A commentary on domestic animals as dual-purpose models that benefit agricultural and biomedical research[1]

J. J. Ireland,*[2] R. M. Roberts,† G. H. Palmer,‡ D. E. Bauman,§ and F. W. Bazer#

*Department of Animal Science, Michigan State University, East Lansing 48824-1225; †Department of Animal Science, University of Missouri, Columbia 65211-7310; ‡Department of Veterinary Microbiology and Pathology, and School for Global Animal Health, Washington State University, Pullman 99164-7040; §Department of Animal Science, Cornell University, Ithaca, NY 14853-4801; and #Department of Animal Science, Texas A&M University, College Station 77843-2471

ABSTRACT: Research on domestic animals (cattle, swine, sheep, goats, poultry, horses, and aquatic species) at land grant institutions is integral to improving the global competitiveness of US animal agriculture and to resolving complex animal and human diseases. However, dwindling federal and state budgets, years of stagnant funding from USDA for the Competitive State Research, Education, and Extension Service National Research Initiative (CSREES-NRI) Competitive Grants Program, significant reductions in farm animal species and in numbers at land grant institutions, and declining enrollment for graduate studies in animal science are diminishing the resources necessary to conduct research on domestic species. Consequently, recruitment of scientists who use such models to conduct research relevant to animal agriculture and biomedicine at land grant institutions is in jeopardy. Concerned stakeholders have addressed this critical problem by conducting workshops, holding a series of meetings with USDA and National Institutes of Health (NIH) officials, and developing a white paper to propose solutions to obstacles impeding the use of domestic species as dual-purpose animal models for high-priority problems common to agriculture and biomedicine. In addition to shortfalls in research support and human resources, overwhelming use of mouse models in biomedicine, lack of advocacy from university administrators, long-standing cultural barriers between agriculture and human medicine, inadequate grantsmanship by animal scientists, and a scarcity of key reagents and resources are major roadblocks to progress. Solutions will require a large financial enhancement of USDA's Competitive Grants Program, educational programs geared toward explaining how research using agricultural animals benefits both animal agriculture and human health, and the development of a new mind-set in land grant institutions that fosters greater cooperation among basic and applied researchers. Recruitment of outstanding scientists dedicated to using domestic animal models for agricultural and biomedical research, strong incentives for scientists to take advantage of training opportunities to write NIH grants, and greater NIH and USDA cooperation to sponsor the use of agricultural animals as dual-purpose animal models that benefit agriculture and biomedicine will also be necessary. In conclusion, the broad diversity of animal models needed for agricultural and biomedical research is at risk unless research priorities at the land grant universities are critically evaluated and financial support for such research is dramatically increased.

Key words: domestic species, biomedical model, comparative animal model, dual-purpose animal model, farm animal research

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BACKGROUND

Abundant, safe, high-quality, nutritious, and affordable meat, dairy products, and eggs, which are important components of nearly every human diet, are vital to US consumers, to the agricultural industry, and thus to the mission of USDA. Consequently, a strong, innovative research and development program dedicated to US animal agriculture is necessary to ensure

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[2]Corresponding author: ireland@msu.edu

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food safety and to improve the quality and affordability of meat and milk, especially in an increasingly competitive global marketplace and during this period of escalating costs to produce animal products. However, despite the enormous economic value of animal agriculture to the US (approximately $110 billion), and the presence of many well-trained animal scientists at the 110 land grant institutions and 28 colleges of veterinary medicine in the United States, only approximately 0.038% ($35.4 million) of USDA's $93 billion fiscal year 2007 budget was allocated to the National Research Initiative for extramural competitive grants for basic and applied research that directly involves agriculturally important domestic animals (cattle, swine, sheep, goats, poultry, horses, and aquatic species). On the other hand, the US Department of Health and Human Services, which is the principal federal agency that protects human health and provides health services, allocated 4.4% ($28.4 billion) of its $641 billion budget in fiscal year 2007 to National Institutes of Health (**NIH**) for extramural competitive grants programs. Despite the likelihood that numerous high-priority human health research areas (e.g., cancer, obesity, aging, cardiovascular disorders, infectious diseases, diabetes, fetal development, and infertility) could benefit from the appropriate use of agricultural species as biomedical models, the use of such animals in biomedical studies remains extremely low. Taken together, these limitations jeopardize not only the future global competitiveness of US animal agriculture, but also the potential for novel use of agricultural species as comparative biomedical animal models to resolve high-priority human health issues.

Few would challenge the concept that an "agricultural perspective" is appropriate and must be maintained at our land grant institutions. Nonetheless, the future of research in animal agriculture depends on strong graduate training programs, faculty engaged in cutting-edge research, and an infrastructure available within animal and veterinary science departments to preserve resources in terms of flocks and herds and a diversity of animal breeds. However, analysis of data in the USDA Current Research Information System illustrates a 44% loss of purchasing power and 22% loss of scientists supported by Cooperative State Research, Education, and Extension Service (**CSREES**) and state appropriations from 1985 to 2006 (Figure 1)! Analysis of data in the National Science Foundation's Survey of Earned Doctorates showed that the number of doctoral degrees awarded from 1985 to 2004 in the animal sciences (including animal breeding and genetics, and nutrition) has declined by 30% (USDA Research, Education, and Economics Information System, 2007; Figure 2)! More recent data show that enrollment in MS and PhD programs in the animal sciences declined by 9 and 16%, respectively, between 2004 and 2006 (Food and Agricultural Education Information System, 2007). Faculty positions in animal sciences at some of the larger land grant institutions (e.g., the University of Missouri-Columbia) have fallen by more than 50% in the last 30 yr, with no apparent end to the decline in sight. Equally troubling is the rapid disappearance of breeds and genetic lines of domestic species, especially poultry (Fulton and Delany, 2003), which are critical to unraveling the importance of genetic variation to optimal health and well-being in animals and humans. For example, in a recent survey of land grant institutions (conducted in 2008 by Karen Plaut and James Ireland, Department of Animal Science, Michigan State University), 30 of 31 animal, dairy, and poultry science departments representing 29 states report significant downsizing or complete loss of beef, dairy, swine, or sheep herds or poultry flocks since 1985! Unless state and federal support for infrastructure at the land grant institutions is increased and the entire USDA-CSREES allocation for competitive grants in animal research is greatly revised upward, both of which require political support from key legislators, the entire research enterprise supporting animal agriculture will fragment, and at best become focused at just a few locations (Bazer, 2007; National Association of State Universities and Land-Grant Colleges, 2007). One alternative that might help this dire situation is the creation of a new funding agency dedicated to supporting agriculture through competitive grants (Danforth, 2006), but even this innovation may not be sufficient.

The USDA-CSREES extramural Competitive Grants Program is inadequate to provide the level of support needed to sustain research directly related to the production, health, and well-being of agriculturally important animals (Overton, 1994; Danforth, 2006; Bazer, 2007; National Association of State Universities and Land-Grant Colleges, 2007). Therefore, many talented animal and veterinary scientists seek alterative sources of funds and use models unrelated to animal agriculture to maintain their research programs. Consequently, unless the traditional research focus of animal science departments is expanded to include biomedicine, bright young scientists will not be attracted to animal agriculture. In addition, research involving agricultural animals is likely to continue to decline as a component of life sciences research in colleges and universities throughout the United States, and this would represent a missed opportunity. As a result of these concerns, stakeholders, including internationally recognized scientists funded by USDA and NIH, university administrators, scientists and fellows in a variety of disciplines, and officials at NIH- and USDA-organized workshops, held a series of meetings at USDA and NIH and developed a white paper (http://www.adsbm.msu.edu; last accessed August 18, 2008) to identify and propose solutions to the major obstacles to enhanced use of domestic species as dual-purpose models that benefit animal agriculture and biomedicine. The purpose of this article is to highlight the stakeholders' findings and recommendations.

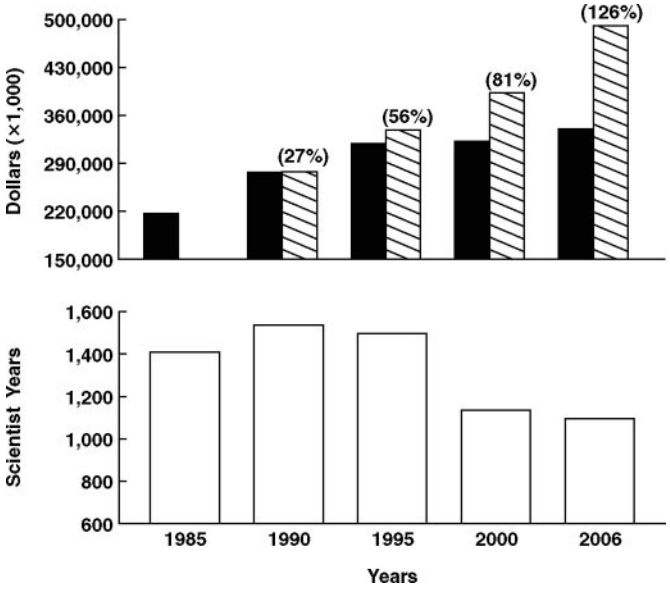

Figure 1. Loss of purchasing power and the decline in scientist years supported by Cooperative State Research, Education, and Extension Service (CSREES) and state appropriations for research using domestic species. Research includes animal production and animal protection programs in CSREES. Cooperative State Research, Education, and Extension Service dollars include expenditures from formula-funded projects and obligations from CSREES-administered grants. In the upper panel, the black bars reflect the combined funding provided by CSREES and state appropriations for research using domestic animals, whereas the hatched bars reflect the purchasing power of the CSREES and state appropriations after adjustment for the cumulative biomedical research and development price index since 1985. Numbers in parentheses indicate the cumulative inflation rate since 1985. Cumulative inflation rates were based on data obtained online (http://officeofbudget.od.nih.gov/UI/GDP_FromGenBudget.htm; last accessed August 18, 2008) from the National Institutes of Health Office of Budget. In the lower panel, the open bars reflect scientist years supported by the CSREES and state appropriations for research using domestic species. Data are from the Current Research Information System (http://cris.csrees.usda.gov; last accessed August 18, 2008) and were provided by F. A. Moore and D. L. Hamernik on February 15, 2008.

OBSTACLES AND POTENTIAL SOLUTIONS

The key obstacles that impede the use of farm animals as dual-purpose models for animal agriculture and biomedicine, and potential solutions to these problems are discussed within the following 4 interrelated areas.

The Advocacy Obstacle

Lack of advocacy is the prime impediment to the enhanced use of agricultural animals for biomedical research. Simply put, scientists unfamiliar with agricultural species as animal models, university administrators, officials at USDA and NIH, politicians, and the public at large do not appreciate the advantages of agricultural animals as comparative animal models for biomedical research. The advantages of domestic animal models are particularly compelling in terms of translational research, moving concepts from the laboratory to human health applications. These same individuals are also generally unaware of the past impact such research has had on societal well-being and human health (http://www.adsbm.msu.edu), nor are they conscious of the high quality of basic science being performed in animal and veterinary science programs. This knowledge void creates major institutional and funding barriers throughout academia. Moreover, it prevents quality research from being conducted proactively to address key issues in agriculture through the use of state-of-the-art genomics biology to benefit production animal agriculture as well as human and animal health and well-being.

Potential Solution

Vigorous, broad, and proactive advocacy and educational programs, administered jointly by land grant institutions [e.g., Academic Programs Committee on Organization and Policy (ACOP) and National Association of State Universities and Land Grant Colleges (NASULGC), www.nasulgc.org, last accessed August 18, 2008; Experiment Station Committee on Organization and Policy (ESCOP), http://escop.ncsu.edu, last accessed August 18, 2008), the Association of American Veterinary Medical Colleges (AAVMC), http://www.aavmc.org, last accessed August 18, 2008] and appropriate animal industries will be required to enhance the use of domestic species for research. These programs must be strong advocates to explain the past contributions and future opportunities of research on agricultural animals and their value as comparative animal models for research that benefits animal agriculture and human health. The advocacy and educational program can take many forms, including symposia at universities, funding agencies, and scientific and public meetings such as recent workshops (http://www.adsbm.msu.edu). They can also involve the development of informative Web sites (e.g., http://www.adsbm.msu.edu) that provide historical and current examples of the importance and advantages of domestic species as biomedical models in a variety of critical areas of research. For example, it is probably not well known that 17 Nobel Prizes have been awarded to scientists who conducted research with cows, chickens, horses, or sheep as biomedical models during their studies.

Land Grant Barriers

The long-standing cultural idiosyncrasy that biomedical research is "inappropriate" to the land grant mission is an unfortunate attitude permeating the culture of traditional agriculture and belief system of many of its administrators and influential faculty members. This cultural barrier explains in part why agricultural colleges have historically been segregated from colleges of human medicine and veterinary medicine, and the basic life sciences disciplines. This science-segregation policy at land grant institutions diminishes communication, the sharing of resources, and collaboration among scientists who could benefit from these interactions. At many institutions, the isolation of animal science programs, in particular, has contributed to a lack of recruitment of top-notch researchers into the area and a failure to tap into the funding available through using agriculturally important animal species for biomedical research. There is often little incentive for animal scientists to collaborate with biomedical scientists, engineers, and others who could bring an interdisciplinary perspective and novel insights into traditional animal science thinking. The land grant schools, hidebound by traditional concepts of the type of research that should be supported, have also failed to provide mechanisms to encourage scientists to think "outside the box."

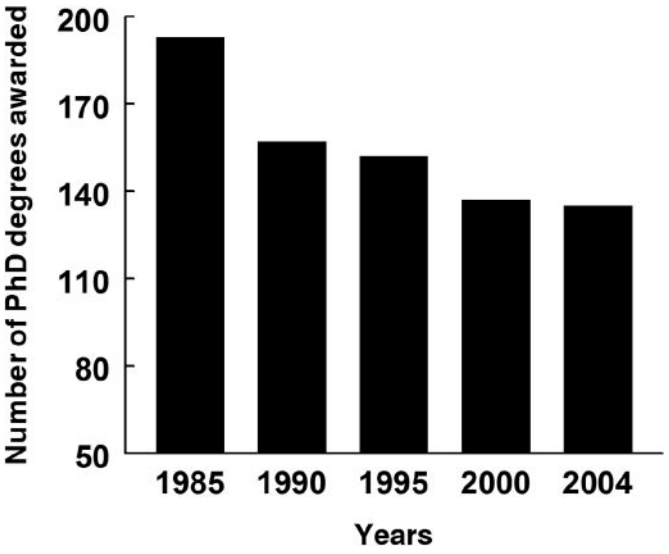

Figure 2. Changes in the number of PhDs awarded in animal science-related fields of study, including animal science, breeding and genetics, and nutrition. Data were obtained from the National Science Foundation "Survey of Earned Doctorates" from all US academic institutions (USDA Research, Education, and Economics Information System, 2007).

Potential Solutions

Enhanced use of agricultural animal species for biomedical research requires the development of a new mind-set within land grant institutions, a mind-set that fosters greater cooperation among basic and applied researchers across a variety of departments, disciplines, and industries. Administrators are aware that the protected island fortress of agriculture is becoming an anachronism that is no longer viable as state and federal support declines. Indeed, traditional agricultural research cannot thrive in isolation. Consequently, administrators must not back away from defending the use of farm animals for biomedical research in animal science departments, especially when dealing with their traditional stakeholders. It is highly recommended that leaders of land grant institutions seek guidance from 2 or 3 successful institutions with existing strong cooperation between colleges of agriculture and the rest of the campus (e.g., University of Illinois, University of Missouri). Suggested ways to strengthen cooperation among animal science departments, medical schools, and basic science departments (Table 1) include the following:

- Create a list of the high-priority research areas at NIH that currently use or could benefit from the use of agricultural animals as biomedical models, and use these high-priority research areas as a blueprint for future faculty hires and incentive plans to foster interdisciplinary or multidisciplinary research.
- When the opportunity exists, hire new administrators with the leadership skills and vision to
  i. Resolve philosophical differences among animal science departments, basic science departments, colleges of veterinary medicine, schools of public health, and colleges of medicine, and
  ii. Enhance cross-departmental research programs.
- Hire faculty and department chairs in animal science and the basic sciences within colleges of veterinary medicine who are not trained simply in traditional animal and veterinary sciences, but who also have experience in, or at least the appreciation of, newer and emerging technologies and the broad scope of animal sciences for society as a whole. Such leaders should be prepared not only to serve traditional agricultural stakeholders, but also to interact with the broader life science community.
- Hire new faculty with joint appointments in medical schools and basic science departments, or interfacing with existing animal scientists in cutting-edge research programs in medical schools, veterinary schools, and basic science departments.
- Create incentives for collaboration among animal, basic, and clinical research scientists by
  i. Providing leverage and seed funds for interdisciplinary research.
  ii. Facilitating and promoting the sharing of facilities and resources.

iii. Encouraging animal science faculty members to collaborate with nonagriculture colleagues to submit NIH grants and to increase publications in high-impact biomedical and basic science journals.
iv. Creating centers of excellence committed to the use of agricultural animal species as comparative animal models. One long-term approach to generate the funds necessary to stimulate interdisciplinary research is to reduce the duplication of research, extension, and teaching efforts in agriculture at land grant institutions. The cost savings from formation of "regional clusters" of land grant universities to conduct extension, education, and research, coupled with USDA formula

Table 1. Research areas (not prioritized) that could be advanced by using agricultural animals as biomedical models

General research area	Specific areas of research
Aging	Skeletal diseases, especially with chicken and pig models; bone metabolism and osteoarthritis, especially with the horse model; reproduction, especially with beef cattle and mares
Biomechanics	
Cardiovascular disorders	Diet-induced atherosclerosis and lethal cardiac tachyarrhythmias (ventricular fibrillation) by using miniature or normal pigs
Comparative physiology	Understanding what makes cattle breeds different with respect to reproduction, lactation, growth, bone structure, fat deposition, altitude and heat tolerance, and resistance to specific pathogens and parasites to elucidate related physiological processes important to human health
Diabetes, types I and II	
Diseases	Transmissible spongiform encephalopathies; respiratory syncytial virus; Crohn's disease; sexually transmitted diseases; enteric diseases, including transmissible gastroenteritis; viral diseases; *Escherichia coli* O157H7; cancer, including prostate, breast, ovarian (chicken), hematopoiesis, and leukemia; salmonellosis, tuberculosis, and cryptosporidiosis, using cattle as a model; and pathogen transmission of emerging diseases that infect animals and humans
Disorders	Liver, epilepsy, and sleep (e.g., narcolepsy)
Epigenetics and the environment	Effect of photoperiod, global warming, seasonality, toxins, and other factors on the modification of gene function
Immunology	Autoimmune diseases, inflammation (innate and mucosal)
Microbial ecology	
Neurobiology	Behavior, stress, learning, pheromonal communication, and neuroendocrinology
Nutrition	Energetic balance, including homeostatic mechanisms, regulation of metabolism, and nutrigenomics; nutrition, metabolism, and gastroenterology using the neonatal piglet as a pediatric model
Obesity	Genetic, dietary, and hormonal influences on pre- and postnatal adipose tissue development, using the pig model
Ophthalmology	Retinal degeneration, retinitis pigmentosa, and macular degeneration
Pregnancy	Placental growth, angiogenesis, congenital and birth defects, developmental biology, especially using chickens; fetal programming, especially with sheep to study stress; malnutrition; effects of the exposure of fetuses to androgens and environmental toxins on adults; the molecular or cellular bases of parturition and premature birth; the well-being of the newborn; and lactation biology
Radiation biology	
Renal biology	
Therapeutics	Xenotransplantation, gene therapy, stem cells, and "farmaceuticals"
Toxicology	Environmental endocrine disrupters
Reproduction	Gametogenesis, gonadal function, and infertility

Table 2. National Institutes of Health (NIH) grant funding for studies using rodent or domestic species as models[1]

Year	Grants reviewed	Grants funding studies using rodents as models	Grants funding studies using domestic species as models	Total grants funding studies using domestic species models[1]
2002	8,842	3,328	79	2.3
2003	10,865	3,898	83	2.1
2004	13,525	3,947	64	1.6
2005	14,877	3,524	52	1.5
2006	16,582	2,262	37	1.6

[1]Data provided by the NIH Center for Scientific Review staff (conducted August 2007). Rodents included the mouse, rat, hamster, guinea pig, and gerbil, whereas domestic species included the cow, pig, sheep, horse, chicken, turkey, duck, and goat.

funds, could be used to sponsor creative research by new or existing productive faculty members interested in generating preliminary data important for both agriculture and biomedicine.

Limited Diversity of Species Supported as Biomedical Models by the NIH

Research involving domestic animals has a well-established role in improving animal agriculture, but a poorly understood, yet critical, role in advancing biomedical research to enhance human health. For example, the relatively recent completion of the sequencing of the human genome provided the genetic blueprint that will eventually help elucidate the interrelationship of genetic variation and the environment with human health. As this crucial new genetic information is generated, it will provide the fundamental new knowledge that scientists need to design more effective preventive or therapeutic methods to eliminate or combat many of the factors that currently have a negative impact on human health (e.g., cancer, cardiovascular disease, obesity, alcoholism, low birth weight, and infertility). However, despite elucidation of the sequence of the human genome, the scientific challenge of translating this information to advance human medicine is daunting, especially because studies involving humans are both expensive and limited to specific interventions. Therefore, a diversity of comparative animal models from different evolutionary ancestries are required not only to identify highly conserved genes and to understand gene function, but also to extrapolate genetic information from comparative animal models to humans (Gibbs et al., 2004). The selection of the most appropriate animal model includes considerations such as size and experimental tractability (e.g., ease of surgical manipulation, frequency of blood sampling, availability of large volumes of blood or tissues for assay, efficiency of cloning, and xenotransplantation), as well as the species physiology and disease pathogenesis that best recapitulate human biology and disease.

Despite the value of using diverse species to understand the evolutionary history of mammalian genomes (Gibbs et al., 2004) and the clear advantages of domestic animals in certain biomedical research applications (http://www.adsbm.msu.edu), rodents (especially mice) remain by far the predominant experimental animal model used for biomedical research. For example, an analysis of all funded NIH grants from 2002 to 2006 for studies that used rodent or domestic species models revealed that approximately 98% used rodent models (Table 2). Moreover, during those years the number of funded grants for studies that used domestic species declined by 30% (Table 2). A recent search of the Computer Retrieval of Information on Scientific Projects (http://crisp.cit.nih.gov/; last accessed August 18, 2008) database of all abstracts of research programs and projects funded in 2008 by the Department of Health and Human Services revealed that 4,134 projects used mouse or rat models, but only 115 projects used domestic species as biomedical models. Another Computer Retrieval of Information on Scientific Projects search for projects funded in 2008 showed that 23,173 projects used mice or rats as a source of reagents, pathogens, or cell lines, or as experimental models, whereas 1,762 projects made use of domestic species. Three conclusions can be drawn from these data. First, these analyses provide clear evidence of increasing reliance on a single-species animal model for biomedical studies. Second, only a small fraction of biomedical research projects take advantage of domestic animals. Third, the use of domestic animals as comparative animal models is in decline.

The Center for Scientific Review at NIH did not release the complete data necessary to determine whether a greater proportion of grants submitted using rodent versus domestic species models are routinely funded at NIH. Consequently, there is no quantitative evidence to support this contention, and whether there is bias against domestic animal models within NIH study sections remains debatable. Nevertheless, it can be argued that applications proposing the use of agricultural species as comparative animal models require more extensive justification and preliminary data than applications that use the more common rodent models. Despite whether this is fair, it illustrates the important role that both institutional and USDA-CSREES support has in establishing specific domestic animal models for biomedical research. In addition, NIH study sections could lack the needed expertise and insight into the use of domestic animal species as biomedical

Table 3. Key attributes of successful National Institutes of Health grants

Attribute
Simple questions with appropriate background
Substantial and compelling preliminary data
Current gaps in knowledge addressed
Unique, comparative value of the chosen model explained (cannot recapitulate prior observations in other species)
Explanation of how the model led an area of research and answered questions
A broad range of disciplines and expertise
Potential bias or concerns of reviewers addressed
Senior investigators had a significant track record of success, including publications in high-quality journals
Applications were critiqued by experienced investigators before submission, and applicants heeded the advice of the program manager, scientific review officers, and reviewers

models. Finally, the quality of publications describing research in agricultural animals, which provides the main criterion used to assess the performance record of investigators, could be perceived as inferior by NIH reviewers, because most publications by animal scientists tend to be in commodity-related journals, rather than biomedical or disciplinary journals.

It is unclear why so few grant proposals that use domestic species are funded through NIH. One likely explanation is that there are relatively few animal scientists with the necessary training, expertise, or motivation to develop and submit high-quality applications with the potential of being funded by NIH. This is coupled with the fact that few scientists on NIH review panels recognize and understand the unique opportunities offered from research with domestic animals. The long-standing land grant tradition of providing "hard money" support for research has resulted in having scientists in agricultural experiment stations that do not depend on grants to conduct research; thus, they have limited or no experience in writing grant applications. In short, grantsmanship among animal and veterinary scientists is generally weak, and few scientists within colleges of agriculture have been compelled to write grant proposals to keep their research programs alive and even to provide their own salary support.

Potential Solutions

To maximize the potential of using domestic animal species as models for NIH-supported biomedical research, universities must strongly encourage and provide incentives for animal and veterinary scientists to attend intensive training workshops to learn how to write competitive NIH grants and justify animal models (Table 3). Furthermore, scientists must strive to publish in the highest quality journals and to place their scientific findings in a broad context of biology and biomedicine. To do so, the flagship land grant universities must dedicate efforts toward recruiting outstanding scientists who conduct research with domestic animals as biomedical models and toward distinguishing themselves from other animal science programs at 4-year colleges and universities that do not offer doctoral degrees.

Proactive forms of advocacy should be implemented to enhance awareness by the broader scientific community, NIH officials, and policy makers of the uses and benefits of agricultural animals as biomedical models. To accomplish this objective, more effective interagency (NIH, USDA) dialog and cooperation must be established to advocate the use of agricultural animal models in an effective manner (perhaps by sponsoring symposia or workshops with awardees from both agencies at biomedical meetings) and to develop funding opportunities or training grants. For example, stakeholders have identified 6 high-priority research areas common to both animal agriculture and biomedicine that could be advanced further if both USDA and NIH formed partnerships to fund programs jointly. The potential tangible benefits to each agency are listed in Table 4.

The NIH Center for Scientific Review should ensure that applications that use domestic animal models receive informed and comprehensive reviews. The scientific community, including those scientific societies that focus on animal science and veterinary medicine, needs to encourage and support their members to serve on study sections. The NIH has recently instituted changes that reduce the burden of permanent membership in a study section by permitting panel members to submit their own NIH applications on a flexible schedule. Scientific Review Officers should select both permanent and ad hoc members as needed to ensure that the expertise required for a specific animal species is represented within the review, and that the emphasis is on the contributions of the animal model to human health and not on the model itself. Finally, NIH

Table 4. List of high-priority research areas common to both animal agriculture and biomedicine, and potential impact of each research area

Common research area and potential impact
Development of improved methods 1) to promote genetic recombination in somatic cells to enhance the efficiency of generating genetic "knockout" animals through somatic cell nuclear transfer and 2) to enhance the efficiency of nuclear reprogramming to create stem cells and improve the efficiency of cloning domestic species is recommended. Tangible impacts relevant to the mission of USDA and National Institutes of Health (NIH) include the development of transgenic farm animals with economically important traits (e.g., disease resistance, high fertility, enhanced meat quality or growth) or nutraceutical value, and the development of new biomedical models with domestic species for human diseases.
Elucidation of the mechanisms that regulate the competency of oocytes to develop into viable offspring (egg quality) and to identify reliable markers of high-quality oocytes. Tangible impacts relevant to the mission of USDA and NIH include improved success of in vitro fertilization and embryo transfer, improved cloning efficiency in farm animals, and enhanced success of assisted reproductive technologies in humans.
Elucidation of the impact of the environment in utero on developmental programming leading to the onset of disease in adulthood, and identification of the mechanisms whereby the environment alters developmental programming of the embryo or fetus and subsequent health, growth, and fertility of the offspring is recommended. It is becoming more evident that the mother's environment (e.g., nutrition, obesity, toxicants, drugs, disease) during pregnancy can have a major impact on mechanisms that regulate embryonic and fetal development (developmental programming), which in turn may compromise the health of the offspring. However, little, if any, attention has been paid to the impact of the environment during the pregnancy of farm animals on subsequent economically important traits in the offspring such as growth rate, lactation, disease resistance, and fertility. Moreover, biomedical models to investigate the developmental origins of human disorders are scarce. Tangible benefits to USDA and NIH include the development of new therapies to prevent or treat the negative effects or enhance the positive effects of the environment on embryonic or fetal development and the subsequent health of human beings, and on economically important traits (e.g., growth, fertility, disease resistance) in farm animals.
Elucidation of the biology of adipocytes, including the mechanisms regulating lipid metabolism and fat deposition in a tissue- and stage-specific fashion in domestic species is recommended. Tangible benefits to USDA and NIH include development of a better basic understanding of the causes of obesity in humans and improved meat quality and enhanced performance (e.g., lactation) in farm animals. This new information will not only provide a better understanding of how fat deposition is regulated, and thus lead to treatments that improve the consistency of meat products in farm animals and their nutritive value, but also provide valuable insights into the mechanisms involved in human obesity, perhaps leading to novel therapies to combat this worldwide human disorder.
Control of diseases in animal reservoirs before their spread to humans has a tremendous impact on public health and provides unequaled cost-effectiveness. The control of rabies and milk-borne *Mycobacterium* and *Brucella* provide clear examples of this efficacy, approaches that can now be applied to other pathogens such as avian influenza, *Escherichia coli* O157:H7, and *Salmonella*. This approach, clearly recognized in the recent American Medical Association-American Veterinary Medical Association initiative, requires new coordination between USDA and NIH, and joint funding by both agencies is recommended to study pathogen transmission within animal populations and the development of vaccine strategies to block transmission at the animal level, before emergence into the human population.
Development of a funding program to provide a supplement to awarded grants that develop new reagents, resources, and transgenic farm animals as part of the overall research plan (in place of "stand-alone" reagent, resource, or transgenic animal development funding) is recommended. The supplement could include additional funds to develop critical antibodies, transgenic animals, tissue repositories, gene chips, high-throughput genome screening, and complete genome sequencing of all food animal species of economic importance (e.g., the sheep).

could also improve networking among scientists who use agricultural species as comparative animal models by announcing to land grant universities the successful NIH proposals that used agricultural animals in this capacity. Better networking would lead to better use of expensive resources and would provide additional opportunities for motivated animal scientists to generate preliminary data.

Limitations in Research Tools

For some agricultural animal species, the resources to conduct creative research are limited. Challenges faced by animal scientists include 1) a lack of available species-specific tools and reagents, including antisera and antibodies, cytokines, and growth factors; 2) small or poorly managed collections of cell lines, germplasm, and databases for computational biology and bioinformatics; 3) inadequate genetic resources, such as defined inbred lines with characterized genetics; and 4) a lack of required genetic tools, such as genomic sequences for sheep, turkeys, and aquatic species; inexpensive microarrays for a range of agricultural animal species; and clone sets and primer sets for major genes.

Potential Solutions

The USDA, NIH, and National Science Foundation and industry must cooperate to develop strategic plans, set priorities for research, and generate the financial support necessary to fund the development of critical resources.

Summary and Conclusions

Agriculturally important animals can be used not only for research to improve animal agriculture, but also as biomedical models that often more closely mimic

human physiology and disease than do rodent models. Because research using domestic animals requires special facilities and expertise, highly qualified research scientists using domestic animals for research in animal agriculture, as biomedical models, or both need support by federal funding agencies to enhance their unique contributions to new agricultural and medical knowledge. Consequently, USDA and NIH should jointly advance domestic animals as dual-purpose models to resolve high-priority problems common to both animal agriculture and biomedicine. First, the missions of USDA and NIH are inextricably linked because the health, well-being, and fertility of domestic species underpin the availability and affordability of high-quality, nutritious food, which contributes directly to health maintenance and the prevention of chronic diseases in humans. Second, genetic lines of agricultural animals, facilities, and faculty expertise are valuable resources that are substantially underused for studies to benefit human health. Therefore, enhanced use of domestic animals as biomedical models will provide the additional benefit of generating important new information directly relevant to many areas of research in animal agriculture.

In conclusion, the immediate challenge is for stakeholders to continue to embrace high-quality research and to communicate, cooperate, and work unselfishly to eliminate the obstacles impeding the use of domestic animals as animal models in agriculture and biomedicine to ensure that citizens of the world will continue to be provided with a safe and abundant supply of food, excellent health care, and a high quality of life.

LITERATURE CITED

Bazer, F. W. 2007. How to boost agricultural research. The Scientist 21:29.

Danforth, W. H. 2006. Funding basic agricultural research. Science 314:223.

Food and Agricultural Education Information System. 2007. Animal Science Graduate Enrollment. http://faeis.ahnrit.vt.edu/newsletter/december_07/newsletter.html Accessed March 14, 2008.

Fulton, J. E., and M. E. Delany. 2003. Genetics: Poultry genetic resources—Operation rescue needed. Science 300:1667–1668.

Gibbs, R., G. Weinstock, S. Kappes, L. Schook, L. Skow, and J. Womack. 2004. Bovine Genomic Sequencing Initiative: Cattle-izing the Human Genome. http://www.genome.gov/Pages/Research/Sequencing/SeqProposals/BovineSEQ.pdf Accessed August 18, 2008.

National Association of State Universities and Land-Grant Colleges. 2007. Creating Research, Extension, and Teaching Excellence for the 21st Century (Create-21). http://www.create-21.org/index.htm. Accessed April 4, 2008.

Overton, J. 1994. Investing in the National Research Initiative: An Update of the Competitive Grants Program of the U.S. Department of Agriculture. Natl. Acad. Press, Washington, DC.

USDA Research, Education, and Economics Information System. 2007. Reports: NSF/SED Reports. http://www.reeis.usda.gov/portal/page?_pageid=53,545315&_dad=portal&_schema=portal&smi_id=38 Accessed April 4, 2008.