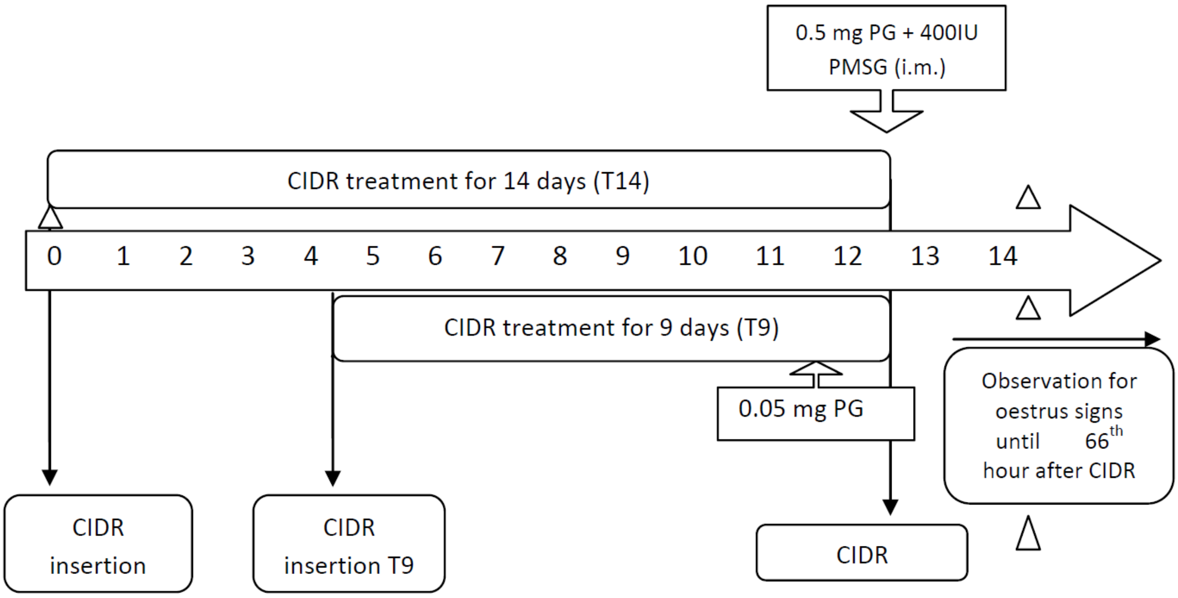
BREED	HORMONE	PROTOCOL	N	OESTRUS RESPONSE (%)	CONCEPTION (%)	REFERENCES
Red Sokoto	PGF2α	7.5 mg 1st & 2nd IM (flushing)	25	64 (1st) & 84 (2nd)	**90**	**Ogunbiyi *et al.*, 1980**
WAD	PGF2α	5 mg, 10 mg	10	100, 100	-	**Akusu and Egbunike, 1984**
Red Sokoto	FGA	30 mg	25	-	-	**Pathiraja *et al.*, 1991**
Red Sokoto	PGF2α	7.5 mg & 10 mg	18	70 & 75		**Alemede and Fasanya, 1999**
Savannah Brown	Synchromate-B	3 mg Subcut for 9 days (postpartum interval)	15	40 – 100		**Kawu, 2000**
Red Sokoto	$PGF_{2\alpha}$	-	-	-	-	**Jatau, 2002**
Red Sokoto	$PGF_{2\alpha}$	250 µg 1st & 2nd IM	28	75 & 92.86		**Voh (Jr) *et al.*, 2003**
WAD	P_4	100 mg IM	28	-		**Egbunike and Ola, 2003**
WAD	P_4	-	-	-	-	**Ola and Egbunike, 2005**
WAD	P_4	12.5 mg, 25 mg, 37.5 mg IM daily for 14 days	24	66, 33 & 36	-	**Abu *et al.*, 2008**
WAD	MPA	25 mg, 50 mg IM; 5 mg, 10 mg oral for 5 days	40	77, 85; 66, 88	71.4, 62.5, 75, 77.7	**Imaseun and Ikhimioya, 2009**
Red Sokoto	$PGF_{2\alpha}$	5 mg, 7.5 mg, 10 mg (dose and parity effects in the mid rainy season)	80	4.3, 15.8, 4.8	100, 66, 100	**Tauheed, 2010**
Red Sokoto	FGA, CIDR	30 mg, 300 mg for 21 days IV	20	20, 55	-	**Omontese *et al.*, 2010**
Savannah Brown	$PGF_{2\alpha}$	7.5 IM (season)	30	80 (cold dry), 20 (hot dry), 20 (rainy)	-	**Kawu, 2011**
Red Sokoto	FGA, $PGF_{2\alpha}$, Control	30 mg for 12 days IV, 12.5 mg (double) IM	52	33, 55, 37		**Bello *et al.*, 2011**
Sahel	FGA, FGA + eCG	30 mg for 12 days IV plus 200 IU IM	100	73, 58	-	**Omontese *et al.*, 2012**
Red Sokoto	$PGF_{2\alpha}$	50 µg, 75 µg, 100 µg	24	100, 100, 100	-	**Umaru *et al.*, 2012**
WAD	$PGF_{2\alpha}$, P_4, MPA	10 mg IM, 375 mg SC, 60 mg IV	24	100, 100, 100	100	**Oyeyemi *et al.*, 2012**
Red Sokoto	FGA & CIDR ± eCG	30 mg or 330 mg for 14 days IV, 400 IU, IM	110	22, 84 & 45, 95	100, 87, 89, 80	**Omontese *et al.*, 2013a**
Sahel	FGA & CIDR ± eCG	30 mg or 330 mg for 14 days IV, 400 IU, IM	110	47, 100 & 57, 74	75, 88, 62, 100	**Omontese *et al.*, 2013b**
Sahel	$PGF_{2\alpha}$ + eCG	10 mg plus 200 IU IM	36	66, 91, 41		**Omontese *et al.*, 2013c**
Red Sokoto	$PGF_{2\alpha}$ + eCG	10 mg plus 200 IU IM	30	90, 50, 20	77.78, 80, 100	**Omontese *et al.*, 2014**

Key: $PGF_{2\alpha}$= Prostaglandin CIDR=Controlled Internal Drug Release devices eCG=Equine chorionic gonadotrophin IM=Intramuscular IV=Intravaginal

2

Source: Compiled by (Omontese et al. 2016) from various references as per table.
(Ogunbiyi et al. 1980, Akusu and Egbunike 1984, Pathiraja 1991, Alemede and Fasanya 1999, Kawu 2000, Jatau 2002, Egbunike and Ola 2003, Voh (Jr) et al. 2003, Ola and Egbunike 2005, Abu et al. 2008, Imasuen and Ikhimioya 2009, Omontese et al. 2010, Tauheed 2010, Bello 2011, Kawu 2011, Omontese et al. 2012, Oyeyemi et al. 2012, Umaru et al. 2012, Omontese et al. 2013a, Omontese et al. 2013b, Omontese et al. 2013c, Omontese et al. 2014)

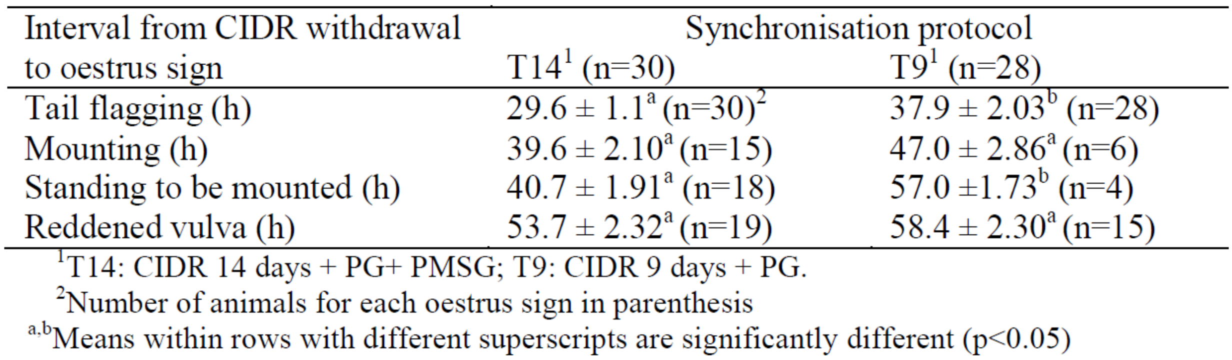
In Perak, Malaysia, 60 intensively-raised Boer does, were divided into two groups and exposed to two different synchronisation protocols. The 'T14' group were administered a progesterone-impregnated CIDR for 14 days, with pregnant mare serum gonadotrophin (PMSG, now called 'equine choriononc gonadotropin' or eCG) and cloprostenol given just prior to CIDR removal. The 'T9 'group were administered a CIDR for 9 days and cloprostenol alone before CIDR removal. The two regimes are shown in Figure 29. All of the does (30) in the T14 group showed oestrous signs within 66 hours of CIDR removal, while only 67% of the T9 group did. The T14 group also had a shortened time of oestrous response that resulted in a more compact oestrous. The results are shown in Table 41 (Abdul Muin et al. 2013). Pregnancy rates were not recorded in this study.



Source:(Abdul Muin et al. 2013)

Figure 29: Two oestrous synchronisation protocols for goats in Malaysia

Table 41: Results from the two synchronisation protocols for goats in Malaysia



Interval from CIDR withdrawal to oestrus sign	Synchronisation protocol T14^{1} (n=30)	T9^{1} (n=28)
Tail flagging (h)	29.6 ± 1.1^{a} (n=30)^{2}	37.9 ± 2.03^{b} (n=28)
Mounting (h)	39.6 ± 2.10^{a} (n=15)	47.0 ± 2.86^{a} (n=6)
Standing to be mounted (h)	40.7 ± 1.91^{a} (n=18)	57.0 ± 1.73^{b} (n=4)
Reddened vulva (h)	53.7 ± 2.32^{a} (n=19)	58.4 ± 2.30^{a} (n=15)

[1] T14: CIDR 14 days + PG+ PMSG; T9: CIDR 9 days + PG.

[2] Number of animals for each oestrus sign in parenthesis

[a,b] Means within rows with different superscripts are significantly different ($p<0.05$)

Source: (Abdul Muin et al. 2013)

PROGESTERONE / PROGESTAGENS

Hormonal manipulation of the oestrus cycle commonly utilises the continuous administration of progesterone or a progestagen for a period of time. The exogenous progesterone mimics its natural counterpart, which is produced by the corpus luteum after ovulation. Progestagens have been used since the 1960s to synchronise sheep oestrus. Forms of the drug include fluorogestone acetate, medroxyprogesterone acetate and melengestrol acetate (Abecia 2012).

Drug delivery is usually by either impregnated sponges or controlled internal drug release (CIDR) devices inserted vaginally, although oral and other modes of delivery have been used (Abecia 2012). The recommended protocol involves the use of sponges for 16-18 days or CIDRs for 18-21 days. A gonadotropin injection (eCG) is given just prior to or at the time of removing the progesterone (Wheaton et al. 1993). eCG has LH- and FSH-like activity and has the effect of initiating pre-ovulatory activity and increasing the number of lambs born (Abecia 2012).

In the study of (Wheaton et al. 1993), the number of ewes bred, the number of ewes lambing and lambs born were similar in sponge and CIDR groups. The administration of a CIDR a month before the onset of the normal breeding period followed by exposure to rams (the ‘ram effect’) caused oestrus, conception and lambing to be brought forward. Synchronisation of Boer goats outside the breeding season was also found to be effective using intravaginal sponges or sponges with prostaglandin and eCG (Greyling and Van Niekerk 1991).

An interesting recent study from Texas A&M examined the effect of the permanent presence of teaser bucks on the time from CIDR removal from does to oestrus onset, oestrus duration, ovulation time, number of ovulations, and interval from CIDR removal to ovulation time on oestrus-synchronized Boer does. The oestrus-synchronised does, exposed to a male from the time of CIDR removal, had sooner onset of oestrus and shorter oestrus compared to does with intermittent exposure. The males were aproned and so were unable to mate with the does but could otherwise exhibit all-natural sexual behaviour including striking of the foreleg, mounting and close contact and vocalising. Neither ovulation time nor the number of ovulations within the breeding season were altered by this buck exposure. It was proposed that with better management of the teaser, more oestrus synchronised does could be prepared optimally for artificial insemination (Romano et al. 2016).

In tropical areas, there is the potential to use procedures to synchronise oestrus all year around due to the lack of seasonality of breeding season (Godfrey et al. 1997). For does in season, progesterone will only need to be supplied for less than 16 days (Bretzlaff and Romano 2001).

PROSTAGLANDINS AND ANALOGUES

Prostaglandins work by causing luteolysis, that is, the termination of the corpus luteum and induction of a follicular phase and ovulation. The corpus luteum is susceptible to prostaglandin from about day 3 of the oestrus cycle (Rubianes and Menchaca 2003), so females in anoestrus, or in the early or late luteal or follicular phase, will not respond to prostaglandin treatment. Two treatments, 9-10 days apart, are therefore necessary to ensure most animals respond. Prostaglandin F2-alpha is the primary luteolytic agent in ruminants so it or its analogue (cloprostenol) are used (Abecia 2012).

Prostaglandins can be used as an alternative to progestagens for synchronising oestrus, but only during the breeding season. A study of prostaglandin use in Boer goats that were outside the normal breeding season showed a poor oestrus response (Greyling and Van Niekerk 1991). Prostaglandins are only effective when a corpus luteum is present.

A problem with the twin prostaglandin treatment regime is that fertility in ewes at first mating is only around 70%, lower than that achieved after progestagen treatment. This appears to be because the maturation of preovulatory follicles is affected by the presence of corpora lutea, which are terminated by the prostaglandin program. There is also variability in the timing of ovulation (Abecia 2012). More recent studies have therefore applied a 7-day interval between prostaglandin doses (for example Menchaca et al 2004, Contreras-Solis et al 2009) as well as the application of the male effect (Contreras-Solis et al 2009) to address these problems.

Another protocol that has been described involves the administration of GnRH by two injections seven days apart, with prostaglandin also given on the fifth day. Insemination by intrauterine laparoscopy can occur 12-24 hours after the second GnRH treatment ((Amiridis et al. 2005), as cited by (Amiridis and Cseh 2012)).

Prostaglandins do not accumulate in the tissues as they are rapidly metabolised through the lungs. This might make them a good alternative to progesterone for consumers concerned with ‘clean, green and ethical’ meat production. Prostaglandins are typically administered subcutaneously or intramuscularly. There are some reports of an intravulvo-submucosal technique being investigated ((Piper et al. 1970), as cited by (Omontese et al. 2016)).

MELATONIN

Melatonin is important in regulating reproduction in animals that are seasonal breeders. The light stimulus enters through the eye and the retina and transmits a message to the pineal gland via a neural pathway, modulating melatonin release. Blood melatonin concentrations are highest at night and lowest during the day. Goats are short day breeders, which means the positive stimulus to breed begins as the day length shortens, causing an increase in melatonin secretion. The main effect of melatonin is on the hypothalamic-pituitary axis where it stimulates the release of GnRH and LH ((Viguie et al. 1997), as cited by (Abecia 2012)).

The breeding season of anoestrus goats can be advanced by the use of melatonin implants. These mimic a situation of short day stimulus for breeding (Malpaux et al. 1997) as cited by (Abecia 2012). The implants contain 18mg of melatonin and deliver high plasma levels of melatonin for at least 60 days in sheep ((Forcada et al. 2002) as cited by (Abecia 2012)). In sheep, the recommended protocol involves injection of rams with implants seven days before ewes are also treated. The rams are introduced to the ewes 40 days after that (Abecia 2012).

There have been various studies on the use of melatonin in goats. It has been used to induce cycling in anoestrus goats where the bucks remain with the does ((Zarazaga et al. 2009), as cited by (Abecia 2012)). The effect of the melatonin can be maximised when photoperiodic treatment (long days) is provided for 2-3 months preceding administration (Chemineau et al. 1986) as cited by (Abecia 2012). However, (Abecia 2012) describes the application of melatonin implants in goats as ‘not fully established’.

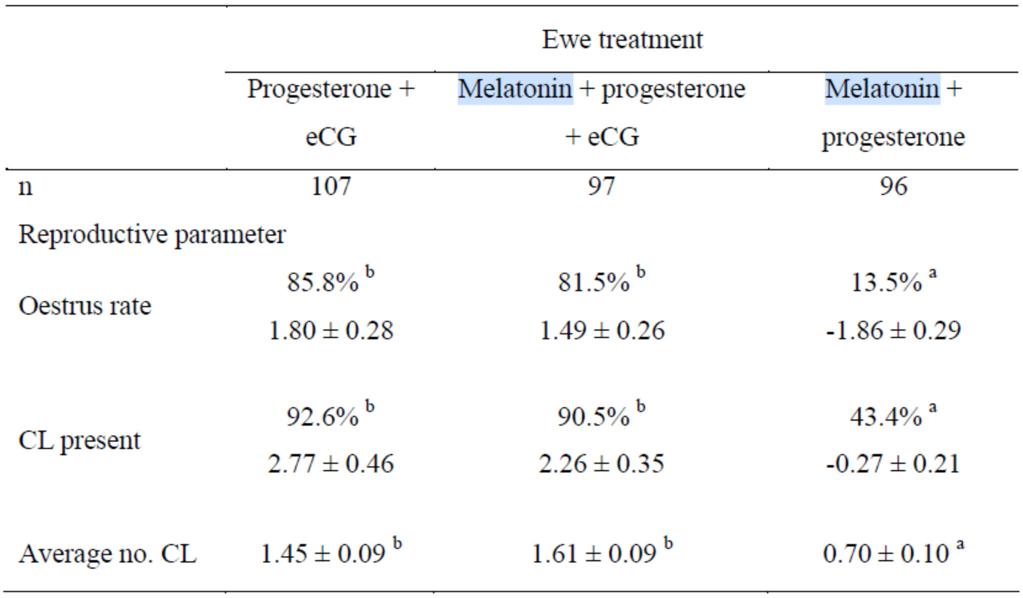
Melatonin was included in a study by deNicolo (2007), near Palmerston North, New Zealand (40ºS), in spring through to summer, in which 300 mixed-age Romney composite sheep were divided into three groups and treated with either:

- Progesterone and eCG;
- Melatonin implants and progesterone and eCG; or
- Melatonin implant and progesterone.

Table 42 and

Table **43** show the results from this study. It was found that melatonin and progesterone alone were not effective in improving reproductive outcomes out of the normal breeding season. Productivity was 67% higher in the melatonin, progesterone and eCG group compared to the controls.

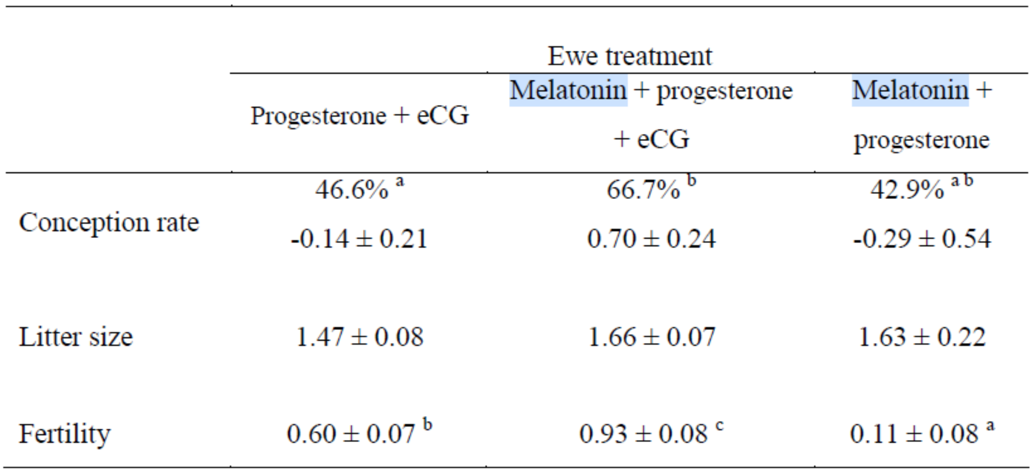
Table 42: Effect of three treatments on oestrus rate, presence of CL and number of CL in ewes



	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]

Source: (deNicolo 2007). CL=corpus luteum, eCG=equine chorionic gonadotropin

Table 43: Effect of three treatments on conception rate, litter size and fertility in ewes



	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% ^{ab} -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}

Source: (deNicolo 2007). eCG = equine chorionic gonadotrophin. Conception rate defined as number of ewes pregnant per ewe mated. Litter size defined as number of foetuses per pregnant ewe. Fertility defined as number of foetuses per ewe exposed to the ram

7.4.2 ACCELERATED KIDDING / LAMBING SYSTEMS

Accelerated kidding or lambing may involve breeding twice in one year, three times in two years or five times in three years. These systems rely on the ability of does or ewes to breed during any season (Lewis et al. 1996).

Some of the advantages of an accelerated lambing (kidding) system include:

- More consistent supply of lamb;
- A higher number of offspring produced per female per year;
- More consistent cash flow (Ehrhardt 2019)
- Access to market when prices are higher;
- Better distributions of the personnel resources; and
- Higher income (Vicario et al. 2013), (Ehrhardt 2019).

The United States Lamb Resource Center (Ehrhardt 2019) provides a summary of accelerated lambing systems. It suggests that the major barrier to successful implementation of such systems is the limit created by variable to poor out-of-season breeding. The Center advises that particular attention should be made to genetic selection of animals with less marked or no seasonality of breeding. Rams need to be sound, be in good condition and have good mating activity. Other considerations in adopting accelerated systems include:

- They are more suited to land of higher productivity;
- High quality feed is required;
- There is an increase in labour input required, although this is fairly consistent over the year;

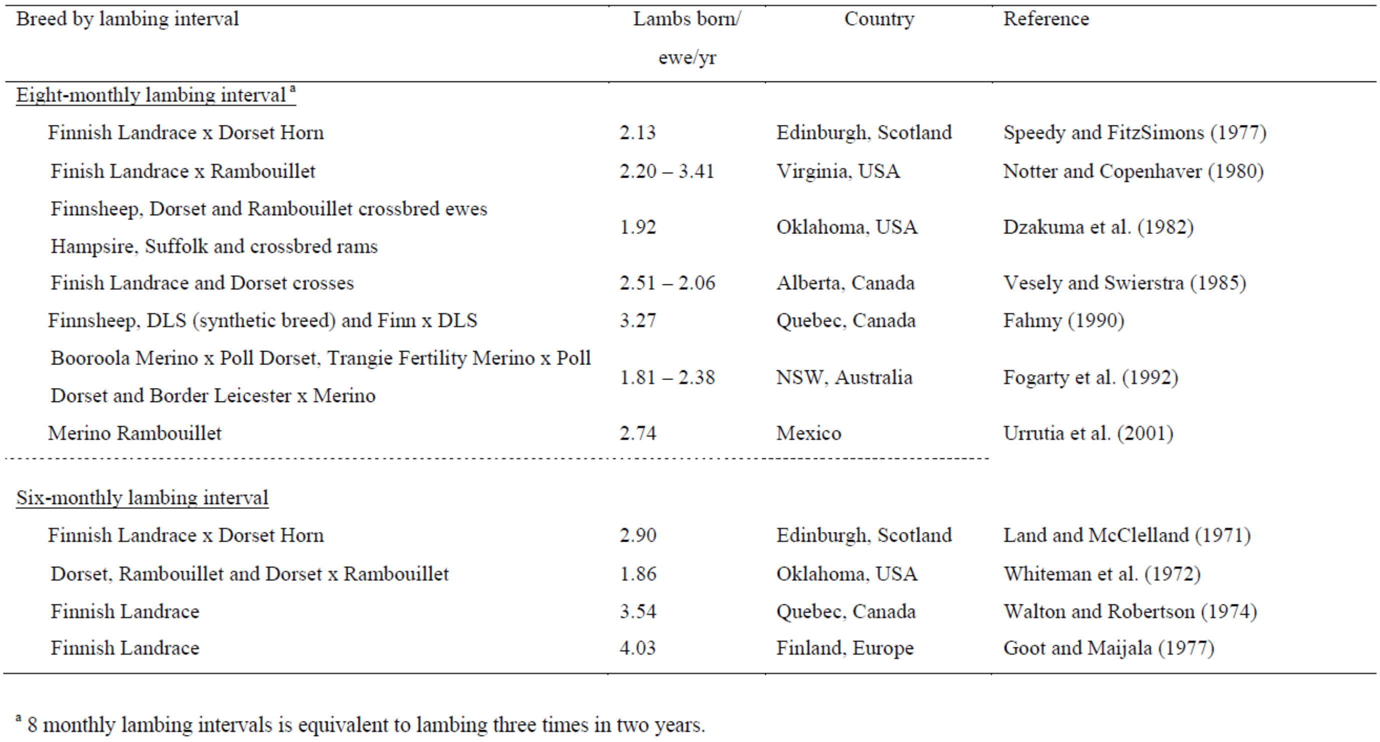
- Indoor lambing facilities may need to be provided (when lambs are born in suboptimal times when very cold and wet); and
- Good attention to health is required (Ehrhardt 2019).

Much of the literature on accelerated breeding programs comes from research in sheep. Interpretation of this information in the context of goat meat production in Australia should be undertaken with caution. The majority of the studies do not have an annual breeding group in the study as a control. Also, most studies do not continue through the whole of the animals' productive lives. This means there is no data on the overall increase in production over that time. In addition, there are few analyses of the high costs of running such systems (especially in supplementary feeding and management).

Gina deNicolo (2007) completed a PhD thesis on 'Accelerated lambing and out-of-season lamb production in New Zealand'. It provides an extensive literature review and some research material that has been extensively referenced through this section (deNicolo 2007).

Table 44 provides a summary of the number of lambs born per ewe per year in two types of accelerated lambing systems across several studies. It shows the large variation in results achieved (deNicolo 2007).

Table 44: Summary of various studies showing the number of lambs born in two different accelerated lambing programs, including country of study 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.

Source: Complied by (deNicolo 2007) from references as listed in the table (Land and McClelland 1971, Whiteman et al. 1972, Walton and Robertson 1974, Goot and Maijala 1977, Speedy and FitzSimons 1977, Notter and Copenhaver 1980b, Dzakuma et al. 1982, Vesely and Swierstra 1985, Fahmy 1990, Fogarty et al. 1992, Urrutia et al. 2001)

In deNicolo's (2007) work in New Zealand the ability to breed ewes out of season was tested. It was found that in August and November pregnancy rates were 45-54% and 41-49% respectively which were low compared to a peak of 91-94% from a March joining. In addition, the effect of mating lactating ewes (68-73 days post-partum) was reviewed. The results showed there was no effect on the number of CL present, oestrous activity, pregnancy rate or litter size (deNicolo 2007).

TWO KIDDINGS / LAMBINGS PER YEAR

This program involves kidding / lambing every six months, that is, twice a year every year (while in the 3-in-2 system, described below, kidding / lambing occurs twice in a year every second year). This review was unable to find scientific literature on a twice-yearly system in goats and only a few references for sheep. Most of the reference material in sheep is quite old, using small numbers of stock and due to various experimental design features the data are difficult to translate to goat production systems in Australia. The literature is summarised below.

Walton and Robertson (1974) describe work in Canada (45ºN) in which 23 Finnish Landrace sheep were joined in autumn and spring for five consecutive matings. Ewes were allowed to suckle their lambs only at first lambing, while for subsequent lambings the lambs were removed at 24-48 hours post-partum and fed on milk replacer. Overall, 33.3% of ewes conceived at every joining and the mean lambing rate over the five breeding opportunities was 1.77 per ewe, equivalent to 3.54 lambs per ewe per year. This was only a short-term study and with the influence of lactation on anoestrous post-lambing removed in 4 of the 5 lambings, it is difficult to gain a full appreciation of the success or otherwise of this system. In addition, there was no control group (annual breeding group).

In another study in Finland, 118 Finnish Landrace sheep were bred twice-yearly for four-five years (1968-1972/73). Forty-five percent of ewes lambed twice a year and 55% once. There was no decline in reproductive performance over the years studied. Ewes that lambed twice a year produced 5 lambs +/-1.4 annually. The lamb mortality was 12.8% and annual ewe wastage was 21.9%. As expected, there were lower conception rates going into the summer and highest going into the winter. There was no impact on litter size from the year, lambing period or age of the ewe (Goot and Maijala 1977). While the report states that reproductive performance was not impacted over the period of the study there was a high wastage rate among the ewes. In addition, there was no control group (annual) to allow a comparison.

One hundred and eighty-two Dorset and Dorset x Rambouillet ewes were bred twice-yearly between 1964 and 1968 in a study by (Whiteman et al. 1972). Thirty-six percent of lambs born over the study were conceived from joinings that occurred in the season that the ewe lambed, and these can be considered the extra lambs that were delivered from this reproductive program. The study highlighted the variation in breeding with the seasons as the ewes that lambed in the autumn had a lambing percentage of 35% while those in the spring had a lambing percentage of 84%. There was also some variation between the breeds.

Another study saw Finn-Dorset ewes joined four time in two years. Ewes that were over 2 years of age at the beginning of the experiment averaged three pregnancies out of the four opportunities with an average of 5.8 lambs per ewe. The rate of pregnancy for ewes in the mating immediately after a lambing was 32%, while it was 93% otherwise (Land and McClelland 1971).

Yavuzer (2005) reported twice a year lambing in Awassi sheep in Turkey. Twenty-five ewes were joined while they were still lactating without exogenous hormone intervention. The pregnancy rate from this joining was 40%, which was much lower than the original pregnancy rate of 100% but, the overall pregnancy rate for the year was 140%. The research showed that some of the sheep were able to breed despite lactation. This study only looked at a single year, therefore the long-term impact on the productive capacity of the ewes was not evaluated.

THREE KIDDINGS / LAMBINGS IN TWO YEARS

An Australian study conducted in 1985-86 compared three groups of different crossbred-type ewes (Booroola Merino x Poll Dorset, Trangie Fertility Merino x Poll Dorset and Border Leicester x Merino) joined every 8 months (February, October and June) over two years. A total of 711 ewes were included in this study. The ewes were 4-7 years of age and there was no control group. The trial was conducted under field conditions with natural mating for periods of 5, 6 and 5 weeks for the three joinings. The accelerated system showed an annual lambing rate of 211% (lambs born) and 160% lambs weaned. The 1.3 lambings per year was 0.4 more than for the February joining. As expected, the highest lambing rate was achieved after the February joining, which is closest to the normal breeding season. The authors noted that in an accelerated lambing system there is significant variation in performance between breeds. This variation is due mainly to variation in fertility when joining outside the breeding season, and the variation in length of the non-breeding season (Fogarty et al. 1992).

In a longer follow-up study, conducted over four years from 1987-90, 1182 crossbred ewes were divided into three production systems: two groups lambing three times in two years, joined four months apart; spring joining with autumn backup joining; and autumn joining. The trials took place in Cowra and Wagga Wagga, NSW. Two genotypes of ewes, Border Leicester × Merino and Hyfer (Dorset × Merino composite) were used at both sites, with ewes joined naturally to Dorset, Suffolk or Hyfer rams. Feed for the ewes and lambs was described as ‘not a limiting factor’ and included improved pastures of subterranean clover / perennial ryegrass / phalaris and some barley grass. The study found that the accelerated ewes had 41% more lambings per year with 45% more lambs born, weaned, and weight of lamb weaned per year than the spring-joined group (Fogarty and Mulholland 2013).

The same study examined the metabolisable energy requirements of ewes in the three different breeding programs. The energy requirements of the accelerated group were fairly consistent throughout the year and showed a lower peak than that of the other systems. The spring and autumn joining groups showed a marked increase in energy demand in the last week of pregnancy and a peak at weaning, but the energy requirement was relatively low for the rest of the year (Fogarty 2015). The ewes in the accelerated lambing group had a 11% higher metabolisable energy requirement overall than the spring joining group. This meant that, using a ‘weight of lamb weaned per DSE [dry sheep equivalent]’ measure, the accelerated system was 16-47% more efficient (Fogarty 2015).

Three lambings in two years is the most common accelerated sheep breeding system in Canada (Goulet and Castonguay 2004). Economic modelling of Canadian lamb systems (accelerated lambing, spring and winter), taking into account costs of production and market prices for lamb, indicated that a ewe (over a seven-year period) would provide a total contribution margin of $755 in an accelerated lambing system (from 17.64 lambs), $357 spring lambing (9.80 lambs) and $517 in a winter lambing system (12.25 lambs) (Fisher 2005).

According to (Goulet and Castonguay 2004), ‘an increasing number’ of producers in Canada attempted to rebreed ewes 60-70 days postpartum in order to achieve three lambings in two years. Their study on primiparous ewes indicated that extending the lambing-breeding interval from 75 to 90 days improved the lambing rate, number of lambs per ewe, litter weight at birth and the condition of the ewes at mating (Goulet and Castonguay 2004).

In the United States, a study by Notter and Copenhaver (1980) compared the reproductive performance of various Finnish Landrace-cross ewes in an advanced breeding system (three lambings on two years). As predicted, the conception rate varied according to the joining time (August, 90%; November, 79%; and April, 53%) (Notter and Copenhaver 1980a). In Scotland, Finnish Landrace x Dorset Horn and Border Leicester x Scottish black- or grey-face ewes were bred 3 times in 2 years, without hormone assistance in the breeding season (November) and with hormones for the August and February joinings. The conception rates in the three matings were 88, 82 and 72% for the Finnish cross and 96, 56 and 26% for the Border Leicester cross. The differences highlight the variation that can be seen between breeds and between seasons (Speedy and FitzSimons 1977).

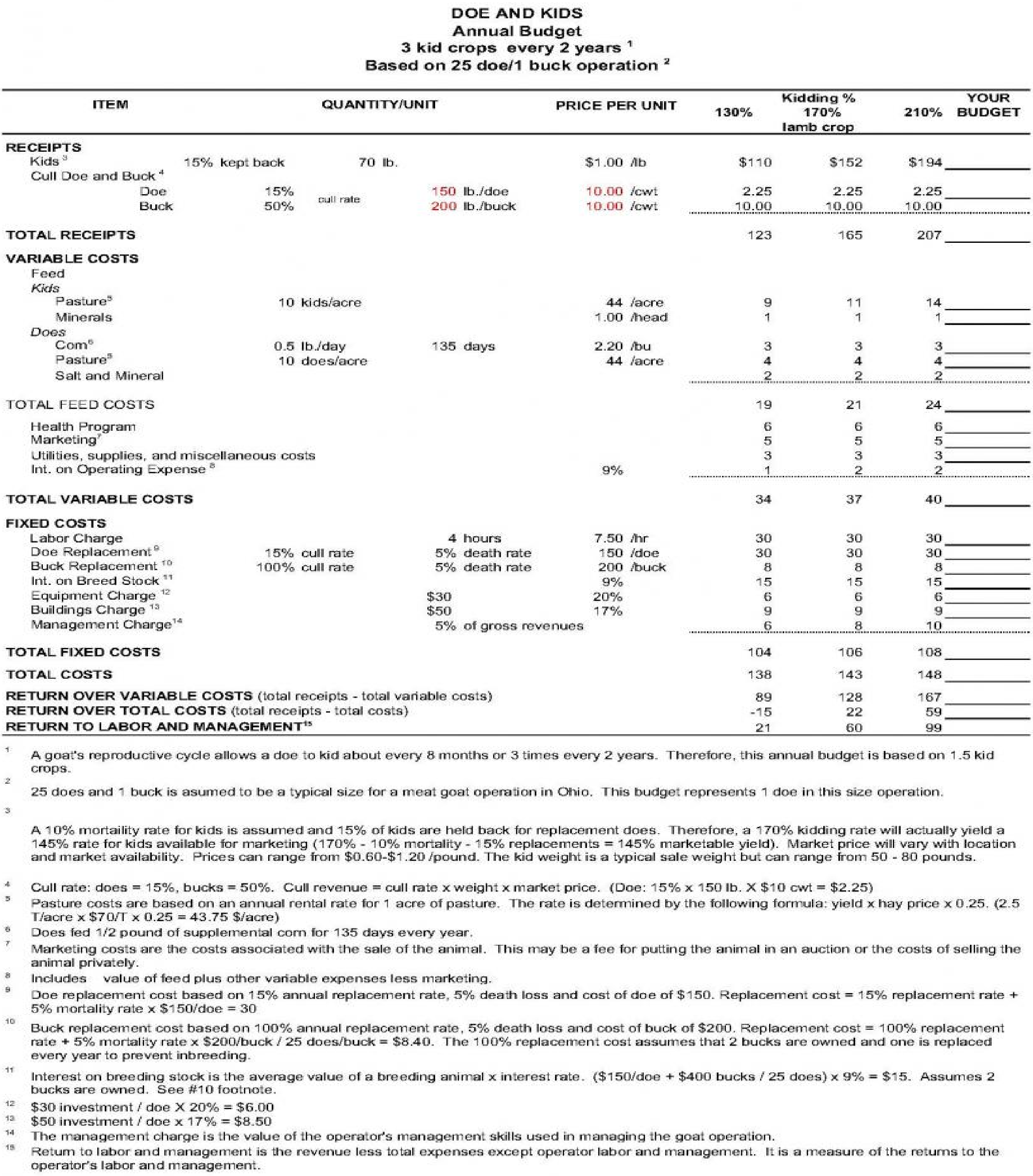
Accelerated breeding in sheep is used elsewhere in the world. In Mexico, (Urrutia et al. 2001) reported a study in which 129 Merino Rambouillet ewes were joined to lamb every eight months over two years There was no significant difference between the lambing rates at the three mating times (including the mating that occurred in the non-breeding season). The time of joining did however affect the number of lambs born per ewe that lambed. The authors suggested that the photoperiod may have had more of an influence on follicular development and ovulation rate than on oestrus behaviour. Overall the accelerated system increased lamb production by 37% at birth and 28% at weaning. There was a slight decrease in lamb survival in the accelerated breeding program over time (Urrutia et al. 2001).

In Pakistan, Kivircik ewes that lambed three times in two years showed an increase in lamb production of 15% at birth and 19% at weaning compared to an annual system (Koyuncu 2005).

There is far less literature on three-in-two accelerated systems in goats. Accelerated kidding was found to produce more kids per doe than an annual system in a group of Beetal goats in Pakistan. The study was a small one (n=25 in each group) and the authors noted that further research with a larger cohort would be necessary to validate the findings of the study (Nisar et al. 2015).

Ohio State University (Nye and Moore 2004) provides some web-based extension material on goat meat production and budgeting, including an annual budget for a 3-in-2 breeding system, based on a sample herd of 25 does and one buck. The budget provides some guidance as to what needs to be considered in budgeting for an accelerated program (Table 45).

Table 45: Example of a budget for a 3 in 2 year accelerated breeding program. Calculations for one doe



DOE AND KIDS
Annual Budget
3 kid crops every 2 years [1]
Based on 25 doe/1 buck operation [2]

ITEM	QUANTITY/UNIT		PRICE PER UNIT	130%	Kidding % 170% lamb crop	210%	YOUR BUDGET
RECEIPTS							
Kids [3]	15% kept back	70 lb.	$1.00 /lb	$110	$152	$194	________
Cull Doe and Buck [4]							
Doe	15% cull rate	150 lb./doe	10.00 /cwt	2.25	2.25	2.25	________
Buck	50%	200 lb./buck	10.00 /cwt	10.00	10.00	10.00	
TOTAL RECEIPTS				123	165	207	________
VARIABLE COSTS							
Feed							
Kids							
Pasture[5]	10 kids/acre		44 /acre	9	11	14	________
Minerals			1.00 /head	1	1	1	________
Does							
Corn[6]	0.5 lb./day	135 days	2.20 /bu	3	3	3	________
Pasture[5]	10 does/acre		44 /acre	4	4	4	________
Salt and Mineral				2	2	2	
TOTAL FEED COSTS				19	21	24	________
Health Program				6	6	6	________
Marketing[7]				5	5	5	________
Utilities, supplies, and miscellaneous costs				3	3	3	________
Int. on Operating Expense [8]			9%	1	2	2	
TOTAL VARIABLE COSTS				34	37	40	________
FIXED COSTS							
Labor Charge		4 hours	7.50 /hr	30	30	30	________
Doe Replacement [9]	15% cull rate	5% death rate	150 /doe	30	30	30	________
Buck Replacement [10]	100% cull rate	5% death rate	200 /buck	8	8	8	________
Int. on Breed Stock [11]			9%	15	15	15	________
Equipment Charge [12]		$30	20%	6	6	6	________
Buildings Charge [13]		$50	17%	9	9	9	________
Management Charge[14]		5% of gross revenues		6	8	10	
TOTAL FIXED COSTS				104	106	108	________
TOTAL COSTS				138	143	148	________
RETURN OVER VARIABLE COSTS (total receipts - total variable costs)				89	128	167	________
RETURN OVER TOTAL COSTS (total receipts - total costs)				-15	22	59	________
RETURN TO LABOR AND MANAGEMENT[15]				21	60	99	

[1] A goat's reproductive cycle allows a doe to kid about every 8 months or 3 times every 2 years. Therefore, this annual budget is based on 1.5 kid crops.

[2] 25 does and 1 buck is asumed to be a typical size for a meat goat operation in Ohio. This budget represents 1 doe in this size operation.

[3] A 10% mortaility rate for kids is assumed and 15% of kids are held back for replacement does. Therefore, a 170% kidding rate will actually yield a 145% rate for kids available for marketing (170% - 10% mortality - 15% replacements = 145% marketable yield). Market price will vary with location and market availability. Prices can range from $0.60-$1.20 /pound. The kid weight is a typical sale weight but can range from 50 - 80 pounds.

[4] Cull rate: does = 15%, bucks = 50%. Cull revenue = cull rate x weight x market price. (Doe: 15% x 150 lb. X $10 cwt = $2.25)

[5] Pasture costs are based on an annual rental rate for 1 acre of pasture. The rate is determined by the following formula: yield x hay price x 0.25. (2.5 T/acre x $70/T x 0.25 = 43.75 $/acre)

[6] Does fed 1/2 pound of supplemental corn for 135 days every year.

[7] Marketing costs are the costs associated with the sale of the animal. This may be a fee for putting the animal in an auction or the costs of selling the animal privately.

[8] Includes value of feed plus other variable expenses less marketing.

[9] Doe replacement cost based on 15% annual replacement rate, 5% death loss and cost of doe of $150. Replacement cost = 15% replacement rate + 5% mortality rate x $150/doe = 30

[10] Buck replacement cost based on 100% annual replacement rate, 5% death loss and cost of buck of $200. Replacement cost = 100% replacement rate + 5% mortality rate x $200/buck / 25 does/buck = $8.40. The 100% replacement cost assumes that 2 bucks are owned and one is replaced every year to prevent inbreeding.

[11] Interest on breeding stock is the average value of a breeding animal x interest rate. ($150/doe + $400 bucks / 25 does) x 9% = $15. Assumes 2 bucks are owned. See #10 footnote.

[12] $30 investment / doe X 20% = $6.00

[13] $50 investment / doe x 17% = $8.50

[14] The management charge is the value of the operator's management skills used in managing the goat operation.

[15] Return to labor and management is the revenue less total expenses except operator labor and management. It is a measure of the returns to the operator's labor and management.

Source: (Nye and Moore 2004)

FIVE LAMBINGS IN THREE YEARS

Brian Magee and Doug Hogue from Cornell University have developed an accelerated lambing program for sheep called the STAR system.

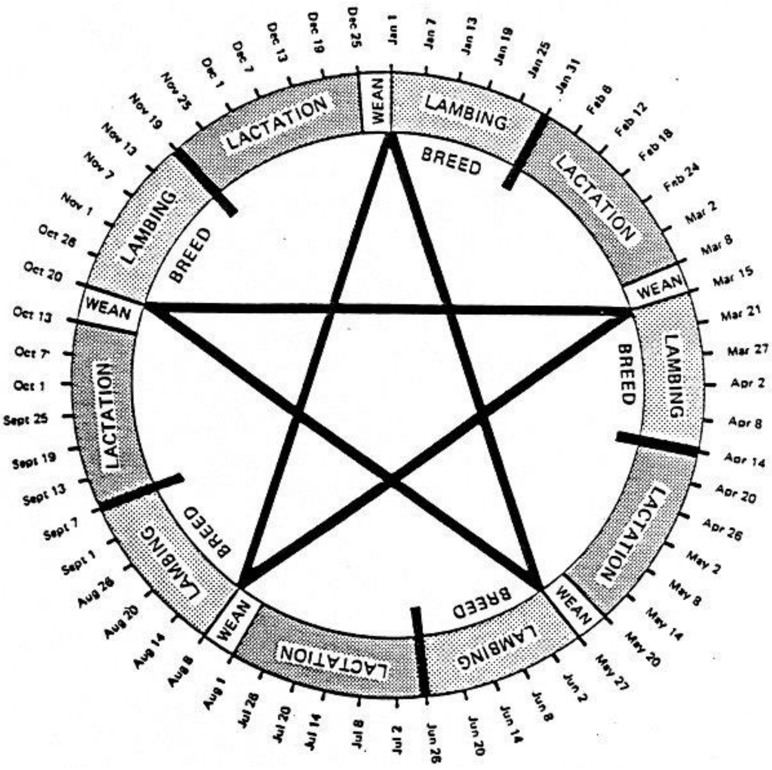
Prior to STAR, Hogue developed the Cornell Alternate Monthly Accelerated Lambing (CAMAL) system. CAMAL involves ewes being exposed to the ram on alternate months and lambing on every other month. Individual ewes lamb at either 6, 8 or 10 month intervals. One of the main challenges with this system is the ability to identify the stage of pregnancy of the ewes, to allow for appropriate feeding (Hogue et al. 2015b) based on the varying nutritional requirements for the different stages of pregnancy. In addition, it proved difficult to predict the appropriate time for flushing (Hogue et al. 2015b).

In study published in 1986, the first lambing ages, interval between lambings and likelihood of conception were compared between Morlam sheep that were continuously exposed to the ram, and Dorset sheep in the CAMAL system that were exposed to the ram every second month. The influence of the season on the likelihood of conception and the lambings per ewe were slightly higher in the Morlam group. The authors concluded that both systems were effective at reducing the age of first lambing and the interval between lambings. The Morlams produced 1.28 lambs per year and the Dorsets, 1.21. There was genetic variation in the probability of conception and age at first lambing, suggesting that improvement could be made in these traits with selection (Iniguez et al. 1986).

The CAMAL system was compared to a conventional annual lambing in Awassi ewes in Turkey (Gül and Keskin 2010). The accelerated group were stimulated to ovulate using progesterone-impregnated intravaginal sponges and PMSG and were joined to produce three lambings in two years. The authors concluded that the accelerated lambing did not increase the number of lambs born overall. The birth weight and weaning weight of lambs and the milk yield for the suckling period was less for the ewes in the CAMAL group than the control group. Awassi sheep are known to be a seasonal breed and with accelerated breeding at least one or two of the breeding times required are during the anoestrous period (Gül and Keskin 2010).

CAMAL was modified by the Cornell group to become the STAR system. This system is based upon a calendar year being divided into five phases of 73 days. There is 30 days of lambing and joining at the beginning of each 73-day phase. Lambs are then weaned at day 66 and then the ewes rested for 7 days before joining again (at the beginning of the next phase). In each phase, empty ewes are joined and ewes that were joined two intervals earlier will lamb (Lewis et al. 1996).

The system can be represented diagrammatically by a star (Figure 30), hence the name. Each point of the star represents the beginning of each one of five ‘breeding opportunities’ (phases) for the year. At the beginning of each of these phases, the ewes will be either: empty, or in early or late gestation. The empty ewe group includes those ewes that have just weaned lambs and those that have failed to conceive on previous cycles (Lewis et al. 1996).



Source: (Hogue et al. 2015a)

Figure 30: Diagram of the STAR system

To use the STAR system the flock is divided into three functional groups, each of which is subject to production-specific management. These three groups are:

- Breeding and pregnant ewes and rams;
- Lambing/lactating ewes and lambs; and
- Lambs being grown out for market or as replacement ewes (Hogue et al. 2015a).

These groups are formed for ease of management, grouping together animals with similar nutritional and management needs. The goups have quite different needs and hence they are managed as three different mobs.

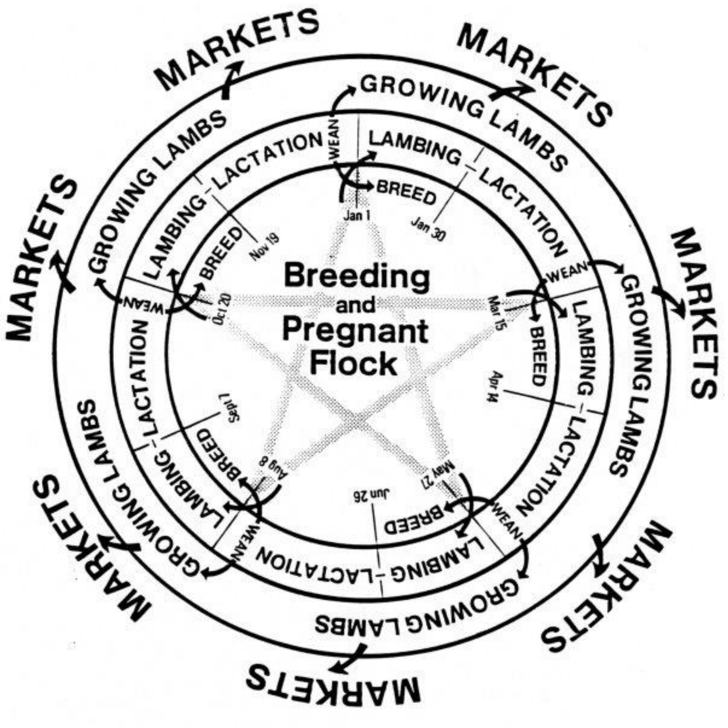
Table 46 summarises the three main groups of animals in the STAR system. It outlines the main nutritional and management requirements to allow them to reach their productive targets.

Table 46: STAR system – summary of animal groups

STOCK TYPE	BREEDING AND PREGNANT EWE FLOCK	LAMBING AND/OR LACTATING EWES AND THEIR LAMBS	GROWING LAMBS
Description of animals	⌖ Ewes from weaning until ready to lamb again ⌖ Rams ⌖ Young replacement ewes	⌖ Lambing ewes ⌖ Lactating ewes ⌖ Lambs	⌖ Lambs from weaning to market or replacement ewes in breeding flock
Main aim of the group	⌖ Establishment of flock genetics ⌖ Sire selection ⌖ Selection of non-seasonal breeding stock	⌖ Maximal birth weight and survivability to weaning ⌖ Good growth rates	⌖ Weight gain and growth to meet selected market expectations ⌖ Uniform supply of meat for regular cash flow
Nutritional considerations	⌖ Mostly fed on pasture	⌖ High level of feed ⌖ Ewes fed according to pregnancy (single, twins etc) ⌖ Excessive lambs may require artificial rearing, possible creep feeding for lambs from 2 weeks	⌖ May be fed a formulated mixed ration
Management requirements	⌖ Relatively low	⌖ High level of management ⌖ Maintenance of ewe condition ready for re-mating	⌖ Management to keep up feeding ration until desirable market weight, or to enter the breeding mob

Source: (Hogue et al. 2015a)

Figure 31 shows how animals move between the three different groups in the system.



Source: (Ehrhardt 2019)

Figure 31: Diagram showing movements between the groups in the STAR system

According to (Ehrhardt 2019), the STAR system features faster rebreeding and higher productivity and profitability than a system of three lambings in two years. On the other hand, the latter system offers improved post-lactation recovery, a longer time before weaning, the possibility of greater lamb weights at weaning and slightly more flexibility. Table 47 compares measurable reproductive characteristics of the two systems.

Table 47: Comparison of STAR (five lambings in three years) with three lambings in two years

CHARACTERISTIC	STAR © (5 IN 3 YEARS)	8 MONTHS (3 IN 2 YEARS)
Minimum lambing interval	7.2 months	7-9 months
Lactation length	42-72 days	42-100 days
Breeding period	Less than 30 days	Less than 51 days
Lambing periods/year	5	3 (or 6)
Maximum births per year	1.67	1.5
Time from parturition to mating. **Time to re-breeding**	70 days 72 days	93 days. Approximately 120 days

Source: (Ehrhardt 2019)

Lewis et al (1996) implemented the STAR system over a period of six years in a flock of Dorset ewes. The study was completed at Cornell University in the State of New York, USA. Three of the joinings occurred in the typical mating season (August, October and January) while March and June were not. The study found that, predictably, fertility in the flock varied cyclically through the year and that ewes mated during the usual breeding season were more fertile. The authors concluded that fertility was controlled by the interaction of several factors including the mating season, ewe age and the time since the last mating. A matrix was derived to calculate the expected fertility rate of different ewes in different seasons. Over the course of the study, the average ewe performance was 0.98 lambings per year, delivering 1.5 and weaning 1.23 lambs with a weaning weight of 19.6 kg (Lewis et al. 1996). The gestating and non-lactating ewes were fed on native mixed grass-clover pasture from April until September and then given hay until January. Over winter the ewes received 1.8kg of dry matter (hay crop silage) daily. From late gestation though into lactation, for a total of about 70 days, ewes were confined. They were fed 2.3 kg dry matter of hay crop silage and 0.6-1.0kg/d of grain, depending on the number of lambs the ewe was nursing. Lambs were creep fed (Lewis et al. 1996).

In a study of extensively-grazed Merino sheep in Spain (38ºN) by (Vicario et al. 2013), the STAR system was introduced gradually over several years. Feeding in the extensive ‘dehesa’ ecosystem is pasture-based with supplementation with wheat, corn and oats from June to October. After weaning lambs are fed fodder and hay. A natural mating system without control was succeeded by a system of three lambings in two years with hormonal management and then the STAR system. Anoestrus ewes were treated with melatonin and vaginal sponges. Two weeks prior to mating the ewes were nutritionally flushed and exposed to the ram effect. The ewes were pregnancy-tested using ultrasound.

The authors concluded that the STAR system can:

- Achieve high productivity;
- Reduce perinatal mortality;
- Improve overall ewe annual production;
- Overcome seasonality of production;

- Improve financial returns at market; and
- Improve planning (Vicario et al. 2013).

In the study, accelerated lambing resulted in higher profits. Table 48 shows selected production and financial parameters for the three different breeding systems. While the mean total lamb weight was twice as high for the natural mating group, the price per kilogram of lamb was higher in the STAR system than both the natural mating and the system of three lambings in two years because of a much higher price per kilogram (Vicario et al. 2013). It should be noted, however, that the trials were conducted consecutively, not at the same time. This confounds direct comparisons between systems because (for example) seasonal conditions and/or prices may have changed over the period of the study. Also, the costs of the various systems have not been reported.

Table 48: Comparison of three different lambing systems in Spain

BREEDING SYSTEM	TOTAL LAMBS DELIVERED (MEAN)	TOTAL LAMB WEIGHT (KG) (MEAN)	PRICE(€)/KG (MEAN)	PRICE(€)/LAMB (MEAN)
Natural mating (2002-2003)	301	50.98	1.11	56.46
Three lambings in two years (2004-2008)	441	23.98	2.36	56.47
STAR© system (2009-2012)	513	23.92	2.71	64.64

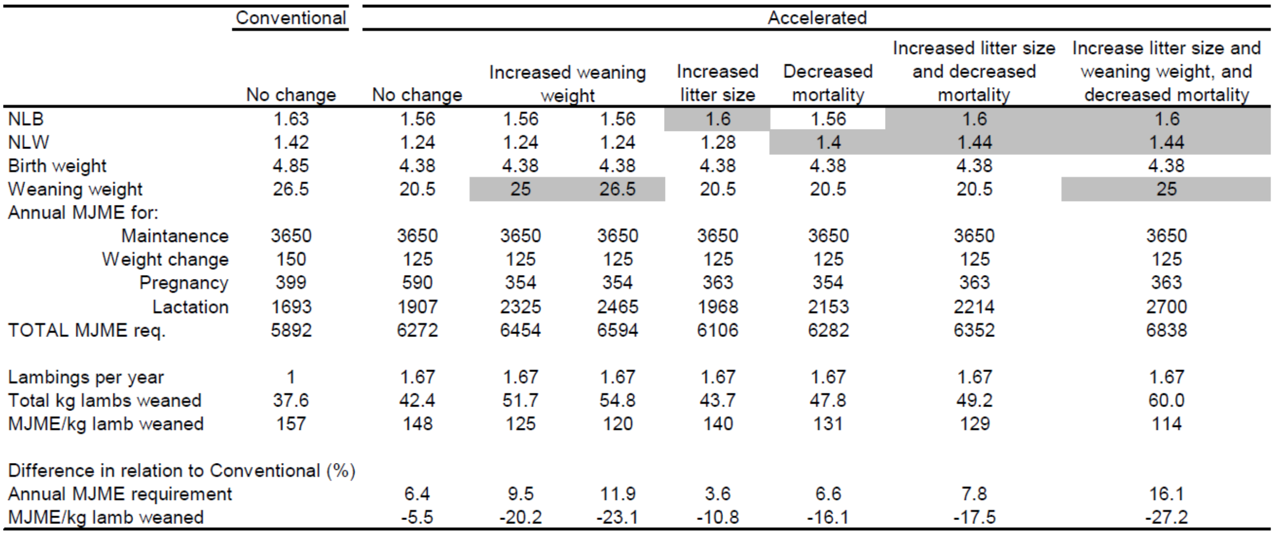
Source: ((Dehesas Cordobesas Cooperative, SCA), as cited by (Vicario et al. 2013))

In a study to determine the economic viability of the STAR system of breeding compared to a conventional system in New Zealand conditions, a model was developed which considered variables such as pasture growth and energy requirements of the flock. The model showed that with a lambing percentage of 160% in both systems, the STAR system generated 26% more income. A lambing percentage of 148% in the accelerated group generated the same return as a conventional system with a lambing percentage of 160%. Allowing for a 10% premium for selling lambs out of season the accelerated system would make 56% more profit (Morel et al. 2004).

Also in New Zealand, a PhD study completed by de Nicolo (2007) compared a conventional annual lambing system with an accelerated system based on STAR with five joinings per year. The sheep were either Romney breed or a composite (one-half East Friesian, one-quarter Texel and one-quarter Poll Dorset). The study was run over three years. Forage crops were fed in summer and annual ryegrass/white clover pasture in winter. The ewes in the STAR system were synchronised and hormone therapy was given to some ewes to assist with breeding during the non-breeding mating periods. The hormone treatment included progestagen-impregnated CIDR devices followed by an injection of eCG, the dose of which varied depending on the predicted depth of anoestrus. These accelerated ewes were also provided with a much higher ram: ewe ratio during mating. Overall the results showed that the rate of pregnancy in the accelerated system was lower than the conventional system. Lamb growth rates were similar, although weaning occurred almost a month earlier in the accelerated system and thus the weaning weights were lower. Over the whole experiment the total weight of lambs weaned was 26,200 kg and 24,300 kg for the accelerated and conventional systems respectively. The labour input in the accelerated system was 35% higher (13% higher per lamb weaned). The accelerated system had a 6% higher energy requirement overall although on a per kilogram of lamb basis the energy requirement was 6% lower (deNicolo 2007).

Table 49 shows the annual energy requirement for a 60kg ewe in either a conventional or accelerated breeding program (5892 and 6272 MJME respectively). It also shows predicted energy requirements for various scenarios of improved outcome in an accelerated system (5 kiddings in 3 years) (deNicolo 2007).

Table 49: The annual energy requirement (MJME) for a 60kg ewe in conventional or accelerated breeding program



	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

Source: (deNicolo 2007)

In summary, in comparison to a conventional program the accelerated system resulted in:

- Higher average breeding and pre-lambing ewe live weights;
- Lower average pregnancy rate, due to the lower pregnancy rate out of season;
- More lambs born and weaned per ewe;
- Lower average lamb birth weight;
- More lambs weaned per ewe;
- Similar average lamb mortality rates;
- Lower weaning weights (but weaning occurred 10-36 days earlier than in the conventional system); and
- Increased production costs (labour, feed, hormone treatment) (deNicolo 2007).

A description of the animal health and veterinary care implications of the STAR system is provided by Smith (2006) from Cornell. Table 50 provides a summary of this report.

Table 50: Veterinary and animal health advantages and disadvantages of the STAR system

ADVANTAGES	DISADVANTAGES
⌖ The entire lamb flock is not at risk at the same time in the case of: - Disease outbreak - Disaster – natural or accidental - Nutritional deficiency ⌖ Having lambs born over a defined period makes disease management easier	⌖ Ongoing presence of disease-susceptible animals (e.g. orf or contagious ecthyma) can mean persistence year-round – vaccine may be required to manage this issue ⌖ Heavily-populated or frequently-used paddocks can become conducive to worm larvae survival, making it much harder to preserve a 'rested' paddock for young stock ⌖ Identification and administration of appropriate nutrition for multiple births may be delayed, increasing the likelihood of pregnancy toxaemia ⌖ Running poor ewes with lactating ewes might increase the spread of Johne's disease to other does and kids ⌖ It is more difficult to enforce age separation which could facilitate the spread of disease ⌖ Vigilance is required about the removal of rams after a defined joining time or management becomes chaotic

Source: Smith (2006)

7.4.3 ASSISTED REPRODUCTIVE TECHNOLOGIES

Assisted reproductive technologies (ART) have been introduced into small ruminant enterprises to overcome the seasonality of breeding and to assist in genetic gain in these species. ART include *in vivo* and *in vitro* embryo production and artificial insemination.

ARTIFICIAL INSEMINATION

Leboeuf et al 2000 state that artificial insemination (AI) has a particular importance in intensive production systems. It can be advantageous in controlling reproduction and, in conjunction with progeny testing, improve meat production of goats (Leboeuf et al. 2000). Other benefits of AI include:

- Precise kidding time (at particular season, and over a limited time);
- Facilitation of supplementary feeding, to meet the increased requirements of does during lactation;
- More efficient genetic selection and improvement;
- Increasing the number of offspring per sire;
- Vast and rapid diffusion of improved genetics;
- Minimisation of the risk of disease associated with reproduction; and
- In the case of frozen semen, 'spatial and temporal…dissociation between collection of spermatozoa and fertilisation'.

Technically, AI in goats is similar to the process in sheep. The method of insemination is determined by the type of semen being used, that is, fresh or frozen. Fresh semen is preferred when the male is present on the property. The optimal time for collection of fresh semen is during the breeding season when semen production peaks. If a male is shared over a number of properties in a small area then the semen may be refrigerated at four degrees but must be used within 24 hours after collection. Freezing of semen allows longer-term storage and distribution over longer distances but is technically more challenging (Baldassarre and Karatzas 2004).

Acceptable pregnancy rates can be obtained using fresh semen via vaginal (pericervical) or cervical (intracervical) semen deposition. Acceptable pregnancy rates are only achievable from frozen semen, however, via laparoscopic or transcervical insemination, due to the decreased ability of spermatozoa that have been frozen/thawed to transit through the cervix (Cseh et al. 2012). The semen needs to be deposited into the uterine lumen close to the site of fertilisation ((Kershaw et al. 2005), as cited by (Cseh et al. 2012)). Pregnancy rates from cervical insemination using frozen semen in does are higher than for ewes but are still considered unsatisfactory (Cseh et al. 2012).

Intrauterine insemination via the cervix is easier in the doe than in the ewe and fertilisation rates, when using fresh semen, can be similar to those from natural matings in does (Cseh et al. 2012).

Laparoscopic AI ensures that the semen (frozen or fresh) is placed close to the fertilisation site in the uterine horn. This technique requires a smaller insemination dose and results in an increase in fertilisation rate (Gibbons and Cueto 2011). The ideal time for laparoscopic AI in goats using fresh semen is 20-24 hours after oestrus begins ((Vallet and Baril 1990), as cited by (Gibbons and Cueto 2011)). When using frozen semen it is best performed 46 hours after sponge removal ((Fieni et al. 1990), as cited by (Gibbons and Cueto 2011)). For timed laparoscopic AI, the oestrus distribution for the females must be known based on the hormone treatment they have received and the time of the year. Results have been variable using frozen semen, and in one study a 50% fertilisation was achieved (Armstrong and Evans 1984). Using heat detection to time laparoscopic AI is more reliable, achieving fertilisation rates of 80% in ewes (Gibbons and Cueto 2011).

Where there is stimulation of ovulation for embryo transfer programs (see below), the rate of fertilisation from AI is lower than that of non-treated control animals(Moore and Eppleston 1979, Armstrong and Evans 1984) as cited in (Gibbons and Cueto 2011)). In a study involving Alpine and Saanen goats, the fertility rate was 49% when there were more than 15 corpora lutea but 66% when there were fewer than 15 corpora lutea ((Baril et al. 1989), as cited by (Gibbons and Cueto 2011)). Fertilisation rates are not increased by performing more inseminations or increasing the concentration of sperm delivered ((Brebion et al. 1992) as cited by (Gibbons and Cueto 2011)).

Table 51 provides a comparison of the different AI techniques in small ruminants.

Table 51: Comparison of artificial insemination techniques in small ruminants

TECHNIQUE	PREGNANCY RATE	KEY FEATURES
Vaginal (pericervical) insemination	30-50% (fresh semen), 5-15% (frozen semen) (Cseh et al. 2012)	Fast and easy to perform and can be conducted in field conditions Inefficient use of semen and low conception rates with frozen semen or after hormonal control of oestrus Best utilised in the natural breeding season after oestrus detection (12-18 hours after the onset of oestrus); reinsemination is recommended if the doe is still 'standing' 12-24 hours after initial insemination ((Nuti 2007), as cited by (Cseh et al. 2012))
Cervical (transcervical, intracervical) insemination	40-80% with fresh and chilled semen after oestrus control ((Chemineau et al. 1991), as cited by (Cseh et al. 2012)) Up to 60% with frozen semen ((Anel et al. 2005), as cited by (Cseh et al. 2012))	Ideal insemination 55 hours after removal of an intravaginal progesterone insert or 15-17 hours after oestrus is detected; for two inseminations, 50 and 60 hours after prog. removal (Cseh et al. 2012) In a large study of does, the transcervical approach achieved intrauterine insemination in 50-60% of does, intracervical in 30% and deep in vagina in 10% ((Nuti 2007), ss cited by (Cseh et al. 2012))
Transcervical intrauterine insemination	Fresh semen 40-70% (Faigl et al. 2012), (Cseh et al. 2012) Frozen semen 30-70% (Faigl et al. 2012), (Cseh et al. 2012)	Specific techniques developed to deposit semen deep in the uterine horns transcervically, similar to that in the ewe but much easier (e.g. (Sohnrey and Holtz (2005)), as cited by (Faigl et al. 2012)) Optimum time of insemination 49-65 hours after removal of progesterone inserts (Faigl et al. 2012) Experienced technicians could traverse the cervix in 75-85% of ewes (Faigl et al. 2012) Requires special positioning, cervical retraction, stabilisation, use of special equipment (Faigl et al. 2012) Cannot be used in maidens (Faigl et al. 2012) Has been associated with cervical injury, abscesses, infections and poor pregnancy rates (Faigl et al. 2012)

TECHNIQUE	PREGNANCY RATE	KEY FEATURES
Laparoscopic intrauterine insemination	60-80% with frozen semen ((Shipley et al. 2007), as cited by (Cseh et al. 2012))	Smaller amount of sperm required for each insemination, but larger volume of inseminate (this allows for better sperm preservation); one ejaculate can inseminate 50 ewes (Cseh et al. 2012) Experienced teams can inseminate 250-300 ewes in a day (Cseh et al. 2012) Ideal timing in does is 43-46 hours after progesterone insert removal (Cseh et al. 2012) , 48-65 hours (Faigl et al. 2012) Requires specific equipment and technical expertise, and is an invasive procedure (Cseh et al. 2012)

Source: based on (Cseh et al. 2012) and (Faigl et al. 2012)

EMBRYO TRANSFER

The terms ‘embryo transfer’ (ET) and ‘multiple ovulation embryo transfer’ (MOET) are used almost interchangeably in the literature. Indeed, Gibbons et al. (2011) define embryo transfer as ‘a method of assisted reproduction based on producing *multiple* [our italics] embryos in a female donor (genetically superior mother) that are then transferred to various female recipients (gestating mothers)’ (Gibbons and Cueto 2011). ‘MOET’ is used throughout this section to describe a package of technologies most commonly applied in livestock, of which ET is one element.

The main advantages of MOET are:

- Rapid introduction and multiplication of new breeds or desirable traits;
- Increased genetic progress from more intensive selection on the female side and reduced generational interval;
- Reduced risk of disease spread (early developing embryos are protected against many infections);
- Support for other reproductive technologies such as sex determination and cloning; and.
- Breed or species conservation, through the ability to store genetic material (Gibbons and Cueto 2011)

The main drawbacks of MOET are its cost, unpredictable success rates and the invasive nature of surgical collection and transfer of embryos (Baldassarre and Karatzas 2004). These factors have limited its application (Gonzalez-Bulnes et al. 2004, Amiridis and Cseh 2012). The main use of MOET to date has been for the production of superior males for semen donation. MOET is also very important for the international trade of genetic material, in flocks where further genetic gain form AI is now limited and for conserving endangered species and breeds (Gonzalez-Bulnes et al. 2004).

MOET can be achieved by either *in vivo* or *in vitro* methods. Embryos produced by *in vivo* techniques are generally preferred to *in vitro*-produced embryos, as they tend to have better implantation rates, produce bigger litters and have better cryotolerance (Papadopoulos et al. 2002).

MOET requires hormonal treatments of the female:

- Donors, to induce multiple ovulations and oestrus;
- Recipients, to induce ovulation; and
- Both recipients and donors to synchronise oestrus (Gibbons and Cueto 2011).

Recommended MOET programs in goats have generally been similar to those of sheep (Gibbons and Cueto 2011). Donors and recipients are treated with an intravaginal progestagen-impregnated sponge or CIDR for 11-17 days at the same time to synchronise oestrus. PMSG or eCG is administered to both donors and recipients 48 hours before sponge removal (Gibbons and Cueto 2011). To improve the fertilisation rate, prostaglandin F2 alpha (cloprostenol) is can also be administered at the same time as the PMSG ((Corteel et al. 1988), as cited by (Gibbons and Cueto 2011)).

Factors that affect the success of multi-ovulatory techniques include the individual's folliculogenesis potential, breed, season and nutritional status. A proportion of females will not respond to multiple ovulation treatments (Gibbons and Cueto 2011). More prolific breeds tend to respond better to multiple ovulation treatments ((Baril et al. 2007), as cited by (Gibbons and Cueto 2011)). The response in number of ovulations is generally higher when females are treated during the breeding season ((Torrès et al. 1984), as cited by (Gibbons and Cueto 2011)). Others however have found in sheep that ovulation rates were similar in the breeding and non-breeding seasons, although fertilisation and the number of recovered embryos was higher in the breeding season (Gibbons and Cueto 2011).

A South African study in Boer goats found that the season impacted on the onset and duration of the induced oestrus period following superovulation. However, the ovulation rate, and total number of embryos and the total number of transferrable embryos was similar in both the breeding and non-breeding season and justified the superovulation (Lehloenya et al. 2008).

As seen with natural reproduction, nutrition is vital in determining how a female responds to multiple ovulation treatment. Poor nutrition can also cause premature luteolysis, regardless of the season (breeding or not), resulting in low embryo recovery ((Jabbour et al. 1991), as cited by (Gibbons and Cueto 2011)).

A study of superovulation techniques in Boer goats in China found that the best season to perform superovulation and embryo transfer autumn. Animals aged between 12 and 35 months gave the best results. The number of ovulations and transferrable embryos was much the same for the first and second treatment although this was reduced for the third superovulation treatment (Chang et al. 2006).

A drawback of MOET is the sometimes-poor fertilisation rates of superovulated females. This is further described above.

Embryo recovery involves flushing the uterine horns with a liquid medium based on phosphate buffer solution with 10% inactivated goat serum. The optimum time for embryo collection is based on the embryo being positioned in the upper third of the uterine horn, showing a zona pellucida (which acts as a sanitary barrier) and being in the compacted morula or blastocyst stage of development. In goats, this means embryos are recovered 8-9 days after the sponges are removed. Both surgical and non-surgical techniques can be used to recover the embryos (Gibbons and Cueto 2011).

Table 52 compares embryo collection techniques in terms of the process involved and embryo recovery rates.

Table 52: Comparison of embryo collection techniques

TIME FOR PROCEDURE	PROCESS	EMBRYO RECOVERY RATE	COMMENT
Surgical (adapted from (Gibbons and Cueto 2011))			
15-20 mins per animal	General anaesthesia Laparotomy Check of ovulatory response (inspection of ovaries) Insertion of catheter though puncture at utero-tubal junction Second puncture on each uterine horn to flush Flushing using phosphate buffer solution (PBS) with 10% inactivated goat serum Closure of punctures Identification of embryos	Average 60-70% (cited 66% from 1st procedure, 41% from 2nd, 35% from 3rd)	Adhesions reduce subsequent embryo recoveries
Non-surgical (laparoscopy) (adapted from (Gibbons and Cueto 2011))			
20-30 minutes per animal	General anaesthesia Three punctures in abdominal wall Input PBS Output PBS Insufflation of balloon	Average 60% (cited 59%, 58%, 68%) (Vallet et al. 1987)	Requires a skilled operator and expensive equipment Clots and mucus can make procedure difficult No decrease in embryo recovery over subsequent operations
Nonsurgical embryo transfer (transcervical) (Fonseca et al. 2016)			
30-40 minutes per animal	Sedation with epidural and local cervical anaesthesia Specially developed catheter is inserted through the cervix into the desired uterine horn Flushing of each uterine horn and	Not measured	Animal can remain standing No requirements to withhold water and food Allows for successive embryo recovery in goats Fewer health risk and sequels Main difficulties are passing the catheter through the cervix and the inability to manipulate the

TIME FOR PROCEDURE	PROCESS	EMBRYO RECOVERY RATE	COMMENT
	collection of fluid and embryos		reproductive tract rectally (Fonseca et al. 2016).

Sources: adapted from (Gibbons and Cueto 2011) and (Fonseca et al. 2016)

It is likely that non-surgical recovery will become the technique of choice in commercial production systems as it has fewer negative impacts on the wellbeing of the animal during the procedure and as a consequence of the procedure. It has also been proposed that, as retrieving embryos by non-surgical uterine flushing uses a larger amount of fluid compared to surgical techniques, this may result in the dilution of any caprine arthritis-encephalitis virus present. No positive samples have been identified to date using this technique, while virus has been from recovered from the surgical technique (Fonseca et al. 2016).

Recovered embryos are assessed on morphological aspects under a microscope. They are checked to ensure:

- Stage of embryo development matching that which has been predicted based on the collection date;
- Integrity of the zona pellucida;
- Sphericity; and
- Clearness of cells (opacity suggests degeneration) (Gibbons and Cueto 2011).

The survival rate for embryos ranged between 75.6% for grade I to 37.5% for grade 4 embryos in Scottish black-face ewes ((Bari et al. 2003) as cited by (Gibbons and Cueto 2011)).

ET itself must occur within two hours of collection or, in the case of frozen embryos, within 20-30 minutes of thawing. ET can involve surgical or non-surgical laparoscopy ((González et al. 1991) as cited by (Gibbons and Cueto 2011)). The embryo is placed in the uterine horn on the same side as the corpus luteum on the recipient's ovary (Gibbons and Cueto 2011).

Optimal synchronisation of oestrus between the donor and recipient improves the efficiency of ET (Rowson and Moor 1966). The number of corpora lutea in the recipient influences the survivability of embryos. In one study the embryo survivability increased from 52, 63 to 75% where 1, 2 or 3 corpora lutea were present ((Armstrong and Evans 1983), as cited by (Gibbons and Cueto 2011)).

Contrary to earlier views that cervical ET is difficult and rarely used ((Flores-Foxworth et al. 1992), as cited by (Gibbons and Cueto 2011)), it is being more commonly used now and has been shown to be effective (Fonseca et al. 2014). A study of non-surgical ET involving small numbers of goats found the cervical technique to be effective with a 50% parturition rate. The authors recommended that further studies into the feasibility of non-surgical ET on a large-scale commercial production scale be conducted (Fonseca et al. 2014) .

The non-surgical cervical route for ET is quicker to perform, and as the procedure does not require general anaesthesia and is less invasive it is safer for the animal. The animal's reaction to the procedure was similar to that seen with AI. Animals did not show behavioural signs suggestive of pain, and there was neither postural discomfort nor vocalisation (Fonseca et al. 2014).

IN VITRO FERTILISATION FOR EMBRYO TRANSFER, INCLUDING PRODUCTION FROM JUVENILES

In vitro embryo production is a lower cost option (Amiridis et al. 2012). *In vitro production* is used where oocytes have been harvested laparoscopically from live donors, or from post-mortem from slaughtered females. The process consists of:

- Collection of oocytes and *in vitro* maturation;
- *In vitro* fertilisation; and
- *In vitro* culture of embryos ((Wani 2002), as cited by (Alexander et al. 2010)).

Embryos are then either transferred into recipients or frozen (Amiridis and Cseh 2012).

To reduce the generation interval and fast-track genetic progress, oocytes can be collected from prepubertal kids or lambs, fertilised *in vitro* and transferred to recipient females, a process known as juvenile in vitro embryo technology / transfer (JIVET). The application of JIVET can result in progeny of prepubertal goats being born at about the same time as the donor animal reaches the stage of development when breeding would normally commence (Baldassarre and Karatzas 2004).

The ovarian follicles of prepubertal animals respond very well to stimulation by gonadotropins. Baldassarre et al. 2004 report that nearly twice as many oocytes can be harvested from prepubertal goats as from adult goats per session. Various methods for ovarian stimulation have been described (Amiridis and Cseh 2012). Baldassarre et al. 2004 advocates a ‘Oneshot’ regime comprising a combination of FSH and eCG given as a single treatment 36 hours prior to harvest. Other regimes involve multiple FSH treatments (Amiridis and Cseh 2012).

There is a critical age, 3-4 months, at which the number of available follicles and the developmental competence of oocytes diminishes (Amiridis and Cseh 2012). However, this situation can be reversed if oocyte collection is first performed before this time ((Valasi et al. 2007), as cited by (Amiridis and Cseh 2012)).

Ova are harvested through techniques such as laparoscopic ovum pick-up (LOPU). The LOPU procedure involves donor goats receiving a general anaesthetic before follicles are aspirated under laparoscopic observation. The procedure on one goat can be completed in 10-20 mins by an experienced operator, allowing the recovery of over 100 oocytes in a 2-3 hour session (Baldassarre and Karatzas 2004). Ova are matured and fertilised *in vitro*, as described above.

The techniques for collection of oocytes from prepubertal lambs are considered safe, with no impact on the onset of puberty, future fertility, growth or endocrine profiles of the donor ((Valasi et al. 2009), as cited by (Amiridis and Cseh 2012)).

SEMEN SEXING TECHNOLOGIES

Recent technologies in cattle have allowed the separation of semen into spermatozoa carrying an X-chromosome and those carrying a Y-chromosome. In theory this mean the sex of the offspring can be chosen (Alexander et al. 2010). It has been reported that bovine semen can be separated with 90% accuracy and that a 50% pregnancy rate has been achieved using this sex-sorted semen (compared to 60-80% with unsexed semen). The offspring born had 90% likelihood of being the chosen sex (Garner and Seidel Jr 2003).

SOMATIC CELL NUCLEAR TRANSFER (CLONING)

At present cloning is carried out for biomedical and research purposes. This technology raises the possibility of producing an unlimited number of genetic copies of an adult or foetus. So far the technology has been used to clone farm, pet and endangered animals ((Vajta and Gjerris 2006), as cited by (Alexander et al. 2010)).

The practical use of transgenic/somatic cell nuclear transfer techniques has not been reported in goats. It is envisaged that these technologies may assist in improving valuable traits in goats such as milk, meat and fibre production. The current cost and technical difficulties associated with these procedures are likely to limit their implementation in the short term (Baldassarre and Karatzas 2004).

7.5 OTHER CONSIDERATIONS

7.5.1 ANIMAL WELFARE

Roger (2012) has written a paper on ‘Welfare issues in the reproductive management of small ruminants’. Reproductive management of small ruminants can cause modification of natural behaviour and this can create welfare issues (Roger 2012). Those impacts can be divided into three areas:

- Direct impact of management strategies on natural behaviour through restriction;
- Direct impact of management strategies through modification of natural behaviours; and
- Commercial or breeding outputs desired by the herd or flock owner (Roger 2012).

It is important to consider the normal basic behavioural patterns of livestock when developing a breeding management plan.

In the Farm Animal Welfare Council’s (UK) report on the welfare implications of animal breeding and breeding technologies in commercial agriculture, one of its eight recommendations is that new and existing breeding technologies are evaluated including any welfare and ethical issues that might occur as a result of that program (FAWC 2004). The impact on welfare through breeding programs needs to be considered as part of the whole environment, as quality of management is vital to ensuring good animal welfare (Roger 2012). A combination of selection for animals with improved production potential and improved management together can manage the welfare risk while improving production outcomes. The providers of livestock care need to be appropriately skilled (Roger 2012). While selection of a breed may be made to meet commercial demand for certain carcase characteristics, the ability of the animals to adapt to the environment must also be paramount. Welfare issues may arise for animals that are poorly suited to certain environmental conditions (Roger 2012). It is suggested that a livestock industry needs to make choices that meet ‘acceptable standards in terms of responsibility and cost sharing and in maintaining a sustainable future’ (Roger 2012). Over time the ability of an animal to ‘adapt’ may be compromised to an unacceptable degree by breeding techniques (Roger 2012). The risks of poor welfare outcomes through breeding management practices include an increased risk of diseases, either directly through potentially aversive techniques or through behavioural limitations associated with the breeding program. The management of nutritional plane removes the animal’s ability to be self-regulate. Finally, more intensive management through the breeding cycle, especially close to joining, can impact animals negatively (Roger 2012).

Roger (2012) suggests that a problem with the development of new technologies is that many are developed from commercial sources. As such, they can become well established in the livestock industries before there has been a proper evaluation of the likely implications on welfare of the animals (Roger 2012). The ‘ovum pickup’ techniques, involving both hormone treatment and laparoscopy under general anaesthesia of doe-kids at about 6-8 weeks of age (see section 7.4.3), have been highlighted as a particular area of concern ((MAFF 1995), as cited by (Roger 2012)).

In addition, while licensed research facilities are inspected regularly by appropriate authorities there is not the same scrutiny of on-farm activities. One of the ongoing challenges is the difficulty in quantifying welfare impacts within the livestock industries (Roger 2012).

Some have suggested that welfare of an animal reflects its ability to cope with its environment ((Broom 1996), as cited by (Roger 2012)) while (Webster 2011) includes an emotional qualitative assessment as a vital part of estimation of the welfare state of animals. It is suggested by others that emotional and legal indicators need to be included with quantitative measurements of pathological, behavioural, physiological and biochemical states to provide a reasonable assessment of welfare ((Roger 2008) as cited by (Roger 2012)).

Table 53 is an assessment by (Webster 2011) of three UK husbandry systems against the ‘five freedoms’ of animal welfare. It provides an example of how farming systems can be assessed in terms of animal welfare.

Table 53: ‘Five freedoms’ assessment of three husbandry systems

FACTOR	HOUSED PRODUCTION SYSTEM	IN-BYE* PRODUCTION SYSTEM	EXTENSIVE PRODUCTION SYSTEM
Hunger and thirst	Adequate	Variable but controlled	Variable
Comfort	Good	Variable – management important	Variable choice available
Disease and pain	Low risk biosecurity and hygiene	Low risk	Risk increased – delayed detection
Stress	Boredom; interactions necessary	More interest	Interest, but exposed to increased risks
Fear	Low, provided empathetic stockpersons	Low	Low, but gathering likely to be very aversive
Natural behaviour	Restricted by pen size and numbers	Controlled	Most natural for most breeds

Source: (Webster 2011), reproduced in (Roger 2012). *=means carried out near the farm buildings

7.5.2 ‘CLEAN, GREEN AND ETHICAL’

Martin and Croker (2006) in Western Australia have developed a ‘clean-green-ethical management package’ for reproduction in Merino sheep. The approach does not use chemical manipulation but is based on reproductive biology. It is proposed that by using this model, production can be improved using cost-effective science while improving the image of the industry (Martin and Croker 2006). In addition, techniques should ensure that the welfare of the animals is not compromised.

There are three strategies for improving reproductive efficiency in small ruminants according to the principles of 'clean, green and ethical' animal production:

1. Use of the 'male effect' to induce synchronised ovulation in females;
2. Targeted nutritional supplementation at various strategic points in the reproductive cycle to optimise reproductive success; and
3. Optimising offspring survival, using genetic selection for temperament, nutrition and improved management (Martin et al. 2004a)

Australian goat production occurs predominantly in extensive systems, which are much harder to manipulate than more intensive systems. More extensive production systems are preferred to intensive systems from the perspective of the 'clean, green and ethical' movement (Martin et al. 2004a)

7.5.3 CONSUMER CONCERNS

There is growing concern of the use of hormones in meat production systems. Particular concerns include the consumption of small amounts of residual hormones or their metabolites and how these may impact on endogenous hormone production, especially in those who are prepubescent. Other considerations include the impact on '*enterohepatic inactivation, cellular receptor-and non-receptor-mediated effects and potential for interference with growth, development and physiological function in consumers'* (Galbraith 2002).

8. SUMMARY

In summary, the literature review identified the following:

8.1 FOUNDATIONAL REPRODUCTIVE MANAGEMENT PRACTICES

8.1.1 HEALTH AND WELFARE

PREVENTATIVE MEASURE FOR ANIMAL HEALTH

- In does, beyond 6 years of age, there is a reduction in birth weight and weaning weight of kids
- Lambs born as multiples to ewes with udder lesions tend not to grow as well

MANAGING STRESS

- The literature has extensive information about the potential for stress to impact on production. Most of the research has been reported in sheep. Some of the negative outcomes of stress include:
  - Interference with follicular development and ovulation;
  - Reduced sexual behaviour;
  - Reduced daily weight gains;

  - Shorter lactation;
  - Altered hormone production;
  - Reduced embryo survival;
  - Reduced embryo quality;
  - Delayed onset of oestrous;
  - Reduced foetal growth;
  - Ovulation occurring without oestrus; and
  - Longer oestrus.
- Research on cattle has shown that calmer cows have shorter calving intervals, faster milking speeds and increased fat and protein yields in milk

PREPARING FOR EXTREME WEATHER EVENTS AND OTHER UNFORESEEN DISASTERS

- McGregor (2005) ‘Nutrition and management of goats in drought’

8.1.2 NUTRITION, BODY WEIGHT AND BODY CONDITION SCORE

NUTRITION

- Comprehensive reviews are found in Jolly (2013) and McGregor (2005) (drought)
- Most extension material from across the world quotes NRC (1981 or 2007) data, which is not based on Australian breeds and is mostly from experimental situations and small number of animals
- The impact of inadequate nutrition on reproductive outcomes in goats and sheep is well documented in the scientific literature and includes:
  - Reduced stress response in offspring:
  - Reduced production of progesterone and increased embryonic mortality in first-pregnancy ewes;
  - Slower onset of oestrus after synchronisation;
  - Reduced ovulation and pregnancy;
  - Higher embryonic mortality;
  - Delayed puberty;
  - Induced anoestrus;
  - Effects on the metabolic and physiological health of the adult and offspring;
  - Decrease in milk yield;
  - Reduced birth weight;
  - Reduced growth rate of kids;
  - Decreased perinatal lamb survival;
  - Permanent changes to the wool follicle population of lambs;
  - Decreased quality and quantity of sperm production;
  - Negative impact on embryonic development; and

  - Insufficient energy in colostrum to support twin lambs.
- Maintenance data in the literature varies considerably and is mostly derived from experimental situations:
  - Average of 22 sources estimates that maintenance for goats is 404.7 kJ ME/kg$^{0.75}$
  - From 140 days' gestation and through lactation does should be fed 2.5 times maintenance
- Some goats may be able to alter their energy requirements by 65% in times of poor pasture availability
- Response to increased nutrition differs between breeds
- More concentrated supplementary fed is recommended for heavily pregnant does
- In sheep, overfeeding after joining can affect embryo survival
- In sheep, poor nutrition of the ewe during pregnancy can affect lamb birth weight, wool follicle production, wool production, growth, carcase quality, reproductive potential
- Improved condition in sheep increases ovulation and reduces embryo mortality
- Improved nutrition in goats has led to longer breeding season (Payoga goats), increase in milk yield, birth weight, growth rate of kids (hairy goats)
- Overfeeding in ewes can cause dystocia
- In ewes, the foetal, placental weight and vascular development increases exponentially from 50-60 days gestation
- In Angora goats, maidens raised on better nutrition had greater joining weight, number of kids weaned (South Africa)

CONDITION SCORING

- Kenyon et al 2014 provide a guide to key condition scores during the reproductive cycle in sheep:
  - Biggest gain is by ensuring all animal are above a target minimum
  - Relying on average BCS of flock means many will be below the minimum
- Gosh et al 2019 provide recommended BCS for various physiological states (the scientific background for the recommendations is unclear but BCS were similar to or slightly higher to those described in sheep)
- In sheep, higher BCS has been associated with increased length of breeding season, ovulation rate, pregnancy rate, embryo survival, lamb survival and lamb growth (but there is a curvilinear relationship between BCS and conception rate, and number of lambs born)
- Ewes in low BCS tend to have a better response to increased nutrition than those in higher BCS

BODY WEIGHT

- As ewe weight increases there is a reduction in lamb deaths and an increase in lamb growth rate
- Larger does tended to have kids that were heavier at 10, 20, 30 weeks (Mebende goats, Uganda)

8.1.3 MANAGEMENT OF JOINING, KIDDING AND WEANING

MILK PRODUCTION

- Improved nutrition in early lactation improved milk production in feral and Boer goats (by 11.5%)

- Cashmere does fed more in the last month of pregnancy had heavier kids at birth and they remained heavier through the testing period until 10 months of age
- In Boer goats, milk production increased with age, parity (until 5th lactation) of the doe and litter size
- The lactating ability of a doe is determined by its breed, nutritional status and a variety of other factors. Young Boer goats tend to respond (in terms of lactation) better to an increase in litter size than older goats

BIRTH TO WEANING

- In Nashville, Kiko had better birth to weaning performance than Boer and Spanish

WEANING

- Timing that is best for kids
    - Weaning may be based on age or weight
    - By weight
        - Weaning by weight produces less weaning shock in kids
        - Weaning weight may be considered 2.5 times that at birth
        - When dairy kids were weaned at 10kg (normal weight) or 30 days later, the later group grew quicker and reached the breeding age (60% of adult weight) one month earlier. But in both systems, they were ready to join by 8-9 months
    - By age
        - Under Australian Industry Standards and Guidelines for Goats, weaning should occur no earlier than 8 weeks
        - Dairy kids weaned at 4-6 weeks suffered more weaning shock than those weaned at 8-10 weeks
        - Goats that are weaned at 8-10 weeks tend to have a better growth rate at 16 weeks than those that are weaned earlier
    - Preparation for weaning success
        - Rumen development is vital to successful weaning and growth post-weaning. Feeding concentrates (in lambs and calves) stimulates development
        - Boer-cross kids receiving creep (with or without roughage) had better ruminal development
    - In Kentucky, kids born in autumn and spring had the same survival rates but the autumn-born kids grew quicker
- Timing that is best for the doe
    - Time of weaning should allow the doe time to recover and regain condition before the next joining season
    - Failure to wean kids can delay the return to oestrus for the doe and lead to a significant loss of body condition
- Failure to wean entire buck kids will result in:
    - Inbreeding (bucks servicing mothers and sisters)

- Joining of doe kids before they reach a suitable body weight (generally regarded as 70% of adult weight)

WEANER CARE

- In weaner goats (French Alpine), those fed high and medium amounts of concentrate, had higher average daily gain and prolificacy than those on low concentrate diet, but there was no impact on lactation
- In weaner Boer goats, there was no difference in daily gain between those on high and low ME diets

JOINING

- Suitable body weight for first joining is generally regarded as 70% of adult weight
- Joining doe kids before they are of an appropriate weight can impact on their lifetime productivity, might result in an unsuccessful pregnancy or difficulties due to size at kidding time (dystocia) and a compromise in health and welfare

MEASURING AND RECORDING

- Reporting and recording are mostly described in the literature in regard to genetic improvement by selection from within the herd
- Careful measurement allows the identification of subtle changes in reproductive performance due, for example, to the presence of a subclinical disease in the does or bucks
- Measurement and recording are essential to genetic selection programs. The unique identification of individuals is also required. Electronic ear tags are being used by some to improve their recording and for the use of automated drafting facilities

8.2 TOOLS TO IMPROVE REPRODUCTIVE PERFORMANCE

8.2.1 GENETICS

- KIDPLAN has three EBVs concerned directly with fertility:
    - Number of kids born (NKB);
    - Number of kids weaned (NKW); and
    - Scrotal circumference (yearling and hogget measurements)
- Producers are also selecting for positive traits (and against negative traits) within their own herds, for example in parasite resistance, growth rates, muscling for meat and mothering
- Reproductive traits generally have low heritability (in sheep, ovulation rate (0.15), litter size (0.13) and lambs weaned (0.05))
- Recording of reproductive EBV data is less common than for carcase and growth traits
- Aldridge (2017) recommends kid survival should be included among EBVs
- Genetics is important in optimising accelerated breeding programs (seasonality, ovulation rate)
- In sheep, selecting for lamb fertility might negatively impact growth
- Selection can improve out-of-season breeding and length of breeding season

- Crossbreeding can be used to increase litter size (must also monitor weaning rate)
- Crossbreeding with Boer goats has also been used extensively in Australia to improve the productivity of rangeland goats, improving cycling and ovulation earlier in the breeding season, prolificacy, litter size and growth rate at weaning
- However, rangeland goats have a greater flight zone and are less calm than Boers
- Calmer ewes have been shown to have lower mortality in their lambs and the same is probably true for does
- As with any intervention to improve reproductive performance, genetic approaches need to be applied carefully, requiring observation, monitoring and recording to detect the emergence of any negative changes

8.2.2 HORMONE INTERVENTION

- In sheep, progesterone-impregnated sponges and controlled internal drug release (CIDR) devices produced similar results
- In sheep, progesterone-impregnated CIDR plus ram effect brought forward oestrous
- Boer goats have been synchronised with progesterone CIDR, prostaglandin and equine chorionic gonadotropin (eCG)
- Common hormone manipulation of oestrous involves progesterone by CIDR or sponge
- Prostaglandin causes luteolysis and induces ovulation, and is only really useful within the breeding season
- Two doses of prostaglandin are needed to ensure most animals respond
- In ewes, 2 doses of prostaglandin less effective than progesterone
- Melatonin with progesterone and eCG increased conception rate in ewes in NZ
- Melatonin with the buck effect was more effective than the buck effect alone at advancing kidding and improving fertility and prolificacy
- Inducing ewes to breed can have four outcomes:
  - Ovulate and conceive
  - Ovulate but not display oestrous
  - Display oestrous and mate but neither ovulate nor produce a corpus luteum (CL), which is rare
  - Display oestrous, ovulate but fail to conceive (most common)
- Hormones are costly and require skill in handling and use to ensure the welfare of the animals and human health is maintained
- The cost is unlikely to be justifiable in a commercial goat meat enterprise, except perhaps in a program to build up numbers of genetically superior animals for breeding stock

8.2.3 LIGHT THERAPY

- In goats, photoperiod manipulation can allow out-of-season breeding in temperate and sub-temperate regions by initiating sexual activity in does and bucks

- It is not effective at synchronising goats
- Light (with progesterone or progesterone and eCG) did not increase reproductive performance in ewes in NZ

8.2.4 TARGETED NUTRITIONAL FLUSHING

- In studies in sheep and goats targeted supplementary nutrition has been shown to:
  - Improve sperm production;
  - Increase ovulation rate;
  - Improve colostrum production; and/or
  - Improve kid survival
- Producers can positively impact fertility, birth weight and colostrum production by providing targeted supplementation at specific points in the reproductive cycle, for example before mating, in the last six weeks of pregnancy or in the last week before kidding
- Other studies have shown that feeding late pregnant ewes or does additional concentrate, even where the diet is already adequate, will improve colostrum production
- Improved colostrum production has been associated with better lamb / kid survival and a better ewe-lamb bond. This nutritional supplementation may only need to be provided for a week and will therefore not alter significantly the weight of the lamb / kid such that the risk of dystocia is increased
- In addition, supplementation is better provided as a concentrate in late-pregnant ruminants (especially those bearing large litters) because of the reduced abdominal space for the rumen to expand
- Ewes fed lupins, maize or barley in last week of pregnancy produce more colostrum
- In sheep, increased nutrition during last few days of oestrous cycle may increase ovulation rate and litter size
- Flushing, providing additional feed to does from 30 days prior to 30 days after joining, may improve fertility, pregnancy rates and lad to a higher number of multiple births
- Nutritional manipulation to optimise reproductive outcomes is clean, green and ethical

8.2.5 THE BUCK EFFECT

- The buck effect requires separation from does from one month at a distance no less than one kilometre
- It can induce puberty, synchronise females, stimulate cycling – in ewes, the first cycle can be advanced by 2 weeks
- It is regarded as ‘clean green and ethical’
- In sheep, the response varies between breeds, time since last lambing, season, body condition, physiological state
- In goats, the response varies with breed and latitude, and sexual activity cannot be induced during anoestrous period in highly-seasonal goats
- The use of photoperiod manipulation of bucks and does prior to the buck effect improved the response, as did nutritional supplementation of does

- In US, the buck effect can deliver almost year-round cycling and improved oestrous behaviours
- The buck effect can be used for artificial insemination (AI), focused feeding
- Synchronisation using (for example) the buck effect would facilitate shedding as kidding dates can be calculated more accurately
- The buck effect could also be used to optimise the chance of a successful mating period, for example by delaying joining where adverse weather is forecast
- As the buck effect is so powerful in some herds, producers need to be sure to provide a sufficient buck: doe ratio
- A variation of the buck effect is to introduce the buck to a portion of the mob initially and then add further small mobs of does to the main mob every 10-14 days, maximising the number of births that occur every couple of weeks, facilitating the use of limited shedding space and/or spreading the labour of tagging
- The buck effect may not be as useful in extensive rangeland enterprises with very large joining paddocks

8.2.6 PREGNANCY TESTING

- In goats, transabdominal ultrasound can detect pregnancy at 30-35 days, and at 40-70 days to count foetuses
- Accuracy to detect number of foetuses reduces beyond two – for three of more foetuses, scanning is best done at 7 weeks' gestation
- In sheep, scanning is either for wet / dry (to allow removal of dry animals from the flock, and saving in feed costs) or differentiating singles and multiples (through more specific targeted feeding)
- The value of scanning increase when perform during a poor season (feed is limiting)
- The value of scanning for multiples increases with number of foetuses / 100 females
- Cost can be a limit the use of ultrasonography especially for those properties that are geographically isolated. The cost of travel for a suitably qualified technician may be uneconomic unless the herd is large, and there are many does to be scanned
- The impact on the welfare of the female should be considered when choosing a method of pregnancy diagnosis – testing that involves tipping the animal over and/or insertion of a probe is more likely to cause distress than procedures that can be completed with the animal standing and the probe placed on the external skin surface
- Ultrasound pregnancy diagnosis is 'clean green and ethical', non-hormonal and non-invasive

8.2.7 REDUCING KID MORTALITY

- Lamb survival was increased in crossbred (10%) and merino (12%) ewes when shelter was provided
- Adequate colostrum distends the lamb's gut and increases the ewe-lamb bond
- The size of the mob at lambing can affect lamb survival (e.g. <200 – 93.3%, >200 – 79.8%)
- In cashmere goats, does that were supplemented had reduced kid mortality up to 16 days of age
- In ewes in NZ, the was a notable rise in lamb mortality for those less than 3kg and more than 9kgs, while lambs born less than 1.5kg did not survive

8.3 ADVANCED BREEDING PROGRAMS

8.3.1 ACCELERATED BREEDING

- The vast majority of the research into accelerated breeding programs has been conducted in sheep, the most relevant being De Nicola's 2007 PhD on 'Accelerated lambing and out-of-season lamb production in New Zealand'
- Most of the studies do not include a control/annual breeding group, nor did they continue through the whole of the animals' reproductive lives, so the longer-term success and sustainability of the systems have not been well assessed
- The diversity of goat enterprises, in geography and management styles, makes it a challenge to devise a 'one size fits all' approach to accelerated breeding – for example, high temperatures can reduce sexual activity, slow foetal growth, reduce appetite, reduce milk production and increase stress
- Joining during lactation will provide some challenges with a decrease in pregnancy and kidding rates and an increase in prenatal wastage
- In sheep in one study, in comparison to a conventional program, the accelerated system resulted in:
  - Higher average breeding and pre-lambing ewe live weights;
  - Lower average pregnancy rate, due to the lower pregnancy rate out-of-season;
  - More lambs born and weaned per ewe;
  - Lower average lamb birth weights;
  - Similar average lamb mortality rates;
  - Lower weaning weights (but weaning occurred 10-36 days earlier than in the conventional system); and
  - Increased production costs (labour, feed, hormone treatment)
- Advantages of the accelerated system are:
  - Having a supply of marketable animals at different times of the year;
  - Achieving a premium price for stock market outside the 'typical' breeding system;
  - Some constancy of nutritional requirements throughout the year, with less dramatic variation in demand compared with a single-kidding system;
  - Reduced vulnerability of the herd to disease outbreaks or severe weather events (not all offspring are born at the same time);
  - More consistent use of staff and infrastructure throughout the year;
  - Potential for improved total production of goat meat annually; and
  - Potential for increased profit
- Disadvantages are:
  - Ongoing presence of disease-susceptible animals (e.g. orf) can mean disease persistence year-round – vaccination may be required to manage this issue;
  - Heavily-populated or frequently-used paddocks can become conducive to worm larvae survival, making it much harder to preserve a 'rested' paddock for young stock;

  - Identification and administration of appropriate nutrition for multiple births may be delayed, increasing the likelihood of pregnancy toxaemia;
  - Running poor ewes with lactating ewes might increase the spread of Johne's disease to other does and kids;
  - It is more difficult to enforce age separation which could facilitate the spread of disease;
  - Vigilance is required about the removal of rams after a defined joining time or management becomes chaotic; and
  - Kidding at different times of the year is a compromise
- Accelerated lambing systems require supplementary feeding, changes to the herd structure and stocking rate and other adjustments. Failure to manage nutrition properly increases the risk of metabolic diseases such as pregnancy toxaemia, especially in does bearing multiples, and poor condition in other classes of stock
- Main challenges are:
  - Overcoming seasonality, possibly requiring hormonal intervention to achieve out of season breeding;
  - Increased time spent in management (especially in extensive grazing systems);
  - Cannot match kidding to pasture curve, requiring constant attention to nutritional requirements, increased cost of supplementation; and
  - Cannot allow worm, health issues to limit production at all
- For an accelerated breeding program to be a success a number of important herd management and environmental factors need to be in place, namely:
  - Early weaning;
  - Ability of does to breed in all seasons and/or to breed while lactating, or shortly after lactation;
  - Sustained high-quality nutrition at all times of the year (which requires good productive land and/or irrigation);
  - A high level of management skill;
  - Rigorous monitoring of the body condition of does;
  - Optimal doe and buck health;
  - Protection / shedding for kids that will sometimes be born when the weather is adverse; and
  - Advanced doe health prevention and response programs.

Two kiddings per year

- There are only a few research articles on twice-a-year production systems and they were all on sheep and mostly from the 1960-70's
- There was no literature investigating and describing the impacts on the lifetime productivity of the does or ewes and profitability in the longer term
- Twice-a-year lambing in Awassi sheep (Turkey) showed 60% reduction in pregnancy rate in second joining
- 2-in-1 system in sheep in Canada produced 3.54 lambs per ewe per year

- In a 2-in-1 system in sheep in Finland, there was no decline in reproductive performance over the trial (4 years), 21.9% ewe wastage annually
- In a 2-in-1 system in sheep, 36% of lambs born were from ewes that lambed in the previous cycle ('bonus' lambs)

Three kiddings in two years

- There have been various studies in sheep and only very few purely goat-focused studies on 3-in-2 two breeding
- The main challenge was getting the does and ewes to cycle in the non-breeding season
- Most studies showed an increase in production with accelerated breeding, but again the majority of the studies were short and did not allow evaluation of long-term outcomes
- Those studies that included nutritional information found in sheep that energy requirements were more consistent across the year and that the overall increase in energy requirement for the doe was 11%, equating to an increase in efficiency of 17-47%
- Another study found that by extending the time from lambing for the first and second-lamb ewes from 75 to 90 days improved the lambing rate, number of lambs per ewe, litter weight at birth and the condition of ewes at mating
- Summary of research trials:
    - Crossbred ewes in Australia ; 41% more lambings than annual system;
    - Merino Rambouillet ewes, in Mexico 3-in-2, increase in production at birth 37% and weaning 28%;
    - Kivircik ewes in Pakistan, increase in production at birth 15% and weaning 19%;
    - Beetal goats, Pakistan, more kids per doe in 3-in-2 than annual; and
    - Crossbred ewes in Australia, over 1/3 more lambs born in 8-monthly joining than February joining alone. There was variation in performance between breeds.
- Economic analysis estimated return per ewe over the 7 years of the study was $755 compared to $357 (annual spring lambing) or $517 (annual winter lambing) in Canada

STAR/CAMAL/5 kiddings in 3 years

- STAR system (studied in NZ over 3 years)
    - 35% more labour input (13% higher per lamb weaned),
    - 6% higher energy requirement (because of the increase in lamb production, although on a per kilo of lamb basis the energy requirements is 6% lower)
    - Total weight of lambs weaned was 26,200 kg and 24,300 kg for the accelerated and conventional systems respectively
- Summary of research trials
    - CAMAL system in Awassi ewes in Turkey, with hormone stimulation had no increase in lambs born overall
    - Morlam ewes with continuous ram access compared to Dorset ewe joined every 2 months. 1.28 Morlam lambs and 1.21 lambs for Dorsets born annually

  - Dorset ewes in US under the STAR system averaged 0.98 lambings per year, delivered 1.5 and weaned 1.23 lambs

8.3.2 ASSISTED REPRODUCTIVE TECHNOLOGIES

ARTIFICIAL INSEMINATION

- Fresh semen can be used when all the does to be inseminated are within a short distance from the source, that is, at the same location or on properties within a short travel distance away
- Frozen semen maybe kept for many years, allowing bucks with preferred traits to be used for breeding for a period well beyond their natural life
- Acceptable pregnancy rates are achievable with:
  - Fresh semen, using pericervical or intracervical AI – intrauterine insemination via the cervix with fresh semen gives similar results to natural mating in does
  - Frozen semen, if deposited in the uterine lumen via laparoscopic or transcervical techniques
- Advantages:
  - Control of reproduction and, in conjunction with progeny testing, improvement in meat production of goats;
  - Precise kidding time (at particular season, and over a limited time);
  - Facilitation of supplementary feeding, to meet the increased requirements of does during lactation;
  - More efficient genetic selection and improvement;
  - Increasing the number of offspring per sire;
  - Vast and rapid diffusion of improved genetics;
  - Minimisation of the risk of disease associated with reproduction; and
  - In the case of frozen semen, ‘spatial and temporal…dissociation between collection of spermatozoa and fertilisation’
- Progesterone-impregnated CIDRs or sponges are commonly used to synchronise does. Does are then given a dose of prostaglandin with or without pregnant mare serum gonadotropin (PMSG) at the time of removal of the CIDRs or sponges. One producer advised that PMSG has recently been taken off for use in goats and that alternatives are being trialled. Alternatively, two injections of prostaglandin given 9-10 days apart is effective at synchronising most does
- Bovine semen can be sorted into sexes with 90% accuracy (there are no reports of semen sexing in goats)

EMBRYO TRANSFER

- Embryo transfer (ET) is much more complicated than AI, involving:
  - Oestrus synchronisation of donor and recipient;
  - Fertilisation of donor (natural or artificial insemination);
  - Embryo recovery from donor; and
  - Transfer of embryo into the recipient

- Advantages include:
    - Rapid introduction and multiplication of new breeds or desirable traits;
    - Increased genetic progress from more intensive selection on the female side and reduced generational interval by allowing both younger males and females to breed;
    - Reduced risk of disease spread (early developing embryos are protected against many infections); and
    - Support for other reproductive technologies such as sex determination and cloning
- Disadvantages include:
    - Cost;
    - Requirement for hormone treatment of both donor and recipient; and
    - Processes of collecting and implanting embryos are invasive and technically challenging, requiring expert skills
- Multiple ovulation and embryo transfer (MOET):
    - Involves the use of hormones to stimulate multiple ovulations, increasing the number of offspring that can be produced per female per cycle of treatment
    - Has had unpredictable success, and with its high cost the technique has had limited its use in goats
- *In vitro* fertilisation is lower cost
- Juvenile *in-vitro* embryo transfer (JIVET), using ova from pre-pubertal (3-4 months old) females, can be used to further reduce the generation gap and increase genetic gain
    - Laparoscopic ovum pickup (LOPU) – harvesting oocytes through laparoscopic aspiration of follicles under anaesthetic
    - Requires an experienced operator and general anaesthetic for the donor animal while the laparoscopy is performed, creating the potential for unreasonable compromise to welfare of the animals
    - Has no impact on onset of puberty, future fertility or growth
- Cost of cloning is likely to be prohibitive for use in goat production systems for now

9. CONCLUSION

Over 400 references were cited from reviews and research scientific papers from authors from all over the world.

The main areas of research reviewed included doe management, frequency of kidding, ideal time of first joining and weaning management, to optimise reproductive success of does over their productive lifetime. There is a substantial body of literature on reproduction in sheep and to a lesser extent goats, and very little on deer. While there is some research material on goat breeds found in Australia much of the data has been generated from studies overseas. There are a diverse range of pure, cross and composite breeds of goats across the world and their reproductive performance varies in particular environments. Differences between breeds include seasonality of breeding (sensitivity to photoperiod), frequency of twinning (or more than two kids), , growth rate, susceptibility to worms, response to nutritional enrichment and response to induction of oestrous.

The literature review has provided detail on advanced breeding strategies but did not uncover any novel or contemporary ideas not previously identified by industry. Most of the studies were in sheep and all require intensive management and advanced standards of nutrition programs and, in some cases, the use of hormones to overcome natural breeding limitations. Many were carried out over just a few years and without a control (annual) breeding group. There is a definite lack of long-term studies looking at doe/ewe lifetime productivity in accelerated breeding programs.

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