Alternative methods for control of reproduction in small ruminants: A focus on the needs of grazing industries

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Implications

- Extensive grazing systems need simple, low-cost tools for managing reproduction that improve productivity while nurturing future markets. To develop such tools, we need to understand the biology of the grazing animals in their particular environments.
- Nutrition is the primary challenge because it is limited to grazing, but nutrition also offers opportunities for improving animal health and carbon emissions.
- Nutritional inputs must be coordinated with reproductive events. We use the term “focus feeding” (optimized management of nutrition, a concept that has much in common with “nutrient synchrony”).
- To coordinate nutritional inputs with reproductive events, we can control the timing of reproduction by restriction of male access to females and then add precision with the male effect and, ultimately, ultrasound for pregnancy detection and measurement of potential litter size.
- Maximum neonatal survival is an imperative, so management of the birth site should be a high priority.
- The power of genetics must underpin any management strategy, with breeding goals that take advantage of the strengths of indigenous genotypes and matching their performance to their environment.

Key words: goats, male effect, nutritional management, sheep, ultrasound

Introduction

Recently, Eisler et al. (2014) outlined the important role of grazing ruminant industries in global food production as we strive to cope with projections of population growth, demand for more animal protein in developing nations, and losses in production capacity because of urbanization, biofuel production, climate change, lack of water, and soil degradation. The authors argued against headlines claiming that ruminant industries cause, rather than solve, such problems. They pointed out, for example, that foraging animals can, and should, consume foods that humans cannot and that crop and livestock systems often complement each other. For livestock industries to contribute to the solution of global food supply, several problems need to be addressed, including: i) consumption of human food by livestock; ii) use of livestock species and genotypes that are poorly adapted to the local environment; iii) poor animal health and welfare resulting in suboptimal productivity; iv) inadequate animal nutrition; and v) significant environmental footprint (Eisler et al., 2014).

Reproductive efficiency is obviously an important component of productivity in the milk and meat industries, so given the issues outlined above, we need to optimize reproduction in extensive management systems. Moreover, reproductive efficiency contributes to the environmental footprint of ruminant industries because methane emissions can be addressed by focusing on “emissions intensity”—the amount of methane produced per unit of meat or milk. Reproductive waste is major factor in emissions intensity because females that fail to reproduce are effectively producing only methane. This magnifies the consequences of delayed puberty, low fecundity, delayed postpartum conception, and high postnatal mortality.

At a superficial level, questions about the management of reproduction usually lead to a discussion of modern, “high-tech” reproductive technologies. However, even the simplest high-tech tools (e.g., cycle synchronization and artificial insemination) are relevant only to the intensive livestock industries or to specialist elite breeders (if they exist) in the grazing industries. The frontier technologies, such as embryo manipulation or cloning, are not even on the horizon for almost all managers of extensively grazed ruminants who see it as irrelevant because of economics, physical geography, and practicality. In the long term, the grazing industries should benefit from genetic improvements that flow down to them as a result of advanced technology, but the breeding goals have often not been planned with extensive management in mind, and in any case, the time delay can be measured in decades. In the short to medium term, managers of extensively grazed ruminants need tools that are simple, effective, low cost, and applicable on a large scale (Martin, 2014).

In addition, livestock industries need to plan with an eye on the future markets of their products, as expressed in the concept of “clean, green, and ethical” (CGE) management (review: Martin, 2014). In brief: “clean” means reduced usage, if not elimination, of practices that depend on drugs, chemicals, and exogenous hormones (e.g., for controlling reproduction); “green” means minimal damage to the environment (e.g., reducing methane production); and “ethical” primarily means consideration of animal welfare (e.g., surgical castration). Therefore, the development and implementation of alternative methods for managing reproduction need to take into account predictable changes in markets and in the regulatory environment.
Table 1. The characteristics of the extensive grazing industries for small ruminants in southern Australia and northern Mexico.

<table>
<thead>
<tr>
<th>Production system</th>
<th>Southern Australia</th>
<th>Northern Mexico</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dominant genotype</td>
<td>Merino</td>
<td>Indigenous</td>
</tr>
<tr>
<td>Meat production – local consumption</td>
<td>✓ ✓ ✓</td>
<td>✓ ✓</td>
</tr>
<tr>
<td>Meat production – international export</td>
<td>✓ ✓</td>
<td>x</td>
</tr>
<tr>
<td>Milk production</td>
<td>x</td>
<td>✓ ✓</td>
</tr>
<tr>
<td>Fleece production</td>
<td>✓</td>
<td>x</td>
</tr>
<tr>
<td>Extensive grazing, natural forage</td>
<td>✓</td>
<td>✓ ✓</td>
</tr>
<tr>
<td>Extensive grazing, improved forage</td>
<td>✓ ✓ ✓</td>
<td>x</td>
</tr>
<tr>
<td>Industry problems</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wide seasonal variation in quality/quantity of feed</td>
<td>✓ ✓ ✓</td>
<td>✓ ✓</td>
</tr>
<tr>
<td>Reproductive seasonality</td>
<td>✓</td>
<td>✓ ✓</td>
</tr>
<tr>
<td>Males and females together all the year round</td>
<td>x</td>
<td>✓ ✓</td>
</tr>
<tr>
<td>Technical control of reproduction</td>
<td>Ultrasound only</td>
<td>x</td>
</tr>
<tr>
<td>High neonatal mortality</td>
<td>✓ ✓</td>
<td>✓ ✓</td>
</tr>
<tr>
<td>Animal health problems</td>
<td>GI nematodes‡ Brucellosis GI nematodes‡</td>
<td>CAEV‡</td>
</tr>
<tr>
<td>Pressure from community</td>
<td>Pollution, urbanization, ethics, product health and safety</td>
<td>✓ ✓ ✓</td>
</tr>
</tbody>
</table>

1Resistance to anthelmintic drugs.
2External parasite (flystrike) – prevention dependent on surgery without anaesthesia.
3Caprine arthritis encephalitis virus.

As we shall see, the need for simple, low-cost tools can complement the need for CGE management. In this paper, we will consider this situation from the perspectives of goat herds in the sub-tropical north of Mexico and sheep flocks in the southern regions of Australia. There are obvious similarities in the physical geography of the two regions, an important consideration because the CGE concept depends on understanding and controlling the responses of the animals to their environment (Table 1). On the other hand, the socio–economic environment and human geography differ markedly. This need not be a problem because the scientific basis of the CGE concept is relevant to all socio–economic environments, from large rangeland systems in developed economies to smallholders in developing economies. They all need simple and inexpensive management options and to target consumers with discretionary spending power if they are to get higher prices (Martin, 2014). Therefore, we expect this discussion to be applicable to livestock industries in a wide variety of socio–economic and geographical contexts.

Key Reproductive Problems

As can be deduced from Table 1, insufficient nutrition is the dominant problem for both environments. This is to be expected because it is the major limiting resource in all animal production systems and it exerts strong and specific effects on most events in the reproductive process. Under extensive management, where nearly all feed comes from pasture and other forages, a solution to this problem can be difficult to find because the nutritional requirements of the animals change as the reproductive process progresses and yet need to be coordinated with seasonal changes in the feed supply. The farmers might decide to try to coordinate the period of highest demand (lactation) with the period of maximum pasture supply but might then be frustrated by the seasonal breeding patterns of their animals. As illustrated in Figure 1, the outcome is often a very large quantitative mismatch between the availability of feed, particularly energy, to grazing animals and their physiological requirements for energy (Martin et al., 2008). Moreover, the cost of supplements is often prohibitive, so even if they are feasible, they must be used with maximum efficiency.

CGE Management of Reproduction—A Possible System

Over the years, our research teams have turned to basic knowledge of the reproductive physiology and behavior of our animals, particularly the processes that the animals developed to cope with changes in their environment over the millions of years of evolution before domestication. In reviewing this knowledge base, we searched for ways to manipulate the environmental factors that affect the reproductive axis rather than using hormones, drugs, or complex technology. Given the importance of nutrition in the context of grazing animals, it was no surprise that it became the core management tool (Figure 2). We use the operational term “focus feeding” for optimized management of nutrition, a concept that has much in common with the “nutrient synchrony” described by Hersom (2008) in the context of intensively fed animals.

The framework in Figure 2 is best viewed as an ideal because full implementation of all aspects awaits more research and development, and in some cases, requires major changes in management. Some of the tools require a new level of precision in management, and for others, we would need to convince farmers to abandon “traditional” practices and, instead, adopt practices such as separation of males and females and the early mating of pubertal females. To ensure change of practice, we would need “fourth generation” adoption strategies because the traditional top-down approaches to extension have largely failed livestock industries based on extensive management (for an example, see Sneddon, 2009). Given that it not feasible to expect producers in either country to adopt the whole CGE package in one step, a staged approach with progressive levels of difficulty seems logical (Martin, 2014). For individual managers, the optimum series of stages would depend on the economic, geographical and societal environment.

On the other hand, it is important to note that almost all of the interventions in Figure 2 are simple, “low tech,” and applicable on a large scale. Moreover, some of the tools will be familiar to many farmers because they have been known, perhaps even part of normal practice, for many years. A possible exception is the ultrasound for which the investment in equipment and skills would be beyond most farmers, and a service industry would be required similar to that which has developed rapidly in Australia.

In the next section of this article, we will describe each aspect of the CGE package in relation to the Australian and Mexican systems. As can be seen from Figure 2, an essential goal is the accurate coordination of nutritional inputs with events in the reproductive process because it would ensure that costly supplements are kept to a minimum while appropriate metabolic signals are used to manage the reproductive outcome. At the simplest level, farmers control timing by managing the presence of the male among females and thus the time of fertile mating. More refined options allow more precise control and offer more opportunities to use aspects of male reproductive biology other than gamete supply.
Figure 1. Upper panel: The annual cycle of pasture availability and its relationship with two common alternative reproductive scenarios for sheep in southern Australia. In Scenario 1, late pregnancy and early lactation coincide with maximum energy availability, the normal situation for temperate genotypes that are strict “short-day breeders.” Scenario 2: Milk production begins when energy availability is at its lowest, a situation that reflects the relationship for temperate genotypes trying to reproduce in a “mediterranean region” such as southern Australia. Lower panel: The annual cycle of pasture availability during natural grazing and its relationship with alternative reproductive scenarios for goats in northern Mexico. Scenario 3 is the most common—conception coincides with high food availability, but birth, nursing, and milking occur when food availability is lowest. In addition, in this scenario, bucks and does remain together all year round. In Scenario 4, the time of conception is modified by the male effect so that birth, nursing, and milking coincide with the period of high food availability. Scenario 5 is similar to Scenario 1, with the breeding season starting in September. Modified after Martin et al. (2008) and Sáenz-Escárcega et al. (1991; cited by Delgadillo, 2011).
Restrict the Duration of Births

In extensive production systems in Mexico, it is common for the males to be with the females throughout the year, so there is no control over the timing of mating, births, and lactation. About 70% of pregnancies occur spontaneously over 4 mo of June through September, and most kids are born between the end of autumn and the end of winter, the worst season for availability of feed (Figure 1). Most young animals are sold when they are only 4 wk old, but young females retained for herd renewal are always with the males, and many of them become pregnant at a young age when they are not physiologically mature.

Why do the Mexican farmers leave the males continuously with the females? Their reasoning seems to be that they cannot feed the males in confinement so must graze them with the rest of the herd. It is difficult to know how much of this practice is due to tradition. Some farmers try to control reproduction by fitting the bucks with aprons that prevent copulation, but this method is prone to failure. Clearly, this problem needs to be addressed by exploring, for example, the possibility of a cooperative that retains all the males for all farmers in a community (it could also incorporate a system for genetic improvement). Challenges that need to be considered include i) the need for a system of animal identification; ii) a facility and a process for separation of animals and control of service; and iii) ways to measure milk production and the growth of kids to generate data for genetic selection. The science is long established, so as mentioned above, the real need is probably a “fourth generation” process to ensure adoption.

In southern Australia, the situation is less extreme because very few sheep farmers would leave rams and ewes together year-round. Nevertheless, many farmers like to offer the ewes the “maximum opportunity to conceive” and so will leave the rams in the ewe flock for up to 12 wk. However, this apparently self-evident principle does not survive scrutiny because the actual gains are much smaller than most appreciate (Figure 3). A short mating period is the better option for several reasons: i) Selection pressure on female fertility—failure to conceive in a short mating period should lead to culling; ii) Avoiding the effects of the seasonal declines in feed supply during mating—small ruminants mate naturally in autumn and, in many environments, pasture quality and quantity decline rapidly as autumn progresses; females that fail to conceive early will inevitably be attempting to conceive when they have lost body mass, leading to lower conception rates and fecundity; iii) Increased value from ultrasound scanning—if conceptions are limited to one or two cycles, ultrasound scanning also becomes more
cost-effective because it will allow segregation of females into groups carrying zero, one, or two fetuses; non-pregnant females can be culled for profit and to improve female fertility; segmentation of mothers carrying single and multiple fetuses is also the first step toward precision management of the birth environment and “focus feeding” for colostrum production (see “Maximize Neonatal Survival” below); iv) Reduced neonatal mortality—a short, concentrated period of births allows intensive management of the birth environment to reduce neonatal mortality, including focus feeding to maximize the production of colostrum (see below); v) Avoiding the “tail”—a cohort of offspring of an even age and size is easier to manage and to market.

To overcome the insecurity of restricted duration of mating, fertility can be detected in individual females. The simplest way is to use a harness with marking crayons on the males and then change the color to determine whether the mated (marked) females come back into estrus. This low-cost technique works well for sheep and goats. Alternatively, as we will discuss below, an ultrasound can be used to identify pregnant and non-pregnant females. Both marking crayons and ultrasounds offer data on fertility that can be used for genetic improvement.
Control the Time of Births

Three fundamental aspects of reproduction limit the time of year for natural mating: Puberty, seasonal breeding, and postpartum anestrus. One of the major causes is the evolution in sheep and goats of brain processes that link their reproduction control systems to changes in the length of the night. Despite 10,000 yr or more of domestication, these processes remain. Science has been working for many decades on ways to use exogenous hormones to overcome this block, and great progress has been made, but these treatments are not compatible with CGE management. In any case, they are too expensive for extensive management systems. Here we describe two non-pharmacological methods that have proven to be efficient alternatives:

Changing the night length

Controlling the night length for about 6 wk can be used to “switch on” the reproductive centers of the brain in goats and sheep. This is attractive for farmers with flocks or herds of seasonal genotypes but is probably limited to the males because they are fewer in number, so implementation would be more practical than for females. In goats, this technique allows a reduction in the duration of contact between the sexes without decreasing fertility (Bedos et al., 2010). The treatment can be used to ensure that the male reproductive axis is working at maximum efficiency when mating is restricted to a brief period, as described above, or for “male effect” is used, as described below (Delgadillo, 2011).

The ‘male effect’

In sheep and goats of many genotypes, the sudden introduction of novel males can induce ovulation in females that are reproductively quiescent because they are pre-pubertal, out of season, or lactating (reviews: Ungerfeld, 2007; Delgadillo, 2011; Jorre de St Jorre et al., 2014). This “male effect” offers control at two levels: i) the timing of births is no longer determined by the natural breeding season of the females; and ii) the induced ovulations are synchronized among the females in the flock or herd. The synchrony can be sufficient for artificial insemination (Martin and Scaramuzzi, 1983; Lopez-Sebastián et al., 2014) and is certainly sufficient for implementation of CGE management tools such as an ultrasound, focus feeding during pregnancy, and the management of birth. Equally as important is the simplicity and practicality—putting males in the field with the females and then knowing with confidence when the females will ovulate, conceive, and give birth.

However, the male effect is not universally effective—it works best with moderately seasonal genotypes, and currently, it can only be applied when the females are not ovulating spontaneously. Even in situations where the response is reliable, there can be wide variation among females in delay to the induced ovulation, in the incidence of short cycles following the first ovulation, and in the outcomes of mating (reviews: Ungerfeld, 2007; Delgadillo, 2011). The synchrony of ovulation declines over subsequent weeks, so focus feeding for fecundity still cannot be refined to the theoretical minimum of 4 to 6 d (see below): 7-d supplementation is needed in goats (Fitz-Rodriguez et al., 2009) and at least 11 d in sheep because ovulations are dispersed by the short-cycle phenomenon (Martin and Scaramuzzi, 1983; Nedelkov et al., 2013). Despite these limitations, there is a significant saving in feed costs over the requirements for mating over a full cycle.

Some of the problems with the male effect will not be resolved without significantly more research and development (review: Martin, 2014), so practical solutions for extensive management can be difficult to imagine at present. However, one area that could be resolved relatively quickly is the quality of male stimulus, as recently summarized in reviews by Fabre-Nys (2014) and Jorre de St Jorre et al. (2014):

i) The intensity of male behavior—sexually active males improve the response (Delgadillo, 2011);
ii) The age and experience of the males (Ungerfeld et al., 2007);
iii) Strategies for stimulating male activity: nutritional supplementation and pre-exposure to estrous females have been tested (Ungerfeld, 2007), but night-length treatment seems to be the most effective, at least for goats (Delgadillo, 2011).

These problems and solutions depend on interactions between genotype and season, so the genotype of the stimulus male is a major factor (Jorre de St Jorre et al., 2014). For sheep, but not goats, the first ovulation is not accompanied by estrus so it might be feasible to use a specific genotype of male for the male effect and then change the genotype for mating after ovulation is induced.

Nutrition

Feed males for fertility

Restricting the duration of mating immediately places pressure on the males, so they need to be managed correctly—adequate numbers, maximum mass of testis, anatomically sound, healthy, and fit. To maximize testis mass and therefore sperm production, rams and bucks need to be fed well for 8 wk before mating (review: Martin, 2014). This is especially important if the normal practice is to mate females that have been synchronized by the “male effect” because up to 30% of the females could be in estrus on some days. In Australia and New Zealand, the number of males might have to be increased from 1.5 to 4.0 per 100 females.

Feed the females for maximum litter size

Ovulation rate determines the upper limit of prolificacy, and thus productivity. Ovulation rate is under primary genetic control, so it can be improved through selection, but the expression of that genetic potential is greatly influenced by the nutritional regime before mating (review: Scaramuzzi et al., 2011). This is evident from the correlations between body condition and litter size, but more importantly in the context of focus feeding, there is also an acute effect—in sheep and goats, supplementation for only 4 to 6 d in the final stages of the estrous cycle can increase the frequency of twin ovulations by 20 to 30% (Viñoles et al., 2005, 2009; Fitz-Rodríguez et al., 2009; Zabuli et al., 2010). In the absence of very precise control over the time of ovulation, supplementation for only 4 to 6 d is not realistic, and it is necessary to offer the supplement for an entire cycle to ensure that all females have an opportunity to respond. If supplements are not feasible, high quality pasture or even cactus cladodes can be used (Viñoles et al., 2009, Rekik et al., 2012).

Nutrition—more than energy and protein

Generally, the relationship between nutrition and reproductive performance is explained by energy supply (review: Martin et al., 2008), but we need also to consider benefits that can be derived from other components of fodder plants, particularly “bioactive” secondary compounds. Interest in this area was initially stimulated by restrictions on the use of growth-promoting antibiotics and by the need to combat drug-resistant gastroin-
testinal parasites (review: Durmic and Blache, 2012). In Australia, for example, more than 100 Australian native plant species have been assessed on their potential to improve rumen function, gut health, nutritional value, and biomass productivity, and many of them can also reduce methane emissions (Revell et al., 2008; Durmic et al., 2010), so they contribute in several ways to the CGE credentials of the industry. This concept is obviously applicable outside Australia (e.g., Akkari et al., 2014) so should be investigated within local contexts.

This concept can be extended to other environments. In Mexico, for example, local forage plants are known to contain bioactive compounds that affect reproduction, as demonstrated by studies on the effects of mesquite in rats (Retana-Márquez et al., 2012). There are many possibilities for research of this type that would be relevant for the extensively managed goat industry in this part of the world, and the concept needs to be investigated for other environments.

**Ultrasound Scanning**

Ultrasound pregnancy diagnosis is now a routine procedure in small ruminants, even for the large flocks and herds that are typical in Australia and New Zealand, with numerous commercial operators offering reasonable rates and accurate results. The rate of adoption in Australia was the subject of a survey of 1,000 sheep farmers by Jones et al. (2014) who found that pregnancy scanning was used by more than 40% of farmers, of which 18% scan for litter size.

Even at the simplest level, the identification of pregnant and non-pregnant females, the information is valuable because it offers: i) an opportunity for remating if there has been a disaster; ii) culling for improvement of fertility; and iii) planning of conditions for birth. If conceptions are limited to two cycles, ultrasound scanning becomes more cost-effective because it will provide two extra levels of information: i) identification of single-bearing and multiple-bearing females, allowing segregation into separate management groups; and ii) estimation of age of fetus to increase the precision of management of birth.

**Maximize Neonatal Survival**

High rates of neonatal mortality have obvious consequences for profitability and also raise questions about the ethical credentials and the emission intensity of the industry. Neonatal mortality, therefore, goes hand-in-hand with any plan to improve fecundity through genetic selection or focus feeding. In addition, if neonates are lost because of mismanagement, then any investment in genetic improvement has been wasted.

**Maximize Colostrum Production**

In addition to the nutritional and immunological benefits, colostrum in the gut improves the ability of the newborn to recognize its mother and thus contributes to the establishment of the mother–young bond (Goursaud and Nowak, 1999; Ramirez-Vera et al., 2012a). With the implementation of restricted, brief mating periods and ultrasound assessment of pregnancy, focus feeding can be used in the last week of gestation to increase greatly the amount of colostrum available at birth (review: Bancho et al., 2006) and improve neonatal survival (Goodwin and Norton, 2004; Ramirez-Vera et al., 2012b).

**Manage the Birth Environment**

The simplest (and often least expensive) strategy for improving neonatal survival is to better manage birth. The provision of a calm environment, shelter, feed, and water close to the birth site will increase the amount of time the mother spends at the birth site and therefore improve the development of the mother–young bond (Nowak, 1996).

**Management of Puberty**

In Mexico, male and female goats remain together throughout the year, so young females often mate at 7 to 10 mo of age, with apparent consequences being high rates of abortion and delayed growth and a decrease in future productivity. In Australia, there is the opposite problem because the traditional practice is to manage the sexes in separate groups but delay the mating of young females until they are 18 to 24 mo old. This approach might avoid the issues encountered in Mexico but has broader consequences for the industry such as high emission intensity, delays in genetic progress, and reduction of the effective size of the breeding flock. The ideal solution lies between these two extremes, with young females mating at the optimum stage of their development. This is a complex problem, with a mix of sociological and biological causes and solutions: i) Sociological: Among Australian farmers, there is a widely held belief that mating young animals impairs their performance in subsequent
In Australia, about 80% of breeding ewes are the Merino genotype, with most managed in improved pastures that are nevertheless very seasonal in productivity. Most of these ewes only have a single lamb, but focus feeding and genetics can improve the frequency of twins. This can then precipitate other problems such as poor colostrum production and ewe–lamb bonding. Photo by Dr. Nui Milton, Casalana, Western Australia.

1.1.2. Genetic Improvement

years, a position supported by the Mexican experience; however, research in New Zealand shows that this is not that case with good management during the first year of life (Kenyon et al., 2004);

ii) Biological: In young females, the timing of puberty is determined by body mass, condition score, and season (night length), with body mass being the primary factor and maximizing weight gain after birth therefore considered essential. It has long been thought that the active component of body mass was fat, but recent work with sheep suggests that genetic selection for accelerated muscle growth can also advance puberty (Rosales-Nieto et al., 2013), offering dual advantages for the efficiency of meat production as well as reproduction. The male effect, ultrasound, and birth-site management are also obvious targets for managing puberty and the reproductive performance of young females, as outlined above for adult females.

Again, there should be positive outcomes for genetic improvement if young females are under pressure to conceive at a reasonably early opportunity.

The Genetic Frontiers

In the discussion above, most of the focus was on the physiological, behavioral, and managerial aspects of reproduction. The possibility of genetic improvement of female fertility has been mentioned, and genotype has been acknowledged as a frequent constraint to implementation of CGE management. In reviewing this situation for Australian Merino sheep, Martin and Greeff (2011) concluded that genetic selection could be used to improve the power of the male effect, increase fecundity, increase fertility, increase colostrum production, and enhance mother–young bonding. In addition, there needs to be a strong focus on resistance to parasites (Karlsson and Greeff, 2012). These traits could be incorporated into Australia’s industry-wide program for genetic selection that is based on published breeding values for important traits for both sheep and goats (http://www.mla.com.au/Livestock-production/Genetics-and-breeding). By contrast, Mexican goat production does not have this sort of plan and, in fact, does not even have a simple system for recording basic performance measures (e.g., milk production and kid growth rate). It is important to move in this direction, perhaps beginning with the introduction of a simple, inexpensive scheme for animal identification.

Importantly, genetic improvement is ideal for extensive grazing industries because it is a simple, low-cost management tool and the benefits are cumulative. Moreover, it is becoming feasible for the extensively managed industries because we are on the verge of a technology-led revolution in the generation of high quality data, such as electronic identification, DNA pedigrees, and the automatic recording of body weights and litter size. It will soon be possible to assess large numbers of animals for a wide variety of production traits under extensive production systems.

Conclusions

For industries based on extensively managed, grazing small ruminants, there is a wide range of simple, effective low-cost tools for managing reproduction, and they can be combined into a CGE scheme that is also responsive to predicted changes in markets and the regulatory environment. Many of these tools can be implemented now, with specific choices based on local geographical and socio–economic constraints. A primary focus must be maximizing the value of feed inputs from grazing, but there is now the possibility of an extra dimension in the choice of forages because some plant species can reduce carbon emissions and improve health. This area deserves research in many countries because the outcomes will help address the international problem of the environmental impact of ruminant industries.

The second major factor is control of the timing of mating, births, and lactation in relation to the seasonal availability of fodder. At the most basic level, the males and females need to be separated for all except the mating period. At a second level, the “male effect” offers excellent precision over the timing and synchrony of births. The most complex modes of implementation of the “male effect” are still subject to basic research and development.

For some components of the CGE scheme, the priority is to work on genetic improvement of the process, and for others, the priority is adoption processes rather than the science of reproduction. The extensive grazing industries have a poor record of transformation from traditional practice to the modern, science-based management that is essential if we are to feed and clothe the world without destroying the planet.

Literature Cited


Dr. J. Alberto Delgadillo earned his Ph.D. at the University of Western Australia (UWA) and then worked in France and the UK for 5 yr. He is now Professor (Chair) at UWA and a member of the UWA Institute of Agriculture. His research team mostly works on how environmental factors influence the reproductive system. He is also committed to science communication and to the use of science to transform industry. Since 2004, he has pioneered the concept of “clean, green, and ethical management of livestock” and promoted it nationally and internationally. He also chairs the UWA Future Farm 2050 project.

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