

13

Ensuring the Scientific Foundations for Agriculture's Future

Robert M. Goodman

Agricultural research must change in fundamental ways if it is to serve the changing needs of agriculture, the demands of national security, and indeed the future of a human population racing toward 10 billion and more. In the United States, economic and demographic trends, changes in the landscape, and our changing roles in the community of nations all have implications for agricultural research, and they call for reordering its priorities. Legitimate public concerns about health, the safety and reliability of the food supply, and the cost and nutritional quality of foods all dictate a rethinking of the agenda and institutional arrangements for agricultural research.

In my vision, agricultural research is fundamentally reformed to serve the needs of modern society and to be responsive to the public. This vision is based on the following principles:

- Agricultural research must serve the broad public, not just a narrow constituency of agricultural producers, agribusinesses, or those exercising partisan political influence.
- It must be scientifically integrative, grounded in ecology, and committed to the highest scientific quality.
- It must be conducted in an institutional context that ensures accountability but must be managed lightly to allow creativity, risk-taking, and invention.
- It must be made attractive to people capable of the highest levels of creativity and scholarship and should be a central part of the intellectual and educational missions of our universities and colleges.
- It should be supported by funding mechanisms and an infrastructure that are open to all.

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Without a renewed commitment to serving society's needs and a drastic overhaul of its place in our nation's intellectual life, agricultural research will continue its decline into pursuit of its narrow self-prescribed interests, unable to attract the outstanding minds or investment needed to make a field exciting, rewarding, and sustainable. As a result, it will continue to lose the political support so vital for assured public funding. Publicly funded agricultural research is justified if it contributes to agriculture's competitive success, sustainability, and environmental quality. Failure to embrace changing social needs and reverse the erosion of public support for agricultural research will contribute to a long-term erosion of our nation's agricultural preeminence and possibly to serious disruptions with implications for internal stability and international security.

Agricultural Research's Harvest of Criticism, Past and Present

Agricultural research and its institutions have been the target of critics from the beginning (Rossiter 1975). Controversy arose from the views of those espousing religious causes, defending farmers' traditional practices, and resisting increases in taxation.

Contemporary criticism of publicly funded agricultural research is motivated by many of the same concerns. However, it has added new ingredients. For more than twenty years, the *results* of agricultural research have been targets of criticism. Instead of celebrating what they consider successes—powerful pesticides, labor-saving equipment, massive export earnings, preservation technologies, and advances in food manufacturing—the champions of agricultural research instead must defend their successes against a wide range of critics who blame the “successes” for increased industrialization, decreased consumer satisfaction, increased food safety concerns, and decreased connectedness to the food system. Also new is a profound and widespread disillusionment and pessimism within the research community itself about the system they work in. Researchers feel isolated from the public they are supposed to serve and from mainstream academic life. For all these reasons, as we rethink the future of agriculture, it also is fitting to rethink seriously the premises for publicly supported agricultural research.

A Fundamental Re-vision of Agricultural Research

The intellectual scope of agricultural research is vast. It embraces many different organisms and different kinds of interactions among

them. It encompasses, from agriculture, medicine, and industry and ranchers to ecologists. Therefore, in any case would responsiveness in sketch some ideas for the future of agriculture.

- *New themes for agriculture*—agriculture and integrative the exploitative system of genetics provide technological, genetics and forward an agricultural quality
- *Engaging an in*—volume write a create new relationships, labor, unity should encourage as many dialogue with the the key to future contrast, public is weak.
- *Rethinking the United States*—agricultural research, isolated and prospective in and ability, not or research in research fund integrated with corresponding ment of Agriculture

them. It encompasses essentially the entire scope of academic disciplines, from agronomy and zoology to anthropology and zoonotic medicine, and its participants range from highly experienced farmers and ranchers to highly trained microeconomists and molecular biologists. Therefore, to prescribe a fully detailed agenda is not feasible and in any case would be inconsistent with my call for flexibility and responsiveness in the research enterprise. However, it is appropriate to sketch some ideas for stimulating the necessary rethinking about the future of agricultural research. These fall into three categories:

- *New themes for agricultural research.* The organizing principles for future agricultural research themes that will serve the emerging needs of agriculture described elsewhere in this volume must be ecological and integrative. Unmistakable signs exist that humans must replace the exploitative model manifest in our pesticide-dependent, industrial system of agricultural production. The unifying principles of genetics provided agriculture with powerful tools, both intellectual and technological. The emerging principles of ecology, integrated with genetics and wisely used, offer society enormous promise to move toward an agriculture consonant rather than in conflict with environmental quality and sustainability.
- *Engaging an informed public in setting the research agenda.* Others in this volume write about engaging and empowering public participation to create new relationships between agriculture and communities, landscapes, labor, and the economy. The agricultural research community should embrace this process. Rather than proving meddlesome, as many contend, new mechanisms for engaged and informed dialogue with the public about the agricultural research agenda may be the key to future political support for agricultural research. Today, in contrast, public commitment is declining and public understanding is weak.
- *Rethinking the roles and funding of agricultural research institutions.* The United States spends a sizable amount of public money on agricultural research, but the institutions that spend most of that money are isolated and insular. I propose instead a funding system open to all prospective investigators, the only qualifications being their interests and ability, not whether they are at a specifically agricultural college or research institution. I also propose a major reallocation of public research funding to universities, where agriculture can and must be integrated with broader educational and intellectual missions, and a corresponding deemphasis of research funding in the U.S. Department of Agriculture.

New Themes for Agricultural Research

Ecological principles should dominate how we think about agriculture and how we choose research questions and approaches. Many of society's concerns about agriculture arise from an emerging appreciation of the limits of agricultural production systems that are based on exploitation rather than sustainable use of resources. Agricultural production must become more responsive to such concerns, as expressed by many authors in this volume. This places a staggering challenge on agricultural research, as discussed by Orr (1992, 50) in his writing about ecological literacy and the planetary consequences of human activity:

Several conclusions are beyond contention. First, we are crossing critical planetary thresholds or will soon do so. Second, we are woefully ignorant of the critical causal linkages between complex systems and the effects of human actions. Third, we do not have readily available data about the "vital signs" of the planet comparable, say, to the Dow Jones index. Fourth, most research is still directed toward manipulation of the natural world rather than toward understanding of the effects of doing so or the development of low-impact alternatives.

From an advanced, industrial, and highly sophisticated exploitative agriculture, we must redefine agriculture in its relationships to individuals, producers, local communities, nations, and humanity. Agriculture no longer is only local because of both global commerce and agriculture's consequences for the biosphere. Similarly, it no longer is primarily the concern just of those who produce or sell agricultural goods.

This redefinition will not be easy or free of risks. We will know that we are making progress if some ancient truths are reestablished. Such truths include the fundamental connection of individuals and responsibility for their food supply and the centrality of agriculture in human civilization.

However, we largely lack the knowledge required to move wisely and effectively toward more ecologically based agricultural systems while ensuring the production capacity to meet the needs of the population. Thus, a significant part of the task of designing a new agriculture will fall to agricultural research.

The fundamental unanswered questions about agriculture are ecological. My vision of agricultural research therefore calls for a major shift toward research that will contribute to a new level of ecological integrity in agriculture. The questions deserving study will require

greater emphasis on energy efficiency and research with a tradition more aggressively toward the study of ecological principles. Research questions in new models for ruralness.

The major gaps are ecological. Agriculture demands better knowledge of plants and animals with approaches now allow research tools from ecology.

Our objective must be in concert with nature, not against them. The needed ecological. The complexity from controlling environmental practice and research concentrated on the diagnosis and solution, embodying both mechanism and participation, will instead focus on participating and avoid the concept will likely in ecological development. It must be rigorous and creative, not be rich with technology, saying this I am not pre-twentieth-century, rejecting the potential approaches that may look to the past. The key is to integrate this knowledge to enrich rather than exploit resources on which agriculture

Agriculture should be of the biotic landscape and consequences of agricultural

greater emphasis on biological cycles, community ecological processes, and energy efficiency. Although we must continue to strengthen research with a traditional disciplinary focus, we also must move much more aggressively and with much greater analytical skill and rigor toward the study of complex systems and an understanding of the ecological principles underlying agriculture. A similar recasting of research questions in the social sciences will likely be needed to underpin new models for rural communities and global economic competitiveness.

The major gaps in our knowledge about the biology of agriculture are ecological. Any vision of ecological integrity for agriculture demands better knowledge of the biotic and abiotic interactions of plants and animals with their natural environment. Promising new approaches now allow us to rigorously study such interactions using research tools from molecular biology to address complex ecological questions.

Our objective must be productive agroecosystems that operate in concert with natural systems rather than simplifying or degrading them. The needed understanding will be both mechanistic and holistic. The complexity of biological cycles in a farming system prevents us from controlling every detail. Therefore, the focus in much agricultural practice and research has been on maximizing simplicity. We have concentrated on the development and application of products and the diagnosis and solution of problems. A more ecological approach, embodying both mechanistic and holistic views of agricultural production, will instead focus on managing naturally occurring cycles and anticipating and avoiding problems. The research underpinning of this concept will likely include discovery, descriptive research, and technology development. It will integrate across disciplines and scales and will be rigorous and creative but also practical and outcome-driven. It will be rich with technology but balanced with management know-how. In saying this I am not rejecting monoculture or advocating a return to pre-twentieth-century practices. On the other hand, neither am I rejecting the potential of polyculture or of nutrient management approaches that may look like the methods used on self-sufficient farms of the past. The key to this vision is to know how systems work and to integrate this knowledge in sophisticated ways that will enhance and enrich rather than exploit and degrade the people and natural resources on which agriculture depends.

Agriculture should be in concert rather than in conflict with the rest of the biotic landscape. This will require better ways of monitoring the consequences of agricultural practices and choosing technologies ap-

propriate for the ecosystems in which they are used. For example, we should know much more about the vast unknown world of microorganisms that inhabit soils, plant surfaces, and the digestive tracts of our livestock. Nutrient cycling, biological controls of pests and pathogens, environmental resilience, and increased biodiversity all are reasons for improving our understanding of the microbes with which we and our crops and livestock share the biotic world.

Our thinking about agriculture should not be limited to a field, farm, or particular cropping system. It must extend beyond the farm to the landscape and to the boundaries between cultivation and other forms of land use. Ecology has much to teach us about the wise management of watersheds, uncultivated and fallow lands, and cultivated lands and crops. A long-term view of agriculture should not be limited to the production of food, feed, and fiber. Renewable sources of alternative energy, chemical feedstocks, industrial raw materials, and even pharmaceuticals will likely one day come from "agriculture." We should be prepared for a time when such opportunities will exist for nations with the know-how, technology, and *understanding*. Again, a holistic and ecological outlook allows one to think about meeting agricultural, environmental, energy, social equity, and even aesthetic requirements that will enrich human life. It holds the hope that we will know enough to detect when something is out of whack before a Silent Spring or a Superfund disaster confronts us.

Engaging an Informed Public in Setting the Research Agenda in Agriculture

There is a powerful lesson in the contrast between our political commitment to biomedical research and to agricultural research. Many educated people cannot give a specific reason for investing tax money in agricultural research. Yet individuals and nations are at risk of catastrophic loss of life as much from starvation as from disease. The public and government have a shocking lack of understanding about the role of agricultural research and more broadly about the factors that determine our food system's resilience and vulnerability. Even in developed countries the link between nutrition and health is a major though often unacknowledged public policy concern. This agricultural illiteracy is the direct result of how our educational system, agricultural institutions, and government have marginalized and isolated agricultural research from other areas of public science such as biomedicine.

We must therefore provide the appropriate feedback in our democratic society so that the public feels part of the agricultural con-

stituency and become culture. This requires that we integrate all aspects of agricultural research and management should be given a fair share of the tribute to making life.

What goals of research to a central agricultural research program integrity mutually as compromising or not now seen, with so many rather than the so-called lines that I am advocating.

Manipulation of the environment that we today have to accept the challenge. The spread of the earth's surface and should not make environmental damage, habitat destruction, and because we understand the causes of unnecessary agricultural practices. The need to accept the challenge, instead has largely allowed agriculture that defies the traditions of many products we have a long way to go to improve environmental quality. The research agenda in a way that alternatives rather than existing practices. Few are blatant apologists. There is room for more holistic agricultural research to help move the research.

Another issue that agricultural research and for reviewing and adjusting functions. Some programs skew markets and disto-

stituency and becomes much more engaged in the dialogue about agriculture. This requires that we incorporate education about agriculture into all aspects of life and throughout the educational system. Such engagement should extend to setting the research agenda and will contribute to making agricultural research more central in our national life.

What goals of broad public appeal could return agricultural research to a central position? One such goal that should be driving the agricultural research agenda is to make agriculture and environmental integrity mutually supportive. Agricultural technology is widely viewed as compromising environmental quality, and agricultural research is now seen, with some justification, as contributing to the problem rather than the solution. Agricultural research along the ecological lines that I am advocating can contribute to resolving this problem.

Manipulation of ecosystems is intrinsic to agriculture. The environment that we today accept as "natural" is an artifact of human intervention. The spread of agriculture around the globe replanted much of the earth's surface with nonnative vegetation. However, this does not and should not make the public complacent about the more recent environmental damage from agriculture through pesticide contamination, habitat destruction, loss of genetic diversity, and soil degradation. Because we understand poorly how ecosystems function, we have caused unnecessary and unwitting ecological damage through our agricultural practices. The agricultural research community has been slow to accept the challenge and opportunity intrinsic to these concerns and instead has largely aligned itself until very recently with those forces in agriculture that defended or denied the negative ecological ramifications of many production practices. Despite promising signs of change, we have a long way to go in fully addressing public concerns about environmental quality in agriculture and recasting the agricultural research agenda in a way that will contribute to solutions and provide alternatives rather than merely mitigating damage caused by continuing existing practices. Few thoughtful people in agricultural research today are blatant apologists for environmental damage, but there is much room for more holistic thinking and strategic redirection in the agricultural research community. Greater engagement of the public will help move the research community in the right directions.

Another issue that should drive public engagement in setting the agricultural research agenda is the need for new global mechanisms for reviewing and adjusting the economic system in which agriculture functions. Some progress has been made in lowering subsidies that skew markets and distort international trade, but we still lack integra-

tion of these steps with the need to ensure regional and global environmental quality. Concerns include the best use of land resources, the preservation and characterization of global genetic resources, and management of intellectual property. These questions and many others asked elsewhere in this volume raise significant and challenging interdisciplinary research questions in the social sciences.

We need new leadership to shape wisely and comprehensively the funding priorities, funding mechanisms, and mind-sets of participants in the research enterprise. Such leadership might be exercised by a select but nonelitist group of people representing responsible national groups from nongovernmental organizations and foundations as well as progressive thinkers from the public, government agricultural institutions, higher education, and private corporations. Such a group could increase public awareness of the issues, command the attention of political leaders, propose themes and priorities, keep the discussion going during times of controversy, and maintain a balance among the pluralistic, divided, multifaceted interests that collectively make up U.S. agriculture. In the biomedical arena, several foundations and civic leaders have played such a role in contributing to informed dialogue about research needs. Corporate leadership and the professions also have played key roles in supporting the need for investment in both fundamental discovery and more applied research. Nothing like this has existed for agricultural research.

Rethinking the Roles and Funding of Agricultural Research Institutions

The agricultural research agenda as such has only recently been a focus of criticism. Past and current criticism has focused more on research institutions. Institutional arrangements and funding mechanisms create many of the biggest barriers to the progressive changes described above. Such changes will not occur without appropriate incentives; providing these incentives is one function of our public institutions. Appropriate incentives include funding in reasonable amounts, career paths that are respected by others, and an environment conducive to both personal and professional dignity and creativity. We therefore must look seriously at how agricultural research is organized and how and for what purposes funding is allocated. We need new approaches that will tie agricultural research more closely to national needs. This should be reflected not just in the agenda for research and the process used to set it but in the institutional arrangements for research. We also need an approach that will better integrate

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agricultural research and education in our nation's universities; this includes rethinking the roles of the federal government.

The public (land-grant) universities that house the state agricultural experiment station (SAES) system and the laboratories operated by the USDA'S Agricultural Research Service (ARS) account for most public expenditures for agricultural research. These institutions have a long history of insularity. In a compelling article published more than two decades ago, André and Jean Mayer (1974, 83) wrote about "Agriculture, the Island Empire" as follows:

Few scientists think of agriculture as the chief, or the model science. Many do not consider it a science at all. Yet it was the first science—the mother of sciences; it remains the science that makes human life possible; and it may be that before the century is over, the success or failure of Science as a whole will be judged by the success or failure of agriculture.

The present isolation of agriculture in American academic life is a tragedy. Not only does it deprive us of the most useful models of the systems approach to human affairs, but it puts us—and the world—in mortal peril.

From a perspective two decades later in the century, we may be tempted to conclude that the Mayers were wrong. Yet, the dominant problems facing global society today are intimately tied to agricultural issues. These include emerging and reemerging infectious diseases (many of which involve the food supply, agricultural production practices, and other features of the agroecosystem), increasing demands on land use and environmental degradation (including the new uncertainties related to global change), and the uncertain prospects for continuing our successes since the 1970s in increasing agricultural yields. Thus, while the time frame for the Mayers' concern now appears to extend beyond the end of the twentieth century, we should not be complacent about the issues they raised in 1974. The fundamental issues they raised then are valid and even more compelling now. What is the cost of maintaining agriculture as an "island empire"? Should we continue to limit participation in research for agriculture to agricultural researchers (defined by their institutional employment)? Should we continue to maintain the public's astounding ignorance about agriculture by insulating agriculture from mainstream educational, political, scientific, and economic discourse?

I believe that the agricultural research enterprise will become better, stronger, and more vigorous if agriculture is integrated into the scientific mainstream. Rather than keeping agricultural research separate

from other research, we should create a coherent research capability that integrates it into the agenda of societal issues that drives public investment in the discovery and application of knowledge. Abandoning insularity is central to recruiting the highest caliber of people into agriculture; reconciling and integrating agricultural concerns with health, environmental, and other societal issues; and dealing with the increasingly interdisciplinary nature of knowledge and its applications.

The arguments apply beyond academia: the continued isolation of agriculture from general federal science and technology policy also is alarming. This isolation allows agriculture to be marginalized in political discourse and contributes to its tendency to resist change. For both its own political well-being and the national interest, agricultural research should be integrated into federal science policy as a whole.

How might this happen? There are two basic issues: the future roles of universities and the USDA's laboratories, and the connection between research and practice—in other words, who will do the site-specific, applied research and development that allows the equitable and sustainable development of useful practices?

Reinventing the University's Role

Central in my vision of the future of agricultural research is maintaining and enhancing the U.S. public higher education system. The key elements of this system, which contributes so profoundly to society's well-being, are the pluralism of institutions and the integration of instruction, research, and public service activities. Another strength is that students can shift from a general education into a professional agricultural field at many stages, even after receiving a doctorate in a mainstream discipline such as chemistry, physics, civil engineering, economics, sociology, genetics, or molecular biology.

This vision is not entirely new. Twenty-five years ago, a compelling report from a broadly based national committee assembled by the National Research Council (1972, 50) wrote:

The scientific stature of personnel engaged in agricultural research is subject to several determinants including the native ability of those attracted into agriculture, the training they receive, and finally the research atmosphere in which they work. The Committee believes that to produce top flight agricultural scientists there should be little distinction between training in agriculture and training in the basic sciences. Agricultural research needs investigators with minds and training equal to those attracted to any other research area. The important problem is to

make the scientific community aware of the problem. The solution is to make the most of the scientific opportunities needs to be met. *Research in universities: Integrating scientific education into the training of persons of high ability for research.* (emphasis added)

This statement reflects the isolation of agriculture from general federal science and technology policy also is alarming. This isolation allows agriculture to be marginalized in political discourse and contributes to its tendency to resist change. For both its own political well-being and the national interest, agricultural research should be integrated into federal science policy as a whole.

In advocating this, I see a continuing process. The first is the planning process. The agricultural colleges are integrating interdisciplinary curricula, and meeting with their academic colleagues from the campus-wide undergraduate side colleagues from

The second major caution is to provide focused attention to several cautions. First, the typical in many fields is to end up with out-of-date skills at the expense of being able to acquire new skills for which they are and successful. A final

make the scientific community and particularly the young investigators aware of the problems and opportunities in agricultural research. Interest of the scientific community in agricultural problems and research opportunities needs to be increased. The . . . *increased location of agricultural research in universities, together with greater integration of agricultural scientific education into that of the basic sciences* should contribute to attracting persons of high ability and providing good training for agricultural research. (emphasis added)

This statement reflects the agricultural colleges' long history of insularity, with separate academic programs and an infrastructure that generally is inaccessible to scientists outside the colleges. Moreover, they often duplicate the curricula offered in other units of the same institution, frequently at a lower academic standard. There are some signs of changes like those recommended by the 1972 NRC report. Disciplinary shifts and financial imperatives in some universities are forcing agricultural research faculty into a more central role in the academic life of their institutions, a trend that we should encourage. Moreover, we should open agriculture to branches of the university that traditionally have not been agricultural. Conversely, we should require the traditionally agricultural branches to participate in the general curriculum at institutionally accepted standards.

In advocating this, I am not advocating elimination of agricultural colleges. I see a continuing role for them for at least two compelling reasons. The first is to ensure a place for agriculture in the academic planning process. The integration that I am calling for requires the agricultural colleges to play a leadership role, along with others, in doing interdisciplinary and disciplinary research, offering coordinated curricula, and meeting other academic needs. Today, many agricultural colleges merely colonize the universities they are part of, contributing little to their academic life. Instead, their faculties should contribute to campus-wide undergraduate and graduate curricula, working alongside colleagues from the liberal arts, humanities, and sciences.

The second major reason for maintaining colleges of agriculture is to provide focused and high-quality professional training. But I suggest several cautions. First, specialization should occur much later than is typical in many fields. Second, we must not overemphasize training in skills at the expense of education. A poorly educated person is likely to end up with out-of-date skills, whereas a well-educated one will likely be able to acquire new skills as needed. Often, people who move into fields for which they are *not* trained are the most innovative, creative, and successful. A final caution is that we not interpret "agriculture" too

narrowly and instead seek closer integration with training in other professions, such as business, law, medicine, and engineering.

What will guarantee that the "agricultural" in agricultural research will not be lost in this vision? A crucial role will be played by the leadership of universities and colleges of agriculture and by vocal faculty leaders in ensuring that returning agricultural research and education to a central place in our research universities will give it added strength rather than leading to further deterioration and marginalization. Partly, this will result from the strong and collegial participation I am advocating for agriculture in the life of the broader institution. For example, some universities are building new cross-cutting programs as long-range replacements for discipline-based departments. Fields such as rural sociology, applied economics, and reproductive physiology can benefit from integration into such programs while maintaining an appropriate focus on agriculture.

Another way to ensure an important role for agriculture is intelligent planning of funding mechanisms with sufficient levels and duration of funding to be attractive to the broad research community. New funding from federal agencies in several areas related to agriculture illustrates the power of funding programs to shift the focus of the research community. Ecologists and molecular biologists alike (and at times even in collaboration) have been drawn into environmental research by such initiatives. Development of plant and plant-microbe model systems and their appeal for basic researchers have drawn many from outside the agricultural research community to take up such systems for study. The result in both cases has been an increased scope and broadened intellectual appeal of agricultural research. These examples illustrate nicely how funding, along with intellectual factors, powerfully shapes a research agenda and influences participation.

A traditional counterargument has been that agricultural research will disappear unless we maintain specific institutions devoted to it. I do not find this argument compelling. Many important topics in economics research are covered in general economics departments across the country without carving out a separate department for each topic. Why is agricultural economics special? The question is not whether we need a specialized agricultural economics *department*, but how we integrate agricultural economics *topics* into the broader economics research agenda. Agricultural economics would have greater educational value and be more central to the university if it were integrated into the economics discipline instead of remaining separate and isolated, as is typical today. To take another example, research in plant pathology has become so popular in recent years that in a recent survey of the pub-

lished literature I found four were from departments either for or against health of plant pathology. Certainly for many reasons besides choice, the goal should be to attract the most intellectually gifted people with attractive and in which funding and infrastructure

Funding is crucial in discussion often is about multiple funds, training. More important, though, the diversity of funding must have flexible and placement of the funds strength of competitiveness, public participation to have a cultural level of accountability should work, not on mechanicality should be continuous distributing and those inclusive. When funds are distributed—for example, from SAES—they often are awarded with renewal review and institutional funding so petition. Either approach

Rethinking the Federal

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lished literature I found that only a minority of plant pathology articles were from departments of plant pathology. These are not arguments either for or against having a department of agricultural economics or of plant pathology. Colleges will organize themselves into departments for many reasons besides intellectual or scholarly ones. Whatever the choice, the goal should be an environment in which the most academically gifted people will find working on agricultural problems highly attractive and in which they have both respect and the necessary funding and infrastructure to do their best work.

Funding is crucial in making any area of research attractive. The discussion often is about funding mechanisms (competitive grants, formula funds, training grants, career enhancement programs, etc.). More important, though, are the amount and duration of funding and the diversity of funding mechanisms. A field as broad as agriculture must have flexible and diverse funding mechanisms. A crucial need is placement of the funds in capable hands, which is usually considered a strength of competitive grant programs. Equally important is for government, public participants in grant making, and the research community to have a culture that embraces an appropriate and constructive level of accountability regarding the use of the funds. Accountability should focus on the creativity and usefulness of the work, not on mechanical formulas. Methods for achieving accountability should be continuing and should entail interaction between those distributing and those using the funds without being onerous or intrusive. When funds are distributed by an agency or donor to an institution—for example, formula funds from the federal government to the SAES—they often are allocated within the institution by competition, with renewal review and accountability measures. On the other hand, institutional funding sometimes is shared by the faculty without competition. Either approach can yield excellent results.

Rethinking the Federal Role

I envision agricultural research that is integrated with other disciplines, drawing students from mainstream educational tracks, contributing to mainstream education, and linking with local communities, businesses, and farmers in ways that are the major purpose and strength of our pluralistic system of higher education. Yet most federal funds for agricultural research are allocated to support intramural research, largely through the USDA's ARS and the Forest Service. Could these funds be invested better? Do we need government laboratories, separate from universities? For two main reasons, I believe that re-

search funds for the ARS and Forest Service should be radically restructured and reduced, with a corresponding increase in funding used in an intelligent mixture of mechanisms to support university research integrated with the education of undergraduate and graduate students. The first reason has to do with focus and the second with sources of funding needed for implementation.

The major priority for agricultural research in my vision is that it better serve public needs for knowledge on which to base new management practices and new ecologically sound technologies by integrating many scientific disciplines spanning the social, biological, and physical sciences. These disciplines and the intellectual drive to forge new cross-disciplinary linkages are the intellectual capital invested in our university system of higher education. If our priorities are to strengthen the linkages among research disciplines and integrate them better with education and public service, the USDA's intramural research program is largely superfluous.

The second reason is that substantial funds must be available to attract high-caliber people into a revitalized university-based agricultural research and education system. Funds are unlikely to be transferred into agriculture from other priority areas. Moreover, the United States already invests heavily in agricultural research but mainly in the USDA's extensive and expensive ARS and Forest Service research programs. Therefore, the issue is not the total level of funding but how we allocate it. Funds presently allocated to federal laboratories would be better spent in the university system.

The USDA's research organizations have been the subject of many decades of review and constant reorganization. It is time to ask, why bother? Why not instead drastically cut the investment in USDA research and correspondingly increase funding for university-based agricultural research and education? The focus of the ARS and Forest Service is narrow compared with the multifaceted roles and integrative possibilities offered by the university system. Also, these agencies offer no expertise in agricultural education for the general population or training for the agricultural professions. In contrast, the pluralistic university system can integrate agricultural research with other disciplines and with education. Shifting most federal funding to university-based research and associated education and training activities would immediately place agriculture at the center rather than the periphery of academic interest and attention. The result would be to attract excellent students and faculty from other fields.

What, then, would be the future of the USDA's intramural research system? One model might be that of the National Institutes of Health. In the NIH, a small intramural program ensures core programming,

while a larger extramural program takes the grist of inquiry to a broad research community. At NIH, intramural and extramural receive 20 and 80 percent of the funding (USDA, the split is 80 and 20 percent, 1996).

Such a scenario invites a small intramural program at the university level, some corporate-level research, and some well-conceived and well-managed extramural programs that are pivotal in enabling its activities to be as extensive and responsive as possible.

Today's ARS employment model would confine the intramural program to these truly exceptional individuals. Maintaining USDA career scientists and a long-range view that agriculture is a plan would be consistent with the strongest campus-based research programs on their campuses. These investments are government policies and the result of the integration from this arrangement of research and education.

Another radical model of extramural funding, based on grants like the National Science Foundation, along with a career-development program for university-based agricultural institutions. Instead of the traditional system of civil servant researchers at universities, the USDA would support a standing university faculty and a small intramural program should also be offered to support agricultural research careers.

How Would Site-Specific Research Get Done?

Agriculture requires continuous management systems. Often, this research addresses issues and extends well beyond

while a larger extramural program provides flexibility and ensures risk-taking (the grist of innovation) by supporting the creativity of the broad research community and thereby its health and vitality. At the NIH, intramural and extramural (universities and colleges) research receive 20 and 80 percent of total funds, respectively, whereas at the USDA, the split is 80 and 20 percent (General Accounting Office 1996).

Such a scenario invites the question of why there should be any intramural program at the USDA. Borrowing again from the NIH and some corporate-level research models, a compelling answer is that a well-conceived and well-managed central research organization can be pivotal in enabling its associated bureaucracy to better manage an extensive and responsive extramural funding program.

Today's ARS employs a small cadre of distinguished scientists, mostly housed on university campuses across the country. One appealing model would confine a restructured USDA intramural research program to these truly outstanding investigators. As long as the remaining USDA career scientists are allowed the freedom, flexibility, and long-range view that is the hallmark of the best researchers, such a plan would be consistent with my vision. My own view, though, is that the strongest campus-based ARS units are most closely integrated into their campuses. These investigators face a conflict between central government policies and those of the university. So why not take the lesson from this arrangement, where it has been successful, and *fully* integrate these researchers into the university system?

Another radical model for future USDA research would use a mix of extramural funding, based in part on formula funding to the states and in part on grants like those of the NIH and the National Science Foundation, along with a major commitment of federal funds to a career-development program similar to that of the Howard Hughes Medical Institution. Instead of maintaining an expensive and inflexible system of civil servant researchers in national laboratories and even at universities, the USDA would fund the career development of outstanding university faculty members for five to ten years. Support should also be offered to attract promising young faculty into agricultural research careers.

How Would Site-Specific Applied Research and Development Get Done?

Agriculture requires continual innovation in technology and management systems. Often, this requirement is driven by site-specific or local issues and extends well beyond the usual domain of research. The sep-

arate facilities and funding mechanisms that give agricultural research its "island empire" tendencies (Mayer and Mayer 1974) are often justified by agriculture's "special" needs for applied research and development. However, the special agricultural colleges and experimental farms were established in the last century to serve a society with very different needs from those of today. U.S. agriculture now is rich with well-educated and skilled entrepreneurs and outstanding managers. Most successful farmers are multitalented, whatever the size of their operations, and often invent and experiment. This community should be drawn into the research process by having them do more applied research themselves on their own farms. Committing more funds and effort to such research and the growing role and increasing sophistication of private advisers will go a long way toward meeting the needs of agricultural producers. As John Gerber discusses in Chapter 12, a critical role for a revised and reinvigorated Extension Service will be to implement such a vision of farm-based participatory applied research and development. This would decrease the support needed for such research in universities and federal agencies, where it has become increasingly out of date and duplicative.

Conclusions

It is time to take seriously and *act* on the advice of André and Jean Mayer (1974, 94) when they wrote "We need a change, both in states of mind and in institutions, if agriculture is to benefit from the intellectual evaluation it deserves and needs." For agricultural research to meet the varied and complex demands of the coming decades, it needs a flexible institutional framework and sufficient and reliable funding that attracts the best of our life scientists, social scientists, and engineers to work on agricultural problems. The research community must be in constant and substantive dialogue with a broad portion of the public, preferably as part of a larger process in which the public participates in setting goals for agriculture and integrating them with goals concerning health, land use, and infrastructure planning. Agriculture and society as a whole are poorly served by agriculture's traditional isolation from such public policy making. Similarly, we should insist on every opportunity to integrate agricultural research into the broader process of educating our citizens and setting research policies for the public good. Research based on ecological principles and grounded in superior scientific knowledge can contribute to the vitality of agriculture. However, it will do so only if we make major changes in how we conduct the business of research, a challenge we must not shun.

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