ABSTRACT: Over the next quarter century in North America, the following eventualities are likely for physiology and endocrinology research with agricultural animals. 1) Total funding adjusted for inflation will change little but will come less from public sources, and most of that will be in the context of human health. Much of the privately funded research will be herd specific and remain proprietary. 2) The numbers of MS, PhD, and postdoctoral students probably will decrease, but research in the context of credentialing will remain important. 3) Resources such as expanded databases in genomics and proteomics, and remarkable new tools such as small inhibitory RNA will continue to become available, likely at a faster rate than in the previous 25 yr. 4) The huge amounts of data from production agriculture will make agricultural animals ideal models for some kinds of basic research, such as studying fetal programming, resulting in synergy with more applied research. Most of these experimental animals will be in private production herds and flocks, even when work is publicly funded. 5) The trend toward more interdisciplinary research will continue, especially considering interactions among reproduction, health, nutrition, selective breeding, management factors, and societal concerns; reductionist research probing deeper into cellular and molecular mechanisms will remain important, as will whole-animal approaches. 6) Agricultural animals are a product of evolution plus selective breeding. Insights drawn from the former will aid progress in the latter. One focus of research in physiology and endocrinology will be understanding heterosis, inbreeding depression, and epigenetic effects as it becomes possible to manipulate and identify the allelic structure of individual animals. 7) Additional insightful concepts will evolve that will simplify thinking in some respects, such as the maternal to embryonic shift in transcribed RNA in early embryos; however, animal biology will turn out to be even more complex than most of us currently imagine.

Key words: centennial, endocrinology, future, physiology, research

INTRODUCTION

Anyone can predict the future, but except for special cases, such as the 24-h light:dark cycle, no one can predict the future very accurately in any detail for nontrivial items of interest. This does not mean that speculation about the future is useless, because it may stimulate useful thinking, and to some extent, one finds what one looks for. Looking back on such previous speculation might at least be entertaining!

I have no credentials for this assignment that differ from those of any other reasonably competent scientist in the field. I first speculated about the future of certain reproductive biotechnologies nearly 20 yr ago (Seidel, 1991), but will not agonize here about how those predictions are turning out. I admit that my nonacademic life has affected my perspective—growing up on a family dairy farm that included poultry, sheep, and pigs, and owning a 300-cow beef cattle ranch for the past 2 decades; similarly, anyone reading this will interpret via the lens of their experience.

My thoughts will apply primarily to North American animal agriculture, although most also will apply to developed and developing countries on other continents. Most of my experience and competence concerns cattle, which will be the main species for discussion, but most ideas also will apply to sheep and pigs, and to a lesser extent to poultry and horses.

UNCERTAINTIES CAUSED BY CHANGING AGRICULTURAL PRACTICES

For the past 3 centuries, the functional unit of most North American agriculture has been the “family farm,” and arguably this still is true in 2008, when we
celebrate the 100th anniversary of the founding of the American Society of Animal Science. The family farm definitely remains the functional unit in many of the so-called developing countries, and probably most developed ones as well. However, at least in North America, the labor on many family farms involved in animal agriculture no longer is done by the nuclear family members plus perhaps one hired hand. This trend is clear with US dairy farms, in which the numbers of farms selling milk dropped from >2,000,000 to <100,000 in less than one-quarter of a century, and the numbers continue to decline. The total amount of milk produced was relatively steady at approximately 65 billion kg annually during much of this period, although the number of cows dropped by approximately one-half. The decline in numbers of farmers has been even sharper in the swine and poultry industries, resulting in hiring numerous workers per unit in addition to family members. In addition to economic conditions, smaller family sizes and off-farm opportunities have accentuated these trends.

The agricultural animals on these farms also have changed genetically and in age structure, and in many cases breeding and rearing have been separated from production (e.g., some farms specialize in raising heifers and others in milking cows); the same principles apply even more to swine and poultry farms. A somewhat opposite trend is occurring as families with considerable off-farm income have a few beef cows, sheep, or poultry more for recreation than for income. It is likely that the numbers of such “farmers” soon will be considerably greater than the numbers of farmers who derive the bulk of their income from selling agricultural products. The farm animals in these 2 environments will differ in some respects, and the scientific needs of their owners also will differ. A variation on this trend is organic farming. The scientific needs of organic animal husbandry are real, despite some arbitrary constraints of this sector, and these needs will differ from more conventional operations.

The current nonscientific pressures resulting in greatly reduced use of bovine ST for enhancing milk production in dairy cows in North America is another example of an imperfectly predictable, and somewhat disconcerting, change in practices. One can get the science “right” but not have it applied rationally (Capper et al., 2008). This is a particular concern for some types of translational research.

The main point of this section is to illustrate major uncertainties in the future needs of end users of most scientific research with agricultural animals. Although much basic research with farm animals is justified without considering these end users, for example, as models for humans, meeting the needs of agricultural producers is the main reason for the existence of research programs in departments of animal science at universities, as opposed, for example, to departments of biology. Because of this difference, future research in depart-

ments of animal science is inherently less predictable than that in basic biology departments.

**UNCERTAINTIES CAUSED BY CHANGING SCIENTIFIC CAPABILITIES**

One can cite numerous advances in scientific capabilities during the past century that have changed the nature of scientific endeavors and even thinking. Those that come to mind immediately include radioisotopes, electron microscopy, monoclonal antibodies, and recombinant DNA technology, including PCR. The latter has created discontinuities in what research is easily fundable, in what hypotheses are testable, and in what areas new hires are qualified. The rate of development of new tools even appears to be accelerating; recent developments in proteomics and inexpensive whole-genome sequencing are examples. Some new developments are truly astonishing. “In silico” studies, for example, can be truly illuminating, and they require only databases and high-speed computers with appropriate software. Microarrays are another example of a new, powerful tool. Note that this paragraph concerns capabilities; which hypotheses are tested with these capabilities will be even more important.

**SPECIFIC FUTURE RESEARCH IN PHYSIOLOGY AND ENDOCRINOLOGY**

Predictions more than 20 to 30 yr into the future likely are of limited value, although absent any major world conflagration, such as nuclear war, we can expect a more and more affluent society with ever increasing needs for research in the areas of nutrition, recreation, health, and aging. Research with agricultural animals will be greatly affected by these increased needs, although I would not anticipate either a great decline or a great increase in the total collective effort.

Research in physiology and endocrinology is likely to become more interdisciplinary on average than in the recent past. This is not to imply that reductionist research, particularly at the cellular and molecular levels, will not continue to be important. There is no shortage of problems needing research, both from applied and fundamental standpoints. Examples of the latter include how the transition of primordial follicles to primary follicles is regulated on the ovary, what the molecular basis of heterosis is, how information is integrated in the hypothalamus, how gametic imprinting is regulated, what mechanisms are involved in how sperm retain fertility in the epididymis, and how RNA is regulated in oocytes. Such lists can be lengthened easily, but these examples illustrate the point. There also are literally thousands of genes that have no known function but that are clearly expressed in a tissue- and temporal-specific manner. Most of these are also ex-
pressed in humans and model rodent species, whereas others are expressed in farm animals, but not in rodent models. In some cases, species differences are logical (e.g., ruminants are fundamentally different from non-ruminants), whereas in other cases, species have merely evolved differently (Jacob, 1977), for example, in the diverse mechanisms of maternal recognition of pregnancy. In any case, much remains to be learned in farm animals as farm animals or as models for humans and other species.

Although fundamental research will remain important, more applied, translational research likely will predominate in the context of farm animal physiology and endocrinology. Again, there is no shortage of needs. Early pregnancy tests, particularly in cattle, would be most useful. Rapid diagnostics for metabolic disorders and diseases, including the pathogens involved with mastitis or neonatal diarrhea, would be invaluable. Improving procedures for sexing sperm is another example, as is rapid, “chute-side” determination of the allelic status of animals for thousands of genes.

The capabilities of rapid sequencing of stretches of DNA of individual animals will bring a whole new dimension to animal genetics. Within another decade, I predict a major flowering of subfields connecting genetics with physiology and endocrinology.

Interdisciplinary research always has been important but likely will increase. This is in part due to interactions such as reproduction-nutrition-genetics interactions. Societal concerns also will drive research of an interdisciplinary nature. Here again, the list is long: animal well being and the effects of practices on the environment, including global warming, energy use, odors, and competition with human food needs. Regulation of fertility, including contraception in production settings, and especially as models for humans, has many environmental implications.

ADVANTAGES OF FARM ANIMALS FOR RESEARCH

Farm animals have huge advantages over laboratory animals for many kinds of research (Ireland et al., 2008), and this will become more appreciated in the future. First is the dual use of information—basic research that also can be applied to food production needs and the converse. Second is the advantage of size, for example, when repeatedly sampling blood, or the amounts of other body fluids and tissues available. Third is cost. Many experiments can be done with animals in production settings in which large numbers of animals are available that are growing, reproducing, or lactating. Even as a strictly biomedical model, the per diem rates for keeping sheep often are less than for rabbits and are an order of magnitude less than for nonhuman primates. Fourth (and this may be the most important advantage), I predict that animal biology will turn out to be more complex than any of us currently imagine, and it will be necessary to confirm many hypotheses developed in vitro, or even with rodent models, in whole animals themselves, and in relevant environments. Another advantage for many studies is that most farm animals are outbred, in some cases with excellent pedigree information, enabling the study of allelic flow through families. There also are some disadvantages of farm animals for research, such as long generation intervals and the expense of making genetically identical sets of animals.

Two special cases will be mentioned that, again, are examples of advantages farm animals offer, and that may be appreciated more widely in the future. Artificial insemination in cattle provides the only situation in which the fertility of individual male mammals can be measured with any degree of precision at a reasonable cost. This is because many hundreds of inseminations are needed to obtain tight confidence intervals for the binomial response (pregnant or not), and bovine AI provides the numbers required. The same applies to comparing treatment effects. Another special case is inexpensive in vitro production of embryos of several species from oocytes derived from slaughterhouse ovaries and semen collected from males. A societal spin-off is that many of the personnel heading human infertility clinics received their training as graduate students working with this system; this training provides an excellent foundation for moving over to human applications. Such unique opportunities will continue to be exploited in the future.

WHO WILL DO FARM ANIMAL RESEARCH AND WHERE?

Most farm animal research in North America will continue to be done in colleges of agriculture and veterinary medicine at land grant and similar universities. The ARS of USDA also will continue to be an important contributor, as will private industry, including pharmaceutical and biotechnology companies. Increasingly, agricultural production units such as large dairies, feedlots, and poultry and swine enterprises will conduct research specific to their respective operation with a spectrum of rigor ranging from misleading to extremely well done and interpretable. Unfortunately, most of this research will remain proprietary. On the other hand, many such operations already participate in joint research with universities and industry, ranging from simple collaborations, such as charging nominal fees for the use of animals in research, to projects funded primarily by these operations. Most such operations maintain comprehensive electronic herd records, making them attractive collaborators. I anticipate a great increase in the use of this resource over the next few decades.

Animal science and similar departments probably will not change greatly with respect to numbers of faculty, but will evolve to doing less research with food animals and more with companion animals. Departments will increasingly specialize—gone are the days when each
department had research programs in nutrition, management, physiology and endocrinology, and animal breeding spread over cattle, swine, and sheep. However, a certain amount of broad expertise will be retained for teaching undergraduates.

Credentialing at the graduate student level will remain important but likely will decrease, at least with respect to the farm animal component. There are several reasons for this. First, there are fewer students with such interests because there are fewer farmers, and farm family size has decreased. This will continue to be alleviated somewhat by graduate students from other countries. Second, it is becoming increasingly difficult to garner the long-term financial resources needed to sustain large numbers of graduate students for farm animal-related research. The availability of such assistantships, fellowships, and scholarships seems to be declining in many departments at the same time as tuition is increasing, rapidly in some cases. Despite these issues, graduate students will continue to be trained, in part to provide the work force for research, but also because there will be a great demand for persons so trained in industry, government, and especially academia as large numbers of current faculty retire. In my opinion, attention must be paid to shortening PhD programs, which have become too lengthy, especially in the more fundamental biological sciences.

**FUNDING**

There seems to be a growing disconnect between sources of funding for farm animal research and end users of the information. The mid-20th century model of abundant federal and state formula funding with a generous component filtering down for dissemination by extension personnel has become more and more obsolete. There was, however, considerable “buy-in” from taxpayers, legislators, and, of course, participants for this system in the past, and it provided a reliable and substantive framework for research, onto which other funding could be superimposed very efficiently (e.g., grants from AI cooperatives). Overhead costs and faculty salaries were subsumed in the system, whereas today those 2 items often consume one-half of a research budget. Many researchers and administrators not only long for a partial return to more formula funding, but also expend efforts to move things in that direction. Unfortunately, the trend is otherwise.

My cursory analysis is that the end users of research with farm animals are as follows, beginning with maintenance of infrastructure and ending with the more applied end users:

- Maintaining the research programs of the principal investigators
- The use of publications (mostly refereed papers) by other scientists
- Agricultural collaborators
- Industry and government
- The spectrum of farmers
- Nonagricultural public

A few words of explanation are provided here for the first item in the list. Any substantive research program depends on its previous research in several senses: building a foundation of information and tools, continuity of the work, and building and maintaining a reputation. In that sense, principal investigators are their own best customers. This is a legitimate and necessary aspect of maintaining infrastructure that needs to be recognized.

The next issue is how funds and decisions flow through the system. Again, an oversimplified view follows, listed from top to bottom:

- Customers, stockholders, citizens
- Congress, legislators, markets, boards of directors
- Institution, agency, company
- Department, ARS unit, industrial unit
- Principal investigator or equivalent, professor
- Students, technicians, senior personnel

Beginning from the top of this list, at least theoretically, customers vote according to their spending habits and citizens and stockholders vote directly for representatives (line 2), who then find and authorize funding for entities who administer research programs (third line), and so on down the list to the bottom line, person who actually do the research. Of course, funds do not flow perfectly or smoothly down this list, and considerable overhead is used along the way, directly or indirectly.

Probably what needs the most future attention is the flow of information back up the list. Information garnered from research likely would not flow through every entity in this list, at least not in sequence. Nevertheless, it probably would be wise to provide such information to persons at all levels in some form or another.

Where will most funding come from? Likely the federal agencies such as USDA and National Institutes of Health will remain the main sources of funding via competitive grants, and, of course, there will continue to be some federal formula funds plus related funding from state governments. Philanthropic funding will increase, mostly from such individuals as alumni, but also via foundations. Such funding is more likely to be directed toward infrastructure, such as endowed chairs and the construction of buildings, rather than paying for actual research, but there will be some increase in philanthropy for research projects, more for companion than food animals.

Industry will, of course, continue to fund both in-house and extramural research. This extramural component appears to be leveling off. I have no idea whether industry-sponsored research at universities will increase or decrease over the coming decades. Similarly, it is unclear whether miscellaneous sources of funding, such as providing services or teaching short courses, will in-
Concerns and challenges run the spectrum from items scientists can influence or control to those about which little can be done, at least on time scales less than decades. An example of the latter is international political instability. Having said that, a brief digression is in order. One of the most positive things about science is its universal, and therefore international, nature. International scientific collaborations are common, as is training students from foreign countries, particularly in North America, and particularly in animal sciences. In most cases, these international activities foster much good will as scientists of different cultures struggle with similar scientific issues in a collaborative manner. Such efforts may have plateaued within the past few years, but re dedication of scientists to cooperation, open dialog, and high standards of research is as important to the future of science as funding.

I believe that we have just begun to use the Internet effectively for collaboration in farm animal physiology and endocrinology research. The Internet, of course, is used routinely for communication, but there also are great possibilities for research via the Internet that are under utilized, such as operating specialized microscopes, flow cytometers, and mass spectrometers. Such collaborations should be encouraged and even subsidized; the more of this we do internationally, the more the world will become a better place.

One of the most distressing concerns is public scientific illiteracy. This is being addressed somewhat by efforts to improve K-12 education, but for the adult population, this issue is unlikely to be dealt with systematically. However, collectively as individual scientists, we have continual opportunities to speak to lay groups such as service clubs, church groups, 4-H clubs, and similar organizations, as well as some opportunities to speak in grade schools and high schools. Our research with physiology and endocrinology is especially appropriate to pique public interest (e.g., in vitro fertilization and embryo transfer to circumvent infertility, research related to cloning, circumventing genetic abnormalities, diabetes and obesity research). I have found that members of the public are remarkably reasonable about controversial topics such as cloning when experimental findings are presented in an interesting but unsensationalized manner. More of this needs to be done in the future, and scientists should be encouraged by employers, department heads, and tenure committees to participate in such activities.

Another area of concern is how to credit and reward interdisciplinary research efforts. This is especially problematic for untenured, tenure-track faculty, but similar issues exist in industry and government positions. Young faculty often are admonished not to get involved with interdisciplinary projects because they detract from establishing reputations and because contributions that can be evaluated for tenure are difficult to identify. There are several approaches to deal with this in the future, ranging from abolishing or greatly modifying the tenure system to changing how authorship is assigned in refereed publications. As an example, there could be different senior authors for different parts of papers. In any case, to promote and optimize interdisciplinary research, scientists need to be encouraged and rewarded early in their careers for such efforts rather than discouraged and even punished.

It is likely that the most important concern of animal scientists in academic settings is funding rates of competitive grants. For substantive funding via competitive grants, the rate for first-time submissions has dropped to approximately 10%; with repeated submissions of substantially similar proposals to the same agency, the cumulative odds increase to approximately 25%, a miserable situation using up years, especially when there is only one submission opportunity per year. Although there is considerable value in researchers having to present their research plans formally and rigorously, and to have them scrutinized and improved with suggestions by reviewers, the current situation consumes too much intellectual effort and too many resources. Furthermore, it is wearing and psychologically debilitating. For new faculty hires, this problem usually is buffered by substantive “start-up packages,” generally in the range of hundreds of thousands of dollars. These help considerably, although there are issues in how funds are spent, including a lack of flexibility, and a reluctance to use the funds until grants are obtained; also, the size of the start-up package receives undue weight in employment decisions. Some institutions simply cannot compete for the best new hires with this system.

In any case, agencies and administrators likely can arrive at less wasteful methods of distributing funding fairly and effectively than what has evolved. This is important for the future health of the research enterprise, particularly for farm animal research in physiology and endocrinology.

Some Final Thoughts

In thinking about future research in farm animal physiology and endocrinology, it is important to balance the concerns and constraints with the remarkable opportunities, both in scientific capabilities such as testing hypotheses with proteomic tools and in infrastructure, such as distant collaborations via Internet tools. Our main limitation could well be our imaginations, which need to be applied to the science as well as the infrastructure to accomplish the science. It is obvious that as individuals, as administrative units such as departments, and as institutions, we must concentrate on our strengths. At the same time, efforts should be
made to stretch beyond those strengths without being too fearful about making the occasional bad decision. The adage still will hold true in the future that the only ones who make no mistakes are those who do nothing.

**LITERATURE CITED**


