Dairy Farming in the Midwest and USA in 2067

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Summary

Fifty years from now, 81% of the world's population will live in Africa and Asia and world dairy trade will depend on their demand for imported dairy products. Dairy production in North America will shift to areas with sufficient rainfall and adequate growing seasons, primarily migrating from the west and southwest to Great Lakes regions and into the Canadian prairies. Milk yield per cow will exceed 50,000 lb/year and the USA will have 4 to 5 million milk cows. Commercial cows will comprise genes from multiple breeds or from gene editing. New genetics will move into herds primarily through embryos that may carry proprietary genes. Dairy enterprises will share laterally-integrated business structures that include separate units for pre-weaned calves, replacement heifers, early-dry cows, transition cows, milk cows, dairy beef, and feed centers. Feed production will have a greater focus on agro-ecological systems and perennial crops, including perennial maize, sorghums, and energy-grasses that will replace annual row crops. Robotics, automation, and sensors will replace a majority of manual labor and will enhance reliability, consistency, and compliance with regulations. Major shifts in herd management will be driven through management of epigenetics and associated environmental regulation of gene expression, and management of microbiomes of cattle, soils, crops, and farmsteads. Knowledge systems will evaluate herds as independent superorganisms to understand why herds that have similar genetics and environments differ in performance.

Background

The motivation for addressing this topic was a 2015 invitation from Michigan State University to present the Tucker Endowed Lecture in 2016. The author sought independent feedback from colleagues in the USA (Mike Hutjens, IL; Gordie Jones, WI; Jeff Stevenson, KS; Pam Ruegg, WI; Chad Dechow, PA; George Seidel, CO; Bob Cushman, NB; Tony McNeel, MI) and Europe (Hilary Dobson, UK; Martin Sheldon, UK; Patrice Humblot; SE). Independent ideas and thoughts from each were shared with the entire group to generate discussion. After a few iterations, this was used as a primary basis for moving ahead. Over the last year, several modifications have been added based on discussions with other colleagues and new findings in scientific and technical literature.

Harvesting milk from cows has been practiced for more than 10,000 years or approximately 450 generations, so it is unlikely that it will disappear in the next 2 generations. Moreover, a dairy-based food production system will support greater populations per acre or hectare of arable land as estimated for the USA by Peters et al. (2016). Dairy's most sustainable component is high quality protein that meets human dietary needs.

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Data Driven Forecasts

World and country populations

Forecasts for populations in the future are driven by current populations, birth and fertility rates, and longevity. World population will reach 10.7 billion in 2067 with 81% of the population living in Africa and Asia (Figure 1). The United States' population will fall from 4th to 5th place as a country, being surpassed by Nigeria. Population data are updated regularly for each country based on United Nations data, and a user-friendly website is available (DeWulf, 2016).

For growth in world dairy trade, it will be important for the USA to develop products that are suitable and acceptable to customers in countries that have growing populations. In Africa and Asia, the types of products may need to be quite different from those marketed in Europe and Russia. For example, they may need to be lactose free, packaged to withstand long storage without refrigeration, and contain spices on ingredients not typical in today's products.

In recent years, the USA has exported about 12 to 15% of its milk equivalents, and USA per capita consumption has increased to 627 lb (285 kg) of milk equivalent per capita in 2015. Milk equivalent imports have been lower than exports. For future projections, estimates are that 10% of production will be exported – this is a conservative estimate.

Climate change

Forecasts for climatic changes have been derived from a number of sources, depending on the state or region of the country. For the upper Midwest, the Nelson Institute Center for Climatic Research at the University of Wisconsin has useful resources that include application of the 9 major global climate models developed by different agencies or research teams around the world (http://nelson.wisc.edu/ccr/resources/visualization-and-tools.php). Their downscaled illustrations of some climate changes in Michigan in the late century are illustrated in Figure 2. These trends are consistent with trends for other area in the Great Lakes region and the Canadian prairies.

Generally the upper Midwest and Northeast will have longer growing seasons and slightly-to-significantly more precipitation than today. All seasons will be warmer. Water demand will increase less in these regions than in almost any other parts of the country. The eastern Canadian prairies will also see warmer temperatures and more precipitation, so more dairy cattle could move into those regions.

Availability of water for dairy farms will be limited in the south and southwest dairy regions of the USA by late century. Our forecast is that dairy farms will relocate to regions that have ample rainfall and suitable climates. The upper Midwest is likely to see growth in dairy farms because it is projected to have ample rainfall and longer growing seasons (Figure 3).

Projected milk yield per cow

There was strong agreement among forecasters in amount of milk that cows will produce in 2067, especially those in high-input dairy farms where feed is not limited. The estimate was 55,700 lb (25,318 kg) per cow per year. The average cow in the USA today produces 2.65-times the amount that the average cow produced 50 years ago. If we multiply today's average by 2.65, it equals 59,341 lbs (26,973 kg) per year; therefore, forecasters feel comfortable with estimates.

With higher production, the question becomes how many milk cows will be needed in the USA in 50 years. To address this, US Census projections were used to estimate the population and annual consumption was set at 600 lb (273 kg) per capita of milk equivalent, lower than the 627 lb per capita consumption in the USA in 2015. To this was added a 10% overage for export. With these targets for milk equivalent demand, estimates were made to determine number of milk cows needed to meet the demand. The number ranges from about 7.5 million cows at lower levels of production and 3.8 million cows at higher levels of production (Figure 4).

Predicted Forecasts for Technology and Innovations

Genetics of the cow of the future

Genetics of commercial dairy cows will move from breed- to gene-based with movement of genes within breeds and between breeds. Gene editing will be used to change natural alleles from one form to another form, for example, from horned to polled phenotype or from A1 milk to A2 milk phenotype. Data mining of genomes will find many single-nucleotide polymorphisms (**SNP**) that are markers for important health and welfare traits and many will be proprietary and require a fee for identifying a cow or bull's genotype. Synthetic genes may be introduced if their value is important for protecting the nation's food supply and export markets. For example, synthetic genes that would protect against Foreign Animal Diseases (Transboundary Animal Diseases), such as Foot and Mouth Disease, would be of vital interest to the industry and the USA.

Cows of the future will have a smaller environmental footprint and will have higher feed efficiency than today. There will be more emphasis on animal welfare because genetic markers of animal welfare will have been identified and implemented into selection programs. Markers for animal health may the most important genes in genomic indexes.

Forecasters believe that most genetic introductions into herds in 50 years will be by embryo transfer rather than semen. Embryos will be produced by genetic companies that are the descendants of today's AI companies and embryos may carry proprietary genes, limiting sale of females or their daughters from dairy herds. Embryos will be produced using stem cells and cloning technologies.

Globally, milk-producing cows will represent phenotypes and their associated genotypes that fit into various climatic sectors -- generally characterized as temporal, subtropical, and tropical phenotypes. The northern and southern latitudes for these distributions will shift over time and genetics will shift with the climate. Today's global cooperation among dairy geneticists worldwide will make this transition simpler for farmers.

Robotics, sensors, and automation

Adoption of robotic systems, sensors, and automation will continue to escalate in North America and technologically-advanced dairy economies. These shifts will be driven by shortages of labor in rural areas, increased focus on knowledge systems for decision making, and consistency of automated systems. Dairy cows like consistency, and integrated systems will provide that more consistently than manual labor.

Milking, feed handling, mixing and delivery, waste handling, sanitation, vaccination, health monitoring and treatments, planting, harvesting, and storage will be automated and will include driverless equipment, robotic delivery systems, and farmstead-wide sensors that inform enhanced agro-ecological systems that link soils, forages, feeds, wastewater, manure, workers, and other aspects of the dairy enterprise. At the animal level, metabolic profiling and gene activity monitoring will utilize biodegradable implanted sensors as part of the integrated systems.

Management of Epigenetics and Associated Regulation of Genetic Activity

Approximately 18% of the variation in important traits monitored in dairy cattle is heritable, meaning that differences among animals in these traits can be accounted for by ancestors in their pedigrees. Over 80% of variation in such traits is attributed to "Environment" in the classical equation: *Phenotype = Genetics + Environment*. We are beginning to understand that there is extensive regulation of gene expression that occurs in a temporal, predictable manner that can be managed in a beneficial way other than changing the genome. This fits into the "*Environment*" category in the equation and provides opportunities to manage more of the variation in traits.

Historically, epigenetic effects were defined by when changes within bases in a gene's deoxyribonucleic acid (**DNA**) sequence were methylated to prevent that gene from being "turned on". That concept was expanded to include situations in which the histone proteins in the nucleus were acetylated, therefore altering access of enzymes to sites for transcription of DNA. Some of these changes were transmitted to the next generation and sometimes for several generations.

There are a growing number of mechanisms that regulate gene expression in a predictable way and that are good candidates for active management. These mechanisms are expanding the definition of epigenetics in practice. In particular, mechanisms that act on mitotically-active cell lines, such as the mammary epithelial cells or ovarian germ cells, are a top priority. Animal scientists are learning to control some of these processes through developmental or metabolic programming, and this will grow the number of management tools that regulate gene activity without altering the genome (Sinclair et al., 2016).

Examples of epigenetic and related effects

Feeding pre-weaned calves. It is generally accepted that feeding calves greater amounts of milk to produce greater weight gains before weaning leads to enhanced yield of milk during first lactation about 670 days later (Soberon et al., 2014). This is a repeatable phenomenon with a temporal relationship such that a management action (feeding more milk) results in a biological response in a predictable way. This is a classic example of an epigenetic or related effect that is not associated with a change in the animal's genome.

Early postpartum milking frequency and higher yields. Experimental trials have shown that milking or suckling cows 4- to 6-times daily during the first 3 to 4 weeks of lactation boosts milk yield during the remaining lactation when cows are milked twice daily. This appears to be an effect on the mammary epithelial cells caused by the higher milking frequency in early lactation (Bar Peled et al., 1995; Hale et al., 2003).

Fertility of oocytes developing under adverse conditions. Britt (1992) hypothesized that the developing bovine oocyte could be affected adversely by environmental conditions, particularly negative energy balance, that would affect its viability 2 to 3 months later. It has taken about 25 years for this hypothesis to be fully verified and for potential epigenetic or related mechanisms to be identified. As we now understand, the oocyte that is ovulated at around 80 days postpartum begins development around 21 days prepartum (Figure 5). Consequently, this oocyte is subjected to impacts of negative energy balance, metabolic disturbances, and clinical diseases that are elevated during the transition period. Recently, Carvalho et al. (2014) demonstrated that change in body condition score during 3 wk postpartum could have a profound effect on pregnancy rate to timed AI at 82 days postpartum (Figure 6).

We are just beginning to understand how developmental or metabolic programming can influence temporal actions and subsequent responses in dairy cattle. In the future, we will utilize a broad array of management practices to regulate gene expression in beneficial ways and to avoid undesirable environmental effects.

Managing Microbiomes on Dairy Farms

Dairy cattle are role models for interactions between an animal and its microbiome, and dairy farms may be equally appropriate models for an enterprise and its microbiome. Cows have complex microbial populations that occupy the rumen, gut, udder, uterus, urinary tract, skin, feet, and other body components. Dairy farms have complex microbial populations in feeds, manure, farmsteads, equipment, personnel, soils, crops, and water resources.

Too often, we have sought to kill microorganisms without understanding that most are beneficial. Broad use of antibiotics, sterilants, fungicides, and other microbial agents have been effective in many ways, but their perceived effectiveness mislead us from understanding roles that the microbiome plays in animal health and resilience of agro-ecological systems. In the future, we will manage microbiomes in ways that are beneficial (Deusch et al., 2015).

Microbial ecology is challenging to study, but progress in high-throughput DNA sequencing and data mining is leading to clearer understanding of relationships that are targets for management. Shanks et al. (2011) measured over 600,000 high-quality DNA sequences in rectal fecal samples from feedlots to show that microbial populations differ significantly among locations and among primary feed constituents.

In the future, it is likely that mixed cultures of microorganisms will be used routinely to manage and treat diseases and sustain health. For example, calves will be inoculated with mixed cultures around the time of weaning to ensure optimal rumen function. Pubertal heifers will have their mammary quarters and uteri populated with beneficial organisms to limit infections. These are a few of many examples of how management of the microbiome will be implemented (Figure 7).

Feeding the Herd

Energy feeds will shift to a greater emphasis on perennial crops in the future because of development of perennial maize, sorghums, and energy grasses. Perennial maize is under development and is expected to be available on a commercial scale in about 30 years (Murray and Jessup, 2014). It is being produced through selective breeding with related plants that are perennials. Perennial sorghum is closer to development and will be particularly suitable for more arid climates (Paterson et al., 2014). Energy grasses are being developed genetically with a focus on reducing recalcitrance – making them more suitable for producing fuels. These grasses are much less dependent on nitrogen fertilization than maize and may yield 30 to 40 tons of dry matter per acre at maturity (Moore, 2009). Such crops may produce for up to 20 years without being re-planted and their ability to sequester carbon in the soil will be a valuable feature.

Lateral Integration of Herds

Vertical integration is common in other livestock enterprises (swine, broilers, layers, turkeys, farmed seafood, and crickets). Beef feedlots provide partial integration in that sector. The future will see broader lateral integration in the dairy industry, and there will be some specialized vertical integration. The simplest form of dairy lateral integration will comprise sharing of resources for stage-specific animals (Figure 8).

Herds as Superorganisms

Animal scientists tend to study animals, organ systems, cells, or genes. None of these tell us much about herds and why herds differ in health and performance. In contrast, scientists that study bee hives, termite colonies, and similar superorganisms see the hive or colony as the experimental unit, not the individual bee or termite (Seely, 2010). Should we adopt some of their practices in understanding herds?

The USA has many counties or micro-regions that are home to multiple herds that share common precipitation, ambient temperature ,and growing conditions. Yet, herds often differ significantly in health and performance. To understand how management makes a difference, there is a need for collaboration among several disciplines to ask the right questions and collect the right information to understand why herds differ. This is an undertaking that would not be prohibitively costly in terms of agricultural research and it would provide new insights.

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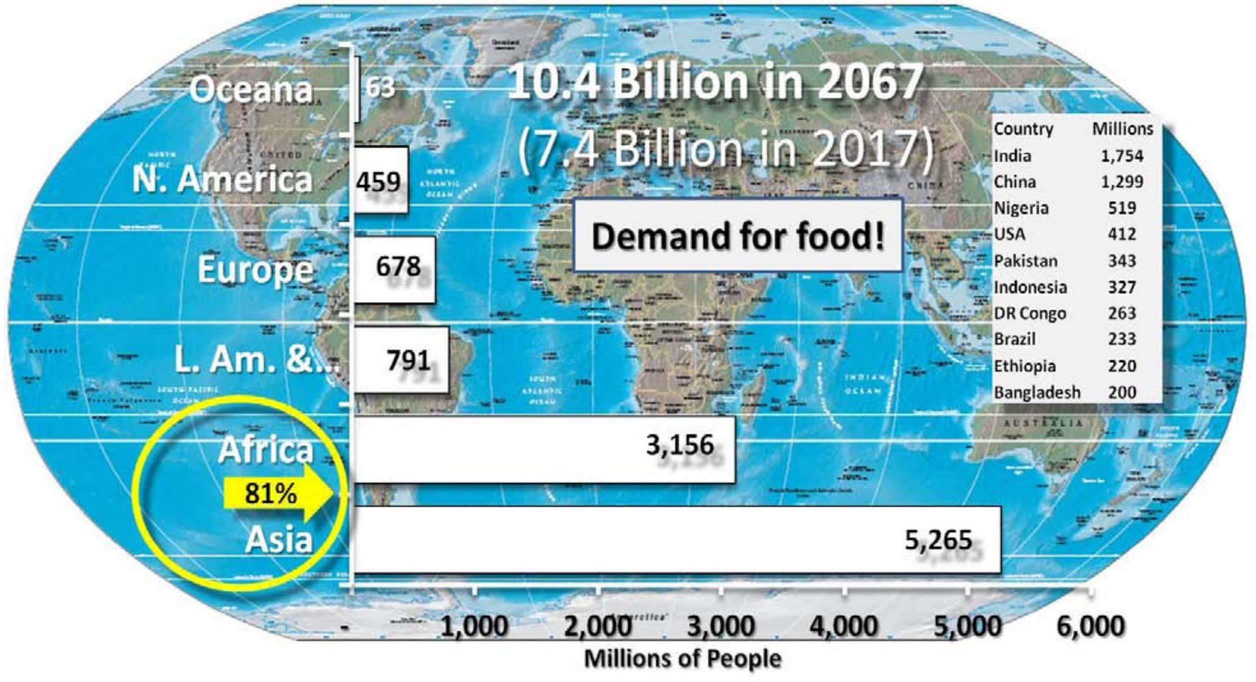
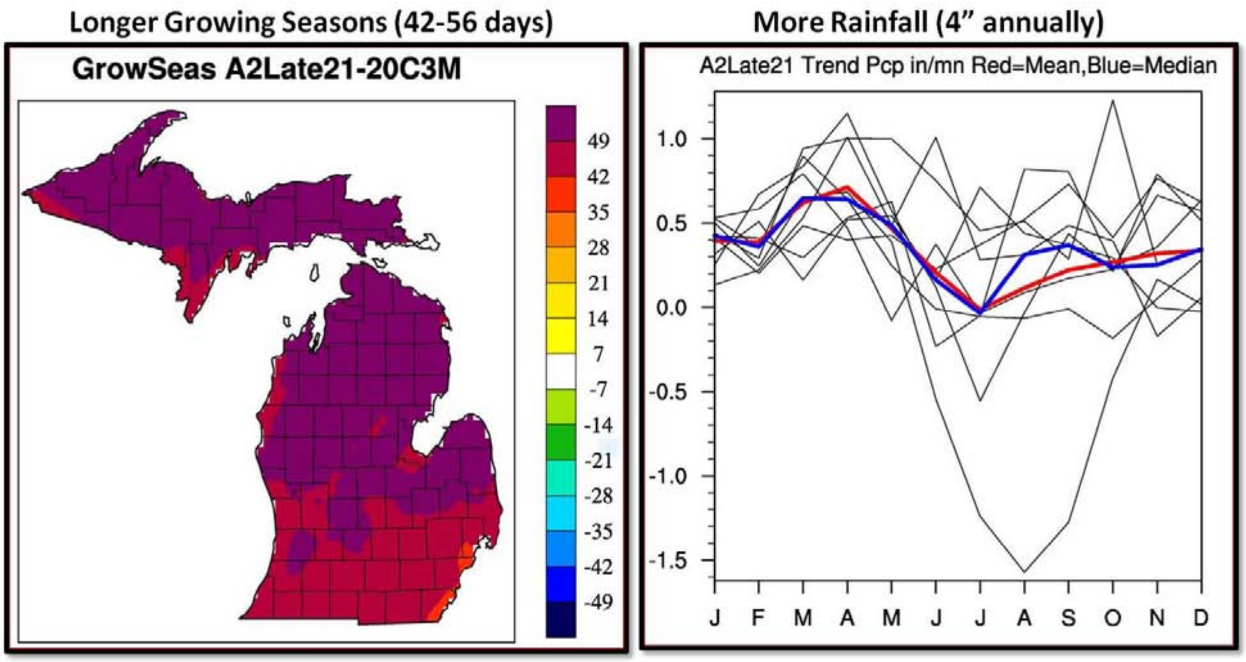


Country	Millions
India	1,754
China	1,299
Nigeria	519
USA	412
Pakistan	343
Indonesia	327
DR Congo	263
Brazil	233
Ethiopia	220
Bangladesh	200

Figure 1. Estimated population of the world and its top 10 countries in 2067, updated January 2017 from https://populationpyramid.net/world/2065/.


Longer Growing Seasons (42-56 days)

More Rainfall (4" annually)

Figure 2. Forecasts for growing season and rainfall in the late 21st century in Michigan. Downscale data from the Nelson Institute Center for Climate Research at the University of Wisconsin. http://nelson.wisc.edu/ccr/resources/visualization-and-tools.php.

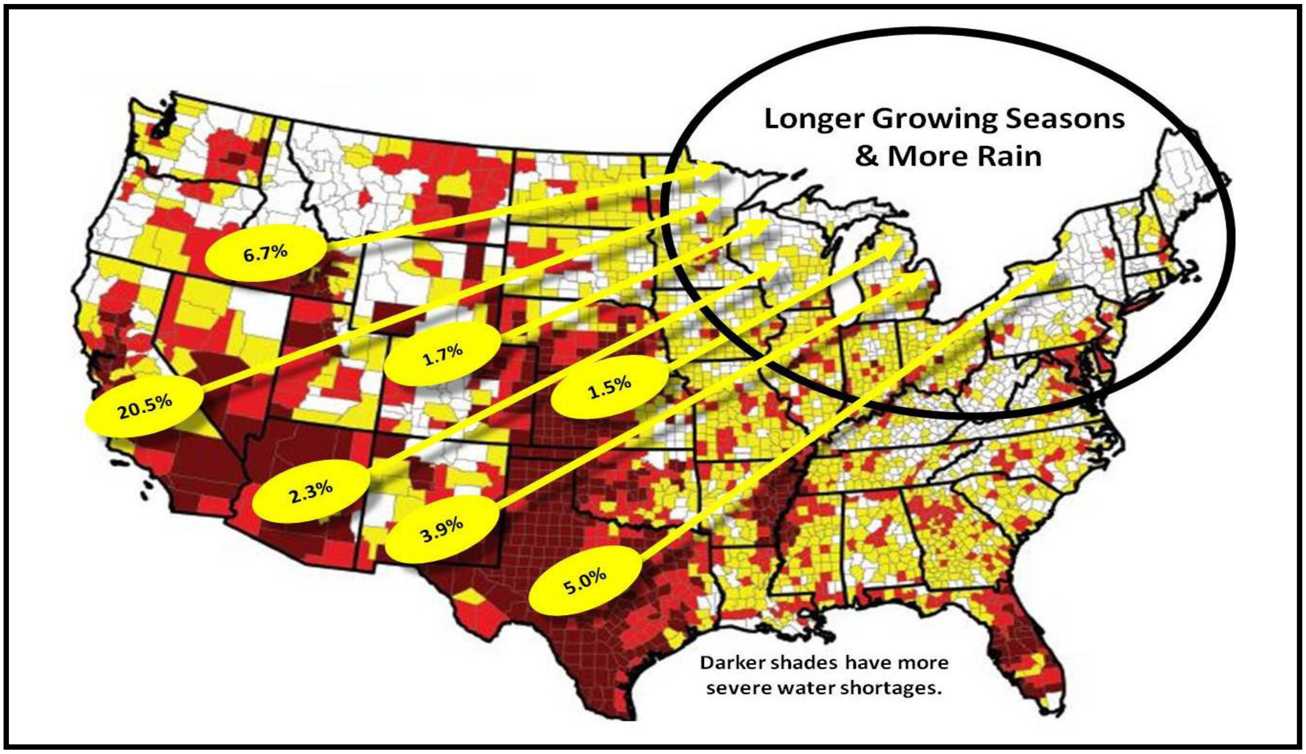


Figure 3. Forecast of movement of dairy cows from southwest and west to regions that will have more rainfall by late century. Map source: Spencer and Altman, 2010.

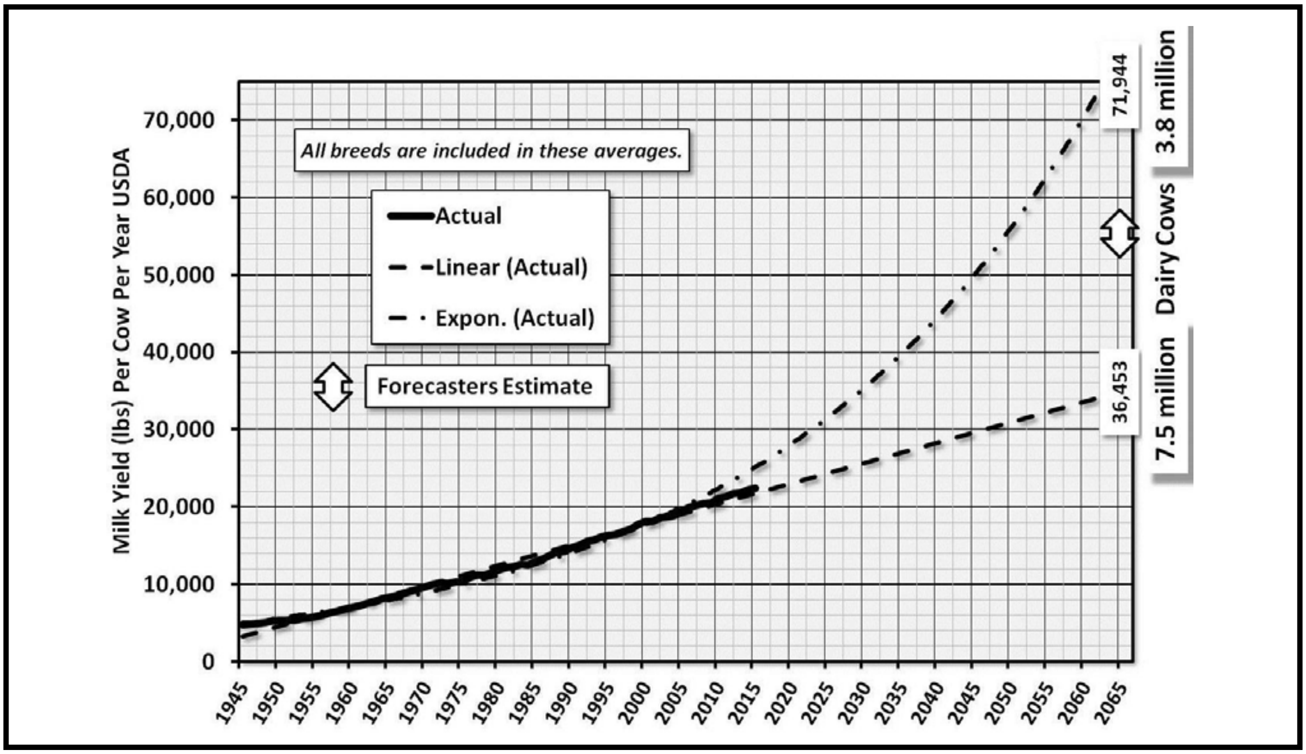


Figure 4. Projected milk yield and number of cows needed to meet USA needs plus 10% export in 2067.

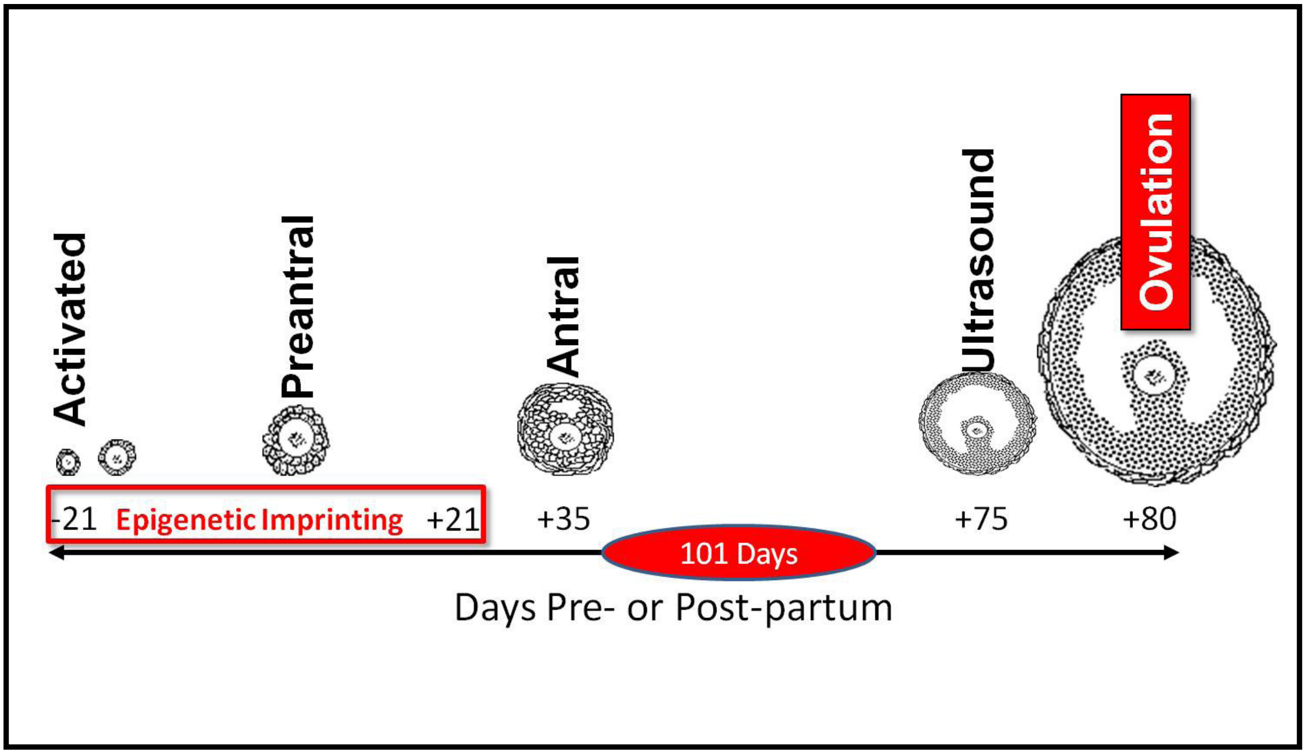


Figure 5. Model for Britt (1992) Hypothesis illustrating temporal relationship between an oocyte's activation about 21 days prepartum and its subsequent ovulation about 80 days postpartum.

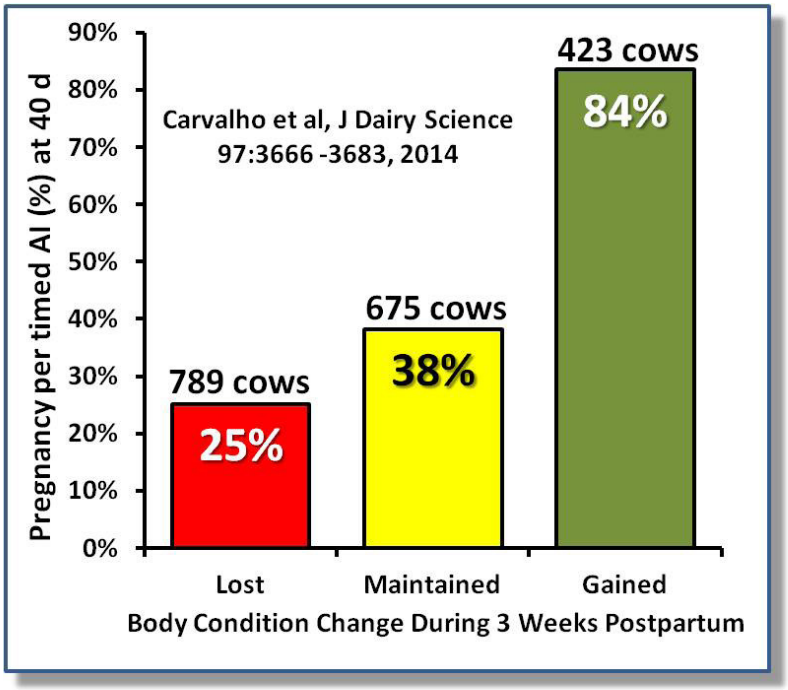


Figure 6. Pregnancy rate to timed AI among cows that lost, maintained, or gained body condition during 3 wk postpartum (Carvalho et al., 2014).

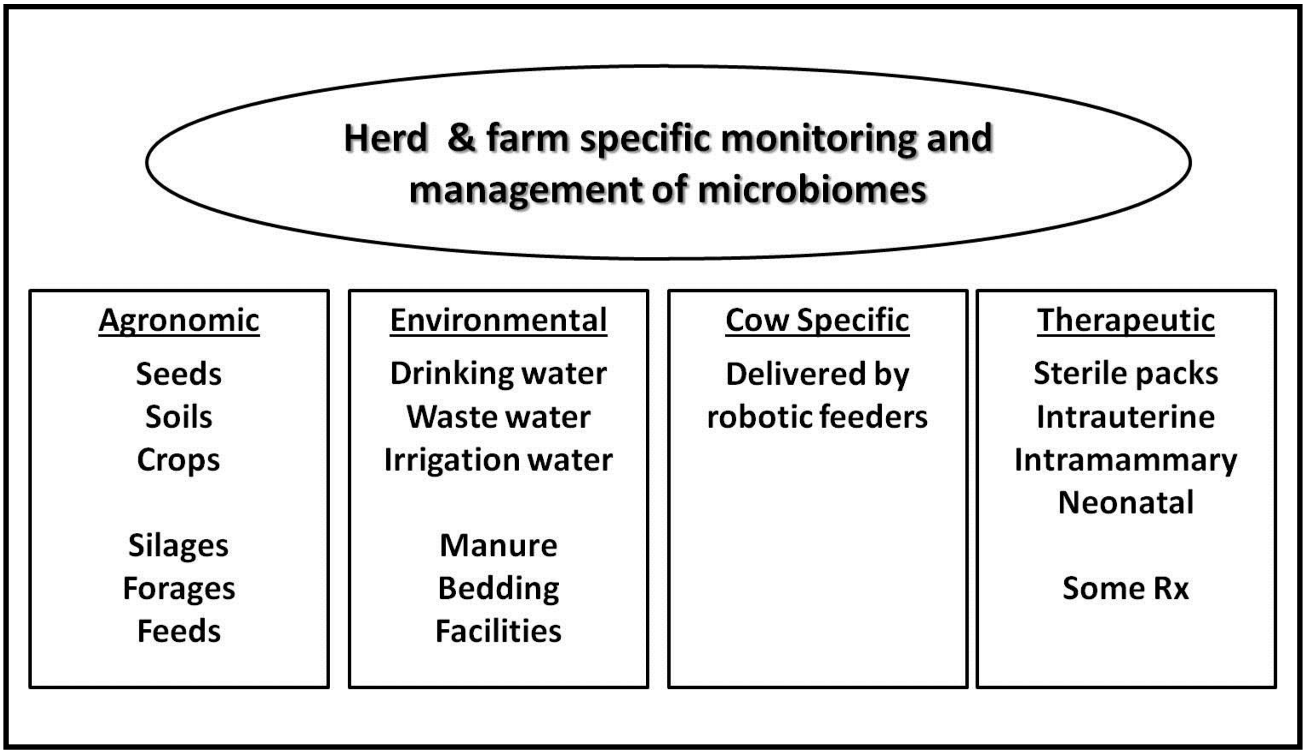


Figure 7. Examples of microbiome management on future dairy farms.

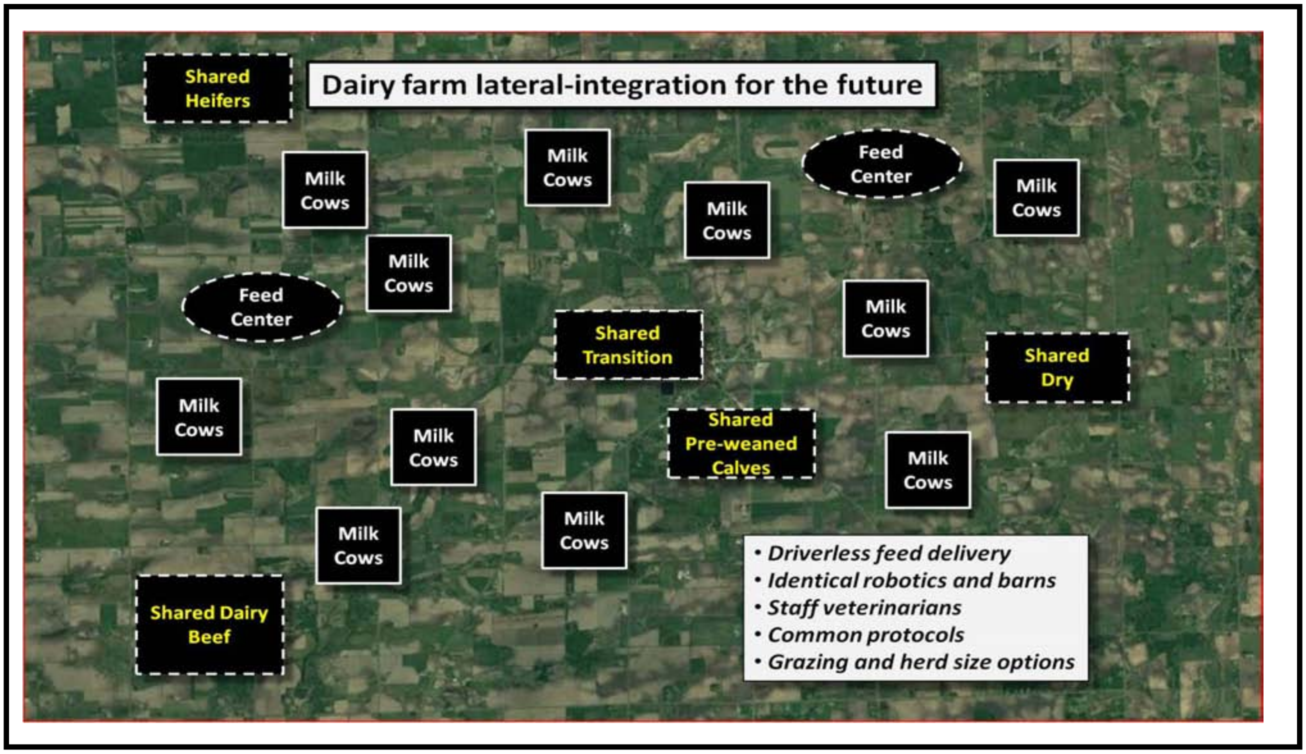


Figure 8. Examples of lateral integration of dairy animal units for efficient production with different scales of enterprises.