Advantages of current and future reproductive technologies for world-wide beef cattle production

G. C. Lamb**, V. R. G. Mercadante*, D. D. Henry*, P. L.P. Fontes*, C. R. Dahlen‡, J. E. Larson§, and N. DiLorenzo

**Department of Animal Science, Texas A&M University, College Station, TX; *North Florida Research and Education Center, University of Florida, Marianna, FL; ‡Department of Animal Sciences, North Dakota State University, Fargo, ND; §Department of Animal and Dairy Sciences, Mississippi State University, Mississippi State, MS

Introduction

Estimations of world population growth indicate that by the year 2050 the population will reach 9 billion habitants (Food and Agriculture Organization, 2009). These estimates impose a tremendous challenge in the current agricultural systems as food supply will need to increase by 100% in the next 35 years (Food and Agriculture Organization, 2009). Beef is the most nutrient dense animal protein on a per calorie basis, supplying several of the essential vitamins and minerals with a relatively low caloric intake per serving (McAfee et al., 2010). Increasing the production of beef will assist in meeting the requirements for a portion of the protein in diets of this expanding global population. However, increasing efficiency of beef production will hinge on the adoption and refinement of current and future reproductive technologies. Reproductive management of cattle is largely under control by humans, and the technologies developed to facilitate that control have a major impact on the efficiency of beef production.

Reproduction in cattle is an energy-intensive process since greater than 50% of the total feed consumption required to produce a unit of meat protein is consumed by the dam of the animal producing the beef (Dickerson, 1978). Improving the efficiency of production of weaned calves has a positive effect on age at puberty which then reduces generation interval (Davis et al., 1983). In addition, reproductive technologies provide opportunities to select cattle for genetic traits that improve production.

Artificial insemination, estrus synchronization (**ES**) and fixed-time AI (**TAI**), semen and embryo cryopreservation, multiple ovulation and embryo transfer (**MOET**), *in vitro* fertilization, sex determination of sperm or embryos, and nuclear transfer are technologies that are used to enhance the production efficiency of beef operations. In many cases, the development of these technologies is responsible for significant changes to traditional livestock production practices. However, adoption of these technologies by beef cattle producers is often slow and lags behind the adoption of technologies in other meat and dairy producing livestock systems. The nature of the extensive beef production systems is likely the primary reason for slow adoption rates. Current difficulties producers have with the incorporation of applied reproductive technologies must not be the reason to overlook the incorporation of more traditional reproductive technologies such as castration, breeding season management, or weaning. In many cases, beef producers fail to incorporate these more traditional technologies, which results in a reduction in production efficiency. Numerous reviews (Dahlen et al., 2013; Hansen et al., 2013; Seidel et al., 2013) have collectively addressed many concepts presented in this review. This review will focus on the state and advantages of both current or traditional and more developed reproductive technologies that will play a role in enhancing future production efficiency of beef cattle production systems.

Traditional Reproductive Technologies

Castration of Male Cattle

Removal of testis from bull calves is likely the most frequently used reproductive technique in United States. beef cattle production systems. A 2007 survey indicated that 59.2% of cattle operations castrated at least a portion of their bull calves and this represented 77.1% of the total calves owned by survey respondents (NAHMS, 2008). Sales price of steer calves are greater than those of bull calves and 91.6% of feedlot operators reported that castration and dehorning at least 4 wk prior to arrival at the feedlot was effective for reducing sickness and death loss (APHIS, 2012). From a standpoint of weight gain, feed efficiency, and final feedlot weight, intact males actually perform better than castrated males (Worrell et al., 1987). However, castration is usually implemented to foster selective breeding. Castration offers producers the opportunity to decide which animals may best be suited to sire future calf crops and those which are better suited to the commodity beef market. Another major concern with maintaining bulls rather than steers is the aggressive tendencies of bulls. This aggressive behavior is both in response to sexual stimuli as well as a desire to maintain social dominance. The sexual stimuli would be relevant if pens of bulls were in the same vicinity of a feedlot as pens of heifers not receiving an estrus-suppressant (such as melengestrol acetate, **MGA**). Behavioral characteristics of bulls cause concerns over safety of humans and of other cattle, as well as maintenance of fences and other equipment.

Castration is prevalent in the US beef production systems also as a result of consumer preference. Tenderness and consistency of products are important attributes for consumers choosing to purchase beef. Compared with that from bulls, meat from steers contains more fat resulting in greater quality grades (Calkins et al, 1986), as well as increased tenderness, juiciness, and flavor ratings of the longissimus muscle along with a brighter color (Carroll et al., 1975). This preference for meat from steer carcasses has been highlighted by prices received when selling finished cattle.

The development and refinement of immunological castration techniques may offer alternatives to banding or surgical procedures that are currently the most predominantly used methods of castration. Bulls vaccinated against GnRH had similar performance and improved meat quality when compared with unvaccinated bulls (Amatayakul-Chantler et al., 2012). A reduction in physical activity (perhaps related to sexual aggression and hierarchy maintenance) in GnRH vaccinated bulls may explain the similar performance measures in spite of the reduced concentrations of endogenous testosterone compared with unvaccinated bulls (Janett et al., 2012). As producers look for alternative castration techniques to optimize animal welfare, and sensitivity of the public increases towards management practices such as castration, immunocastration may become a management practice utilized to a greater extent in the US beef production systems.

Estrous Cycle Control of Females not Destined for Breeding

The frequency of pregnant heifers entering feedlots has ranged from 4 to 17% of all heifers, depending on the management or the heifer source of origin. In addition, some pens of heifers have been harvested where the pregnancy rate approaches 20% (Laudert, 1988). While pregnant heifers gain weight similarly compared with open heifers, a portion of this weight is being partitioned toward the developing fetus and the overall feed efficiency is reduced in those pregnant heifers (Jim et al., 1991). Producers have the option of continuing to feed heifers that are pregnant or to administer an abortifactant to heifers that are found to be pregnant. Retaining pregnant heifers and adding excess body condition may result in major problems associated with calf survival and heifer health when they calve in feedlot pens.

Removal of ovaries (spaying) in heifers is a practice that is conducted on only a small proportion of females but, when successful, eliminates the opportunity for pregnancy in females. Spaying heifers offers feedlot operators the ability to maintain mixed-sex pens or to house pens of spayed heifers in the vicinity of a pen of cull bulls. In addition, spaying reduces the incidence of estrus activity. Estrus activity of intact heifers causes a temporary reduction in feed intake and associated performance, and estrus activity near the time of harvest may cause an increased incidence of dark cutting beef in intact heifers compared with spayed heifers and steers (Scanga et al., 1998). The process of spaying removes the heifer's natural source of estrogen. Therefore, implanting spayed heifers with a steroid implant is an important management strategy to increase feed intake and feed efficiency (Garber, 1990).

In lieu of spaying, feeding MGA is an approved method of controlling estrus in feedlot heifers. The label for MGA claims a suppression of estrus, an increase in weight gain, and an improvement in feed efficiency for feedlot heifers. According to a 1999 survey of feedlot operators, 79% of feedlot heifers in the United States received MGA when in feedlots (NAHMS, 2000). A portion of the remaining heifers were likely prohibited from receiving MGA, because they were destined to specific markets that mandated they do not receive MGA, or heifers were not in confinement but were grazing. The use of MGA in grazing cattle is not as effective since not all heifers will consume MGA daily. Although a small increase in ADG was observed when a low dose of MGA was fed to steers (Moseley, et al., 2003), it is still not approved for use when feeding MGA to steers. Therefore, feedlot operators are prohibited from feeding MGA to mixed-sex pens of cattle.

Incorporation of a Defined Breeding Season

In the US, 55% of operations surveyed had no set breeding season, whereas 34% of operations had a single defined breeding season and 12% of operations had two defined breeding seasons (NAHMS, 2009a). Implementation of defined breeding seasons significantly impacts profitability of beef operations by matching cattle to available resources, refining nutrient delivery to groups of cattle, concentrating labor resources, and increasing the sale price of calves. Many traditional commercial breeding seasons are designed to place a young, growing calf on forages that are at their peak of quality and availability. Matching growing calves to high quality forages allows for maximal weight gains through forage intake and through milk produced via forage intake of the dam during lactation.

A defined breeding season also allows for delivery of proper nutrients to cows during key times of gestation. Having groups of cattle at similar stages of gestation allows producers to set precise targets for nutrient delivery and to manage feeding cattle according to their requirements rather than to their appetite. Without a specific breeding season, producers would have difficulty implementing a precision-based nutrition system without continually over-feeding a portion of their herd and underfeeding another portion. The concept also pertains to allocation of pasture resources to optimize forage utilization.

Labor resources are also more concentrated and focused when a defined breeding season has been implemented. When no breeding season is established, a producer should monitor cows in a herd for calving every day of the year. By implementing a defined breeding season, calving activity is concentrated into a period of time slightly longer than the breeding season (given the natural variation in length of gestation). This phenomenon of more calves being born over a shorter period of time also concentrates the need for labor to monitor and assist cows during calving. The concentrated labor may also increase attentiveness of producers as they monitor cows regularly during calving and ultimately lead to greater calf survival (and coincident profit potential) by offering prompt assistance to heifers or cows experiencing dystocia.

As the number of calves in an auction lot increases, the price received subsequently increases. This is true in both sale barn (Leupp et al., 2008) and in video auction lots (Seeger et al., 2011). Upon arrival at a sale barn, groups of calves are sorted into relatively similar cohort groups and presented in the sale accordingly, unless producers live in a region where calves are sold individually through the ring. A defined breeding season that concentrates calving increases the uniformity of calves, resulting in fewer groups of cohorts being sold at a single time. Fewer cohort lots result in a greater number of calves in each lot and a greater sales price.

Actual dates of the breeding season vary by region, and tradition (cited by 43% of survey respondents) plays a major role in deciding when a breeding season should be held (NAHMS, 2009a). Additional factors of feed cost, cow performance, calf performance, and environmental conditions need to be considered when deciding which breeding season is appropriate for a particular herd (Grings et al., 2005).

Breeding Soundness Examinations

In bulls, breeding soundness examinations (**BSE**) are targeted at identifying sub-fertile bulls. A BSE includes a physical evaluation, measurement of scrotal circumference, and an evaluation of semen motility and morphology (Society for Theriogenology, 1993). Currently, 71% of operations have a BSE conducted on bulls that are newly purchased or leased and the proportion increases with increasing herd size (NAHMS, 2009a). Recommendations are to perform a BSE on every bull annually prior to the initiation of the breeding season. Although specific timing of the examination is vague, it should be conducted far enough in advance of bull turnout to access additional bulls if any is classified as “unsatisfactory”, or to provide sufficient time for a second examination if bulls are classified as “deferred”.

When cows were bred to bulls in either the satisfactory or deferred categories, a greater proportion of females bred to bulls classified as satisfactory breeders (46.6%) were pregnant at the end of the breeding season compared with females bred to bulls classified as deferred (36.5%; Farin et al., 1989). However, no differences were observed among BSE classification in number of times bulls mounted females, number of services, or percentage of females serviced. Thus, a breeding soundness exam is an indication of potential fertility and not an indication of libido. Having a high libido in herd sires is essential to ensure high fertility in the female herd, since bulls with greater libido tend to service more females (Chenowith, 1997). In a multi-sire breeding pasture setting, 7.3% of all bulls exposed to a BSE failed to sire a single calf (Drake et al., 2011). Whether this issue is one of libido, social hierarchy, or other factors not detectable by a BSE is unknown. Bulls failing a BSE sire very few calves (Magee, 2005), and thus should be removed from the herd.

In heifers, a BSE identifies the proportion of females that are likely cyclic prior to the breeding season and to identify the individual animals that will probably not become pregnant and should be removed from the herd. Components of a BSE for heifers include the palpation of the uterus and ovaries to determine the size of the uterine horns and the structures present in the ovaries. A pelvic measurement may also be determined to provide an additional selection tool to identify heifers that have a small pelvis relative to heifer weight and frame size and, consequently, have a greater risk of experiencing dystocia.

As reproductive tract scores increased from 1 to 5, body weight, pelvic area, and the proportion of heifers observed in estrus increased (Patterson et al., 2000), and the proportion of heifers becoming pregnant after breeding also increased (Anderson et al., 1991). Heifers that have multiple estrous cycles prior to the first breeding are more likely to become pregnant compared with those exposed to mating on their first cycle (Byerley et al., 1987). In addition to fertility during the immediate breeding season, reproductive tract scores were found to be positively associated with calf weaning weights and fertility during the following breeding season and, thus, a potential indicator of lifetime cow productivity (Holm et al., 2009).

Diagnosis of Pregnancy

Determination of pregnancy status identifies non-pregnant cows and subsequently provides a tool for management of non-pregnant females in an operation. Pregnancy diagnosis may be the single most effective reproductive management tool available to producers to enhance production efficiency of their operations, especially as input costs, such as feed, fuel, and fertilizer continue to increase. When a non-pregnant cow is maintained in the herd over an extended period of time a significant feed cost is incurred, with no calf to market to offset the expense of feeding a nonpregnant cow. Yet, surprisingly, fewer than 20% of beef producers in the US perform a pregnancy diagnosis on their cow herd annually (NAHMS, 2009a).

Three major methods of pregnancy detection are currently available and suitable for beef cattle producers: palpation per rectum, ultrasound, and pregnancy-associated glycoproteins (**PAGs**). Given the variety of production systems and operation goals that modern beef producers have, each of the methods of pregnancy determination has a place in the industry. For a comparison of attributes among methods of pregnancy diagnosis described, see Table 1 (Dahlen et al., 2013).

Palpation per rectum is the most common and inexpensive method of pregnancy diagnosis, but as veterinarians become more adept at transrectal ultrasonography and the equipment becomes less expensive, ultrasonography is becoming a more popular method of pregnancy diagnosis and has several benefits. By measuring the fetal size (crown-rump length or biparietal distance) accurate fetal age can be determined in early pregnancy. In addition, because the operator has the opportunity to visualize the fetal characteristics, fetal viability, fetal sex, and the number of fetuses may all be determined (Lamb et al., 2003).

In recent years, the development of pregnancy testing of blood samples to identify PAGs has generated less expensive opportunities for beef producers to diagnose pregnancy in their operations. From d 28 after cattle are mated, blood samples may be collected by producers and mailed to laboratories that are contracted with one of three primary companies for analysis of PAGs. Based on data reported by the commercial companies providing these tests, they report that the tests generally yield results that are greater than 99% accurate when a cow is diagnosed as not pregnant (false-negative), whereas the false-pregnant (false-positive) rate for these tests is approximately 5% (Thompson et al., 2010).

Table 1. Comparison of different methods of pregnancy detection in beef cattle (Dahlen et al., 2013).

	Method of Pregnancy Detection		
Item	Palpation	Ultrasound	Blood Tests
Minimum fetal age detected	35-45[1]	25-30[1]	28-32
Accurate fetal aging	Yes	Yes	No
Identification of twins	No	Yes	No
Evaluate fetal viability	No[2]	Yes	No
Determine sex of fetus	No	Yes	No
Veterinarian required[3]	Yes	Yes	No
Immediate answer	Yes	Yes	No
Does experience impact accuracy	Yes	Yes	No
Price	Medium	Higher	Low

[1]Each veterinarian has a comfort level regarding the gestational age they are comfortable detecting.
[2] If the fetus is old enough some movement may be felt using palpation per rectum.
[3] Regulations requiring a veterinarian or allowing lay-person technicians vary by state

Current Assisted Reproductive Technologies

Artificial Insemination

Artificial insemination is not a new technology. The developmental research that preceded our modern techniques dates back to Russia in the late 1800s and early 1900s (Foote, 2002). The accidental discovery that glycerol has properties to protect and maintain semen viability through freezing set the stage for the development of the AI industry as we know it today (Agca and Critser, 2002).

For beef producers a major opportunity exists to increase the genetic potential of their herd through the use of AI. With AI, the most genetically superior sires are available to a large number of producers rather than being confined to the cows that are on a single pasture. In addition, the accuracy of EPDs of young sires with no progeny (typical of most natural service sires) is less than that of sires with a large number of offspring (typical of “proven” AI sires; Harris and Newman, 1994). One of the primary advantages of using AI is that semen from sires with EPDs and accuracies far superior to most natural service sires is available. High accuracy of EPDs in proven AI sires allow producers more confidence that the advertised performance and phenotypic characteristics of offspring will be realized, compared with offspring from low accuracy natural service sires. The risk of unexpected performance is greater when using low accuracy natural service sires (Pruzzo et al., 2003). In addition, improving the accuracy of sire breeding value predictions may increase the overall rate of genetic change on beef operations (Betz, 2007) and improved rate of genetic change can lead to subsequent improvements in overall profitability (Harris and Newman, 1994).

Synchronization of Estrus or Ovulation

Synchronizing the estrous cycle with the use of exogenous hormones (ES and ovulation synchronization) has been developed and incorporated into beef production systems primarily to facilitate the use of AI for more than 40 yr. A primary factor limiting the use of AI is the labor required to perform AI and to detect estrus in females and ensure they are inseminated at the appropriate time. It is now possible to expect to achieve pregnancy from AI in more than 50% of the herd during the 1st wk of the breeding season (Lamb et al., 2006; Larson et al., 2006). The success of ES in increasing the proportion of pregnancies derived from AI will increase the rate of genetic improvement through mating with genetically superior AI sires. However, other benefits have become evident including the potential to alter the calving season and increase uniformity of calves (Dziuk and Bellows, 1983; Rodgers et al., 2012). Estrus synchronization protocols, particularly those which include a progestin, may induce cyclicity in non-cyclic females (Thompson et al., 1999; Lamb et al., 2001; Stevenson et al., 2003). These mentioned advantages to utilize ES have enhanced its use in beef operations and is usually used in conjunction with AI.

Currently only 7.6% of beef operations in the United States utilize AI as a reproductive management tool (NAHMS, 2009a), whereas 72.5% of all pregnancies in dairy females are the result of AI (NAHMS, 2009b). When queried as to their reluctance to utilize AI, over 53% of operations cited labor concerns or complicated estrous synchronization protocols as primary reasons for not implementing this reproductive technology (NAHMS, 2009a). Research projects addressing these key areas of producer concern have been developed, and improvements in the actual protocols and their subsequent ability to effectively synchronize estrus and ovulation have been made (Lauderdale et al., 2009).

Sex-sorted semen

The technology that has been developed to sort spermatozoa by the presence of either a Y or X chromosome has the potential to alter the efficiency of beef production. Depending on the production goals of an operation, the availability of either more bull or heifer calves creates the opportunity for more profitability. Males are preferred over females when feeding animals for the production of beef. Steers are more efficient at converting feed to muscle, which equates to more efficient production of beef. Many producers focus on the generation of replacement females, and in these operations a benefit may be realized for more heifer calves.

Processes to generate sex-sorted spermatozoa are fairly inefficient and costly, which has limited its use. Damage incurred during the sorted process and/or fewer spermatozoa per dose result in decreased fertility with sex-sorted spermatozoa. The difference in fertility between conventional semen and sex-sorted semen is considered to be in the order of 10 percentage points, and this gap is not bridged by increasing the number of sex sorted sperm per inseminate (DeJarnette et al 2011).

In commercial beef cattle operations sexed semen provides the opportunity to use a small number of elite cows to generate replacements while mating the remainder of the cows to terminal sires. However, the most common use of sexed semen in the beef industry is to increase the number of the desired sex of animals in purebred operations. Generating more bull calves from a superior herd sire to produce bulls for the commercial sector is an important consideration. Similarly, deriving more daughters from a purebred maternal line would also be advantageous to certain purebred breeders. Therefore, although sexed semen may not be utilized extensively throughout the beef industry, it will continue to provide beef producers an opportunity to alter management practices that will enhance beef production efficiency.

Embryo transfer

Incorporating embryo transfer (**ET**) into beef production systems is a fast way to change the genetic base of a herd using existing females. Females of poor or even average genetic potential have the opportunity via ET to serve as a surrogate to carry a calf of exceptional genetic merit. *In vivo* embryo production through superovulation of donor females and *in vitro* production following ovum pickup (**OPU**) allow a single female to generate a substantially greater number of offspring than she would be capable of producing in conventional systems. When ET technology is coupled with the use of spermatozoa from genetically superior sires and possibly the use of sex-sorted semen, genetic improvement can increase exponentially within a herd. The use of estrous synchronization protocols to achieve donor-recipient synchrony decreased the number of available recipients necessary. The advancements of cryopreservation also decreased the number of recipients necessary as well as relaxed the timing requirements of ET, making it more feasible and efficient for many producers, and increasing the use of the technology (Hasler, 2003). In spite of these advantages, many procedures used in ET are expensive and inefficient, which limits the practical application for beef producers. Perhaps the most promising aspect of these technologies as they relate to food security is the ability to transport embryos, rather than live animals, to areas where improved genetics would rapidly increase production of beef.

Even though the use of *in vivo*-derived embryos continues to increase, a major limitation has been the lack of successful superovulation in donor females. Although research continues in the development of superovulation protocols as well as techniques to predict which donor females may respond well to superovulation (Hasler, 2003; Betteridge, 2006), this remains an inhibitor of using *in vivo*-derived embryos. As number of embryos per flush increases, the overall cost per embryo produced will likely decrease. Since cost of the technology is one of the reasons that producers have been hesitant to incorporate ET, finding methods to improve superovulatory response and coincident number of transferrable embryos per flush would likely increase its use.

To avoid the potential disadvantage of poor response to superovulation, the use of *in vitro*-produced embryos is increasing. Proper facilities and expertise are required, but when females can be subjected to frequent sessions of transvaginal ultrasonically guided OPU, oocytes can then be subjected to *in vitro* fertilization and culture resulting in more transferrable embryos. These embryos are more likely to be transferred fresh because their viability decreases with cryopreservation to a greater extent than *in vivo*-derived embryos (Palasz and Mapletoft, 1996). Until this hurdle can be mediated, the ability to transport and store these embryos will be limited and will thus limit its use on a global scale to improve overall efficiency of production. It is possible to culture *in vitro*-produced embryos in the oviduct of sheep, and these embryos survive cryopreservation as well as their *in vivo* counterparts (Galli et al., 2003), giving promise to increased potential in this area. Nonetheless, as improvements in this technology continue, it is conceivable to believe that *in vitro* produced embryos will be transferred at a lower cost than *in vivo* produced embryos, ultimately resulting in a decline in the quantity of *in vivo* produced embryos and an increase in *in vitro* produced embryos.

Future Opportunities for Assisted Reproductive Technologies

Somatic Cell Nuclear Cloning

Somatic cell nuclear cloning has been used to produce offspring in at least 20 species (Oback, 2008; Rodriquez-Osorio et al., 2012), and is a commercial reality in cattle. This process involves fusion of a somatic cell nucleus (usually encased in the entire cell) with an enucleated nucleus, activation of the newly formed embryo to initiate cell proliferation, and culture of the embryo until transfer into recipients. The major use of somatic cell nuclear cloning is in the genetic duplication of superior animals. This use is only practical when the individual to be cloned has a high degree of financial or emotional value because inefficiencies in the cloning process make it financially unaffordable. Nuclear cloning could improve rates of genetic selection by increasing selection intensity (only a few sires and dams need be produced) and, because the accuracy of selection can be improved, by recording performance of specific genotypes under a variety of environments (Dematawewa and Berger, 1998). However, unless the efficiency of the technology is increased, the increase in genetic merit achieved by incorporation of cloning in selection programs will not be enough to offset the costs.

Stem Cell Technology

Stem cells are self-renewing cells that can differentiate into specialized phenotypes. Technologies based on the production and manipulation of stem cells not only have implications that may prove useful for developing novel methods for manipulation of male and female gametes.

Stem cells exist throughout the body and participate in maintaining the integrity of regenerating tissues. An intriguing potential use of stem cells could be the use of somatic stem cells of a genetically superior bull transplanted into the testis of numerous less desirable bulls, or bulls that are adapted to tolerate certain climatic conditions could receive a transplant. These stem cells could become established in the seminiferous tubules and give rise to spermatozoa. Presence of sperm from transplanted testicular cells in semen has been demonstrated in cattle (Stockwell et al., 2009) and live offspring have been produced from sperm derived from a testicular cell transplant in goats (Honaramooz et al., 2003). Another stem cell technology that may prove to be useful in the future is to modify males so that all spermatozoa carry the X chromosome. This could be achieved with somatic stem cells derived when genetic females cells are transplanted into the testis (Hansen et al., 2013).

Potential for Transgenic Cattle

Assisted reproductive tools may provide the opportunity to incorporate transgenic technologies into our beef cattle systems in the future. In a recent review (Seidel, 2013), the author postulates that transgenic technologies may be utilized in cattle by 2050. For example, there may be the opportunity to have terminal cross genes expressed on the Y-chromosome. The females may have maternal traits including small size, but give birth to males that are born small but exhibit rapid growth or improved efficiency to the compliment of performance-related genes on the non-pseudoautosomal portion of the Y-chromosome.

Perhaps another transgenic example may be to distort sex ratio transgenically so that 70-90% of calves from a particular sire will be one sex or the other without sexing semen. This concept has already been demonstrated in mice (Herrmann et al, 1999). Therefore, as transgenic technology continues to evolve, the potential may exist to incorporate this technology into commercial beef cattle production systems.

Implications

At the present time, many of the reproductive management tools are too inefficient for application in commercial beef cattle systems. However, this was once true for AI and ET and advances in current technology occur at a faster rate today than when AI was developed more than 75 yr ago. These newer assisted reproduction techniques may have a major impact on beef production systems within the next few decades; however, overcoming negative perceptions of these technologies (regardless of their efficacy and safety) by the general public may be a larger hurdle to scale than refining the efficiency of these technologies for commercial application. Therefore, incorporation of current or future reproductive technologies into production systems will vary depending on cattle markets, infrastructure, production systems, and climate, but education to producers and the general public on the relative merits and safety of these technologies will be imperative.

References

Agca, Y., and J. K. Critser. 2002. Cryopreservation of spermatozoa in assisted reproduction. Semin. Reprod. Med. 20:15-23.

Amatayakul-Chantler, S., J.A. Jackson, J. Stenger, V. King, L.M.S. Rubio, R. Howard, E. Lopez, and J. Walker. 2012. Immunocastration of Bos indicus × Brown Swiss bulls in feedlot with gonadotropin-releasing hormone vaccine Bopriva provides improved performance and meat quality. J. Anim. Sci. 90:3718-3728.

Anderson, K.J., D.G. Lefever,, J.S. Brinks, and K.G. Odde. 1991. The use of reproductive tract scoring in beef heifers. Agri-Practi. 12: 19-26.

APHIS, Veterinary Service: Centers for Epidemiology and Animal Health. 2012. Importance of pre-arrival management practices to operators of U.S. feedlots. Info Sheet: Safeguarding American Agriculture. https://www.aphis.usda.gov/animal_health/nahms/feedlot/downloads/feedlot2011/Feed11_is_Prearrival.pdf. Accessed July 1, 2015.

Betteridge, K. J. 2006. Farm animal embryo technologies: achievements and perspectives. Theriogenology 65:905-913.

Betz, G.C.M. 2007. Using the rate of genetic change and the population structure of cattle to better target genetic progress. Proc. 39th Beef Imp. Fed. Symp. Fort Collins, CO pp. 103-109.

Byerley, D. J., R.B. Staigmiller, J.G. Berardinelli, and R.E. Short. 1987. Pregnancy rates of beef heifers bred either on puberal or third estrus. J. Anim. Sci. 65:645-650.

Calkins, C.R., D.C. Clanton, ,T.J. Berg,, and J.E. Kinder. 1986. Growth, carcass and palatability traits of intact males and steers implanted with zeranol or estradiol early and throughout life. J. Anim. Sci. 62: 625-631.

Carroll, F.D., W.C. Rollins, , K.A. Wagnon, and R.G. Loy. 1975. Comparison of beef from bulls and DES implanted steers. J. Anim. Sci. 41: 1008-1013.

Chenowith, P. J. 1997. Bull libido/serving capacity. Vet. Clin. North Am. Food Anim. Pract. 13:331-344.

Dahlen, C.R., J.E. Larson, and G.C. Lamb. 2013. Impacts of Reproductive Technologies on Beef Production in the United States In: Current and Future Reproductive Technologies and World Food Production, Advances in Experimental Medicine and Biology, Springer Publishing Company, New York, NY. Vol. 752, p 97-114.

Davis, M.E., J.J. Rutledge, L.V. Cundiff, and E.R.Hauser. 1983. Life cycle efficiency of beef production: II. Relationship of cow efficiency ratios to traits of the dam and progeny weaned. J. Anim. Sci. 57:852-866.

DeJarnette J.M., M.A. Leach, R.L. Nebel, C.E. Marshall, C.R. Cleary, J.F. Moreno. 2011. Effects of sex sorting and sperm dosage on conception rates of Holstein heifers; is comparable fertility of sex sorted and conventional semen plausible? J. Dairy Sci. 2011; 3477-3483.

Dematawewa, C.M., and P.J. Berger. 1998. Break-even cost of cloning in genetic improvement of dairy cattle. J. Dairy Sci. 81:1136-1147.

Dickerson, G.E. 1978. Animal size and efficiency : Basic concepts. Anim. Prod. 27:367-379.

Drake, D.J., K.L. Weber, and A.L. Van Eenennaam. 2011. What are herd bulls accomplishing in multiple sire breeding pastures? Proceedings of Applied Reproductive Strategies in Beef Cattle, Joplin, MO. p 305-319.

Dziuk, P.J., and R.A. Bellows. 1983. Management of reproduction in beef cattle, sheep and pigs. J. Anim. Sci. 57(Suppl. 2):355-379.

Farin, P.W., P.J. Chenoweth, D.F. Tomky, L. Ball, and J.E. Pexton. 1989. Breeding soundness, libido and performance of beef bulls mated to estrus synchronized females. Theriogenology. 32:717-725.

Foote, R.H. 2002. The history of artificial insemination: selected notes and notables. J. Anim. Sci. 80:1-10.Galli, C., R. Duchi, G. Crotti, P. Turini, N. Ponderato, S. Colleoni, I. Laqutina, and G. Lazzari. 2003. Bovine embryo technologies. Theriogenology 59:599-616.

Garber, M.J., R.A. Roeder, J.J. Combs, L. Eldridge, J.C. Miller, D.D. Hinman, and J.J. Ney. 1990. Efficiency of vaginal spaying and anabolic implants on growth and carcass characteristics in beef heifers. J. Anim. Sci. 68: 1469-1475.

Grings, E.E., R.E. Short, K.D. Klement, T.W. Geary, M.D. MacNeil, M.R. Haferkamp, and R.K. Heitschmidt. 2005. Calving system and weaning age effects on cow and preweaning calf performance in the Northern Great Plains. J. Anim. Sci. 83: 2671-2683.

Hansen, P.J. 2013. Current and future assisted reproductive technologies for mammalian farm animals In: Current and Future Reproductive Technologies and World Food Production, Advances in Experimental Medicine and Biology, Springer Publishing Company, New York, NY. Vol. 752, pp 1-22.

Harris, D.L., and S. Newman. 1994. Breeding for profit: synergism between genetic improvement and livestock production: A review. J. Anim. Sci. 72:2178-2200.

Hasler, J. F. 2003. The current status and future of commercial embryo transfer in cattle. Anim. Reprod. Sci. 79:245-264.

Herrmann, B.G., B. Koschorz, K.Wertz, K.J. McLaughlin, and A. Kispert. 1999. A protein kinase encoded by the t complex responder gene causes non-Mendelian inheritance. Nature 402:141-146.

Holm, D.E., P.N. Thompson, and P.C. Irons. 2009. The value of reporductive tract scoring as a predictor of fertility and prodcution outcomes in beef heifers. J. Anim. Sci. 87:1934-1940.

Honaramooz, A., E. Behboodi, S.O. Megee, S.A. Overton, H. Galantino-Homer, Y. Echelard, and I. Dobrinski. 2003. Fertility and germline transmission of donor haplotype following germ cell transplantation in immunocompetent goats. Biol. Reprod. 69:1260-1264.

Janett, F., T. Gerig, A.C. Tschuor, S. Amatayakul-Chantler, J. Walker, R. Howard, H. Bollwein, and R. Thun. 2012. Vaccination against gonadotropin-releasing factor (GnRF) with Bopriva significantly decreases testicular development, serum testosterone levels, and physical activity in pubertal bulls. Theriogenology 78:182-188.

Jim, G.K., C.S. Ribble,, P.T. Guichon, and B.E. Thorlakson. 1991. The relative economics of feeding open, aborted, pregnant feedlot heifers. Can. Vet. J. 10:613-617.

Lamb, G.C., C.R. Dahlen, and D.R. Brown. 2003. Symposium paper: reproductive ultrasonography for monitoring ovarian structure development, fetal development, embryo survival, and twins in beef cows. Prof. Anim. Sci. 19: 135-143.

Lamb, G.C., J.E. Larson, T.W. Geary, J.S. Stevenson, S.K. Johnson, M.L. Day, R.P. Ansotegui, D.L. Kesler, J.M. DeJarnette, and D.G. Landblom. 2006. Synchronization of estrus and artificial insemination of replacement beef heifers using gonadotropin-releasing hormone, prostaglandin $F_{2\alpha}$, and progesterone. J. Anim. Sci. 84:3000-3009.

Lamb, G.C., J.S. Stevenson, D.J. Kesler, H.A. Garverick, D.R. Brown, and B.E. Salfen. 2001. Inclusion of an intravaginal progesterone insert plus GnRH and prostaglandin $F_{2\alpha}$ for ovulation control in postpartum suckled beef cows. J. Anim. Sci. 79:2253–2259.

Larson, J.E., G.C. Lamb, J.S. Stevenson, S.K. Johnson, M.L. Day, T.W. Geary, D.J. Kesler, J.M. DeJarnette, F.N. Schrick, A. DiCostanzo, and J.D. Arseneau. 2006. Synchronization of estrus in suckled beef cows before detected estrus and artificial insemination and timed artificial insemination using gonadotropin-releasing hormone, prostaglandin $F_{2\alpha}$, and progesterone. J. Anim. Sci. 84:332-342.

Lauderdale, J.W. 2009. ASAS Centennial Paper: Contributions in the Journal of Animal Science to the development of protocols for breeding management of cattle through synchronization of estrus and ovulation. J. Anim. Sci. 87:801-812.

Laudert, S.B. 1988. Incidence of pregnancy in feedlot heifers at slaughter. Kansas Agric. Exp. Sta. Rep. of Progress. 539: 112.

Leupp, J.L., G.P. Lardy, R. Daly, C.L. Wright, and J.A. Paterson. 2008. Factors influencing price of North Dakota, South Dakota and Montana feeder calves. NDSU Beef Cattle and Range Research Report. Pages: 46-49.

Magee, D. 2005. Breeding soundness evaluation of bulls. In: Proc. Applied Reproductive Strategies in Beef Cattle, College Station, TX. Accessed July 8, 2015 (http://beefrepro.unl.edu/proceedings/2005collegestation/16_tamu_bse_magee.pdf)

McAfee, A. J., E. M. McSorley, G. J. Cuskelly, B. W. Moss, J. M. W. Wallace, M. P. Bonham, and A. M. Fearon. 2010. Red meat consumption: An overview of the risks and benefits. Meat Science 84:1-13.

Moseley, W.M., D.M. Meeuwse, J.F. Boucher, K.J. Dame, and J.W. Lauderdale. 2003. A dose-response study of melengestrol acetate on feedlot performance and carcass characteristics of beef steers. J. Anim. Sci. 81:2699-2703.

National Animal Health Management Service (NAHMS). 2000. Part I: Baseline reference of feedlot management practices, 1999. Page 46-47. Natl. Anim. Health Monit. Serv., Fort Collins, CO.

National Animal Health Management Service (NAHMS). 2009a. Part II. Reference of beef cow-calf management practices in the United States, 2007-08. Page: 5-23. Natl. Anim. Health Monit. Serv., Fort Collins, CO.
National Animal Health Management Service (NAHMS). 2009b. Part IV. Reference of dairy cattle health and management practices in the United States, 2007-08. Page: 27. Natl. Anim. Health Monit. Serv., Fort Collins, CO.
National Animal Health Monitoring Service (NAHMS). 2008. Part I. Reference of beef cow-calf management practices in the United States, 2007-08. Pages: 37-40. Natl. Anim. Health Monit. Serv., Fort Collins, CO.
National Research Council (NRC). 1996. Nutrient Requirements of Beef Cattle. 7th ed. National Academy Press, Washington, DC
Oback, B. 2008. Climbing Mount Efficiency--small steps, not giant leaps towards higher cloning success in farm animals. Reprod. Domest. Anim. 43 Suppl 2:407-416.
Palasz, A. T., and R. J. Mapletoft. 1996. Cryopreservation of mammalian embryos and oocytes: recent advances. Biotechnol. Adv. 14:127-149.
Patterson, D.J., S.L. Wood, and R.F. Randle. 2000. Heifer programs that add value to the beef industry: Procedures that support reproductive management of replacement beef heifers. J. Anim. Sci. 77: 1-15.
Pruzzo, L., R.J.C. Cantet, and C.C. Fioretti. 2003. Risk-adjusted expected returns for selection decisions. J. Anim. Sci. 81:2984-2988.
Rodriguez-Osorio, N., R. Urrego, J.B. Cibelli, K. Eilertsen, and E. Memili. 2012. Reprogramming mammalian somatic cells. Theriogenology 78:1869-1886.
Scanga, J.A., K.E. Belk, J.D. Tatum, T. Grandin, and G.C. Smith. 1998. Factors contributing to the incidence of dark cutting beef. J. Anim. Sci. 76: 2040-2047.
Schnell, T.D., K.E. Belk, J.D. Tatum, R.K. Miller, and G.C. Smith. 1997. Performance, carcass, and palatability traits for cull cows fed high-energy concentrate diets for 0, 14, 28, 42, or 56 days. J. Anim. Sci. 75:1195-1202.
Seeger, J.T., M.E. King,, D.S. Grotelueschen, G.M. Rogers, and G.S. Stokka. 2011. Effect of management, marketing, and certified health programs on the sale price of beef calves sold through livestock video auction service from 1995 through 2009. JAVMA 239: 451-466.
Seidel, G.E. Jr. 2013. Beef cattle in the year 2050 In: Current and Future Reproductive Technologies and World Food Production, Advances in Experimental Medicine and Biology, Springer Publishing Company, New York, NY. Vol. 752, pp 239-244.
Society of Theriogenology. 1993. Guidelines for the bull breeding soundness evaluation. In: Guidelines for uniform beef improvement programs, 9th edition, 2010. Montgomery, AL
Stevenson, J.S., G.C. Lamb, S.K. Johnson, M.A. Medina-Britos, D.M. Grieger, K.R. Harmoney, J.A. Cartmill, S.Z. El-Zarkouny, C.R. Dahlen, and T.J. Marple. 2003. Supplemental norgestomet, progesterone, or melengestrol acetate increases pregnancy rates in suckled beef cows after timed inseminations. J. Anim. Sci. 81:571–586.
Stockwell, S., M. Herrid, R. Davey, A. Brownlee, K. Hutton, and J.R. Hill. 2009. Microsatellite detection of donor-derived sperm DNA following germ cell transplantation in cattle. Reprod. Fertil. Dev. 21:462-468.
Thompson, I. M., R. L. Derri, I. H. Kim, J. A. Green, J. E. Santos, and W. W. Thatcher. 2010. Effects of resynchronization programs on pregnancy per artificial insemination,

progesterone, and pregnancy-associated glycoproteins in plasma of lactating dairy cows. J. Dairy Sci. 93:4006–4018.
Thompson, K.E., J.S. Stevenson, G.C. Lamb, D.M. Grieger, and C.A. Löest. 1999. Follicular, hormonal, and pregnancy responses of early postpartum suckled beef cows to GnRH, norgestomet, and $PGF_{2\alpha}$. J. Anim. Sci. 77:1823–1832.
Worrell, M.A., D.C. Clanton, and C.R. Calkins. 1987. Effect of weight at castration on steer