National Agricultural Research, Extension, Education and Economics Advisory Board

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A REPORT ON AGRICULTURAL PRODUCTIVITY AND AGRICULTURAL RESEARCH

May 2011

EXECUTIVE SUMMARY

The United States Department of Agriculture's (USDA) National Agricultural Research, Extension, Education and Economics (NAREEE) Advisory Board evaluated current agricultural productivity trends, and the status of agricultural research as a part of its October 27 – 29, 2010 meeting in Washington, D.C. Based on those deliberations, and subsequent evaluation of the evidence, the Board prepared a report on agricultural productivity and agricultural research. The report first summarizes the available evidence on agricultural research funding. It discusses the implications of this evidence for agricultural productivity, national competitiveness, international food security and environmental change. It extends this discussion to consider the services produced alongside foods, fuels and fibers on agricultural and forest lands that are critical to meeting the needs of society. The following is a list of the main findings and recommendations of this report:

Findings

1. **U.S. public agricultural research funding has stagnated over the last two decades, and this has had a number of adverse consequences, both nationally and internationally.**

2. **The rate of U.S. agricultural productivity growth has slowed, and will reduce the competitiveness of U.S. agriculture and potentially reduce exports.**

3. **Since world agricultural productivity growth remains sensitive to U.S. agricultural R&D spending, this stagnating funding will reduce global capacity to feed the growing world population without increasing adverse impacts including converting unsuitable land to agriculture.**

4. **The social rate of return on public investment in agricultural research has persistently been very high relative to other areas of public expenditure, signaling long term underinvestment.**

5. **There is additional research required to ensure that increased agronomic productivity does not exacerbate resource limitations and environmental degradation and ideally reduces them.**

6. **There is growing recognition that the non-marketed services produced alongside foods, fuels and fibers in agriculture and forestry (e.g. clean water, flood protection, greenhouse gas mitigation) are of high social value, but remain under-researched, and landowners have no means to realize that value consistent with societal benefits.**

Recommendation

We recommend at least a 25% increase in the annual growth rate of funding of agricultural productivity enhancing research and extension. This growth needs to be in addition to the funding devoted to health, food safety, nutrition, and enhancing the wide range of environmental services we rely on from agricultural lands.

Increasing agricultural productivity enhancing research is critical to:

- the U.S generating sufficient agricultural productivity growth to be able to maintain its competitiveness in global markets without degrading the environment,

- food security domestically, and international food security through U.S. agricultural exports, and

- developing countries increasing their own agricultural productivity growth through adopting or adapting U.S. research results, in addition to funding their own R&D.

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Stagnating public investment in agricultural research has significant adverse implications both for the competitiveness of U.S. agriculture internationally and for global capacity to provide food for a growing world population. If recent trends are not reversed, U.S. agricultural productivity is expected to decline relative to agricultural productivity in countries where public investment in agricultural research is increasing.

Concurrently, worldwide population and accompanying demand for food, feed, fiber and fuel continue to increase but a growing number of the world's population is expected to be food-insecure. The combination of needing to increase agricultural production and reduce the collateral impacts—biodiversity loss, water pollution, soil erosion, water shortages, greenhouse gas (primarily methane and nitrous oxide) emissions—and the need to adapt agricultural production to a changing climate and control emerging zoonotic diseases highlights the importance of increasing the rate of agricultural productivity growth. The challenge is to double world agricultural output by the year 2050 (GHI), a generally accepted target, while more efficiently and sustainably utilizing inputs, both in the United States and worldwide.

Between 1970 and 2004, agriculture accounted for 12.1% of total factor productivity (TFP) growth in the U.S. economy—a much larger effect than would have been expected given the economic importance of the sector. U.S. agricultural productivity has long been among the highest in the world, and is strongly linked to investments in research which leads to technological innovation and practices that increase output per unit of total resources employed in production, or total factor productivity (Fuglie, and Heisey, 2007). Historically, public expenditures on agricultural research and development in the United States and other developed countries, along with private sector spending, has resulted in agricultural productivity growth in all countries, including the less developed ones (Alston, et al, 2010). Rising agricultural total factor productivity reduces the rate of growth needed in inputs to meet global demand, according to the Global Harvest Initiative (GHI)—a collaborative effort between agricultural firms and hunger, conservation and environmental organizations.

At the same time, additional research is required to ensure that increased agronomic productivity does not exacerbate resource limitations and environmental degradation and ideally reduces them. Lands used in the production of foods, fuels and fibers are a source of many important societal benefits—recreation and amenity provision; management or control of water quantity, water quality and soil erosion; carbon sequestration; and wildlife habitat—that need to be maintained while still meeting the increasing global agricultural production needs. While these 'ecosystem services' have value to society, many are currently un-priced in the market and therefore are typically under supplied. It is important to understand these services and how they can be enhanced, as well as to create incentives for their provision—especially for those services involved with sustainably increasing agricultural production.

These are the main conclusions of the USDA's NAREEE Advisory Board's review of the status of and trends in agricultural research funding in the United States and elsewhere.[1] This report first summarizes the available evidence on impacts of agricultural research funding. It discusses the implications of this evidence for agricultural productivity, U.S. agricultural competitiveness, and food security and environmental impacts, and then draws conclusions for the USDA's research activities.

These findings are relevant to the debate over the 2012 Farm Bill, to USAID and the bilateral and to multilateral agreements concerned with international trade, and federal agencies with responsibility for the environmental implications of agriculture.

U.S. agricultural research funding is declining and its composition is changing

Three main characteristics of agricultural research funding within the United States may be noted:

- Inflation adjusted public funding of total agricultural research and development has stagnated over time. The trend of strong growth in inflation adjusted expenditures on agricultural research evident through the 1970s has since been replaced by a slowing of publicly funded research, and spending on extension has been stalled for several decades (Alston, et al. 2010).
- Private funding of total agricultural research marginally exceeds public funding. In 2006, aggregate agricultural R&D expenditures in all sectors in the U.S.A. were $10.3b—federal spending accounted for 29%, state spending 13%, and private spending 58% (Pardey *et al.*, 2006). The latest estimate shows the private sector share of total agricultural R&D is 52% (Alston *et al.*, 2010).
- The composition of publicly funded research has become more diverse, moving from research largely directed at agricultural production and towards health, food safety, nutrition and environmental impacts. In 1975, 66% of state funded research was directed to enhancing farm productivity. By 2007 it had fallen to 57%, in inflation adjusted dollars (Alston *et al.*, 2009).

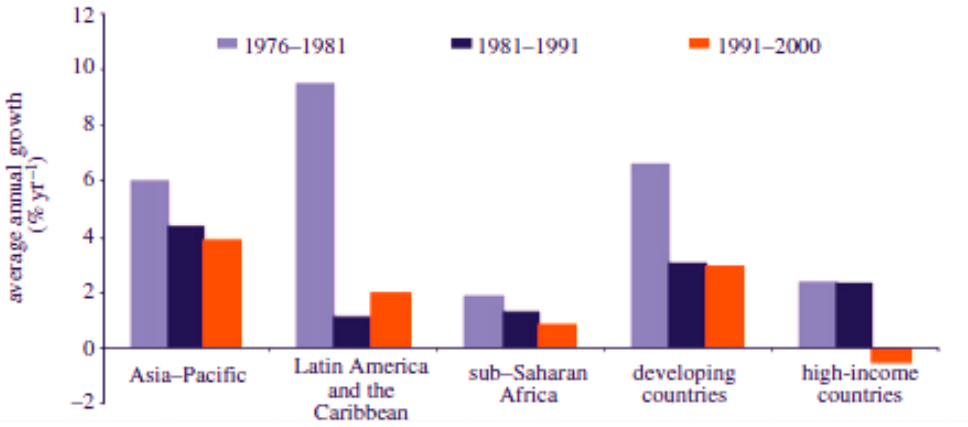
[1] The Board's deliberations were informed by presentations by Keith Fuglie, Economic Research Service, USDA; Wallace Huffman, Department of Economics, Iowa State University; and William Lesher, Global Harvest Initiative.

Globally, the pattern of public spending on agricultural R&D is mixed, but reflects a similar trend over time (Figure 1). Total agricultural R&D spending in developing countries increased from $3.3 billion in 1992 to $3.9 billion 2000, or by 2.1% annually for the last decade of the 20th century. In Asia, annual spending increased by 3.5%, while in Africa the rate was 1.9% (Nin Pratt & Fan, 2010). The largest investors are China, India and Brazil.

The most significant difference between developed and developing countries is in the balance between public and private expenditures. In 2000, for example, private investment accounted for 54% of all agricultural R&D expenditures in developed countries, but only 6% in developing countries (Piesse & Thirtle, 2010). Given the integrated nature of world agricultural markets, however, it is not clear how much can be read into this. A significant part of private R&D expenditure relates to agricultural production in countries other than the country in which the firm happens to be located. Data on the breakdown of private agricultural investment according to the region of the world it is targeted at are not available.

It is likely that in many cases public and private agricultural research are complements, not substitutes; and the public sector often provides research leadership in areas the private sector is likely to ignore. This is particularly true for ecosystem services R&D, but it is also true for many areas in agricultural production oriented R&D—for example for commodities with smaller markets or for longer-term research in which payoffs may be particularly uncertain.

Figure 1: Public agricultural R&D spending trends 1976–1981, 1981–1991, 1991–2000



Source: (Pardey *et al.*, 2006)

U.S. agricultural productivity growth is slowing and dependent on the level of R&D investment

The concern raised by the stagnation of public funding of agricultural productivity oriented research lies in its impact on productivity growth and its associated impacts on

other services provided by agricultural systems—water quality and quantity, wildlife habitat, etc.).

Productivity growth in agriculture is calculated in a number of ways, ranging from simple measures such as growth in yield per acre to various measures of factor productivity growth. Rates of yield increases slowed in most regions over the last two decades, with the exception of Africa and South America (Table 1). Yield growth rates in the U.S.A. have remained nearly unchanged for almost 50 years.

Table 1: Yield growth rates—all grains

Regions	**1961–1985**	**1986–2008**
Developed countries		
North America	2.1	2
Oceania	0.7	-0.1
European Union	2.9	0.8
Former Soviet Union	1.8	0.5
Europe (non-EU)	3.5	0.3
Developed country average	2.2	0.7
Less developed countries		
North Africa	1.5	2.1
Sub-Saharan Africa	0.5	1.0
South America	1.6	3.2
Caribbean	2.5	0.6
Central America	2.2	0.4
East Asia	3.9	1.5
Middle East	2.1	1.8
South Asia	2.2	2.2
South-East Asia	2.1	1.4
Less developed countries average	2.5	1.6

Source: (Piesse & Thirtle, 2010)

Yield growth may be due to either input intensification, or to other factors. These other factors are measured through total factor productivity (TFP). TFP measures the proportion of crop or livestock output not explained by the amount of inputs used in production. It captures the effect of technical progress, the efficiency with which inputs are used, and the impact of environmental factors such as climate. Since technical progress and allocative efficiency are largely driven by R&D expenditures, the impact of R&D is generally measured through its effect on TFP. Fuglie (2008) finds that while yield growth rates may have fallen, globally there has been no reduction in total factor productivity (TFP) growth from 1970 to 2006 (Table 2). World TFP growth increased from 0.9% per year in the period before 1990 to 1.6% per year in the period after 1990. For particular regions, however, the picture is different. In North America, while TFP growth in the period after 1990 was substantially above that in the period before 1990, it has been slowing since 2000 according to Alston, et al. 2010.

Table 2: Index of total factor productivity

Average annual growth rate (%) by period	1970–1979	1980–1989	1990-1999	2000-2006
Sub-Saharan Africa	−0.4	0.9	1.5	0.6
Latin America & Caribbean	0.6	1.3	2.4	2.5
Brazil	−0.5	3.1	3.00	3.7
Middle East & North Africa	0.4	1.7	1.6	1.6
Northeast Asia, developed	1.9	2.2	2.6	3.1
Northeast Asia, developing	0.5	2.6	4.00	3.4
China	−0.2	2.5	3.8	3.2
Southeast Asia	2.0	1.0	1.6	2.2
South Asia	0.7	2.0	1.7	1.4
India	0.8	2.1	1.7	1.4
North America	**1.5**	**1.4**	**2.1**	**1.8**
Oceania	1.1	1.0	1.9	−0.3
Western Europe	1.5	1.7	2.0	1.4
Eastern Europe	0.6	0.3	1.0	0.6
USSR, former	−0.7	0.3	1.6	3.3
Developing countries	0.6	1.7	2.3	2.1
Developed countries	1.6	1.5	2.3	1.8
USSR & Eastern Europe	−0.5	0.3	1.6	2.1
World	0.6	0.9	1.6	1.6

Source: (Fuglie, 2008)

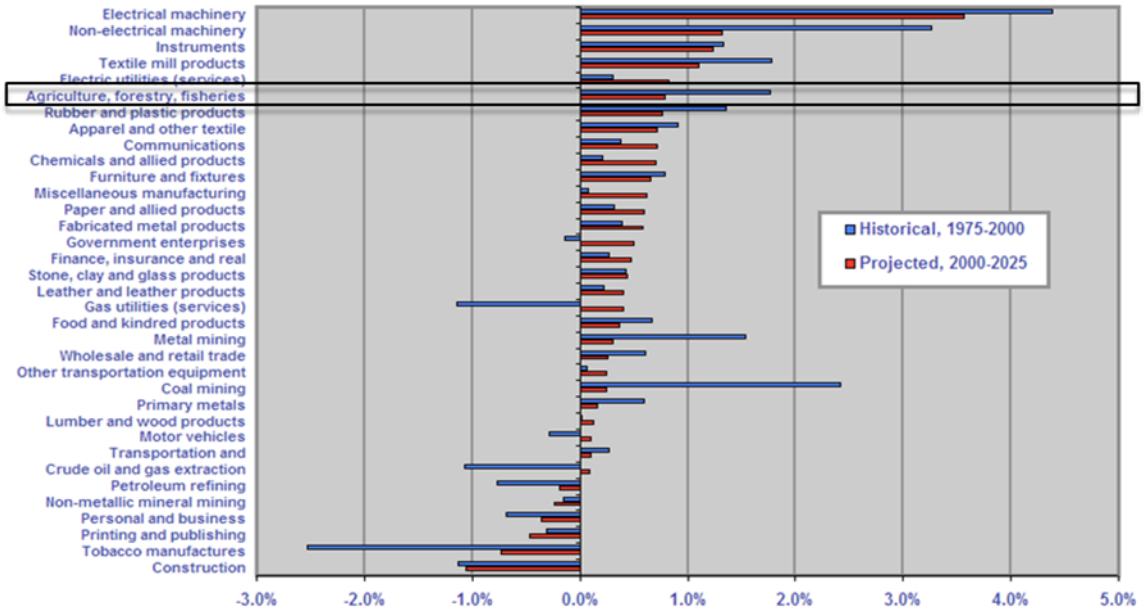
Investment in R&D provides returns through enhanced productivity over some period, the timing and duration of which reflects the rate at which a technology is taken up and the emergence of newer technologies that render it redundant. For the U.S.A., Huffman finds, using a model of prior beliefs about lag structure, that the return on agricultural R&D begin two years after the investment is made, building to a maximum between seven and fourteen years, with continuing but declining returns thereafter (Huffman, 2010). Annual increases in TFP reflect R&D expenditures up to three decades prior, a generally accepted number (Alston et al. 2010).

Return on public investment in agricultural research is high and drives economic growth

A number of studies have shown that the social rate of return on agricultural research investment—the rate of return taking all effects into account—is high relative to other public investments, in the order of 45%-55% (Alston & Pardey, 1996; Alston *et al.*, 2010; Alston *et al.*, 2009). Many improvements in plant materials, for example, derive from public investments. However, though earlier U.S. corn hybrids were based on public sector research, since about 1980 most have been based on private sector inbreds. The social return on such investments depends on the impact improvements have on crop yields, but it also depends on the rate at which the material becomes available, the extent to which it is diffused—including the rate at which it is allowed to spill over into other jurisdictions—and the capacity of users to exploit it (Piesse & Thirtle, 2010).

Between 1970 and 2004, agriculture accounted for 12.1% of TFP growth in the U.S. economy—a much larger effect than would have been expected given the economic importance of the sector. In part because of recent trends in public expenditure on agricultural production oriented R&D, projections of future TFP growth in agriculture are less optimistic. By one estimate, TFP growth over the period 2000-2025 is expected to be less than half the rate achieved between 1975 and 2000 (Figure 2) (Goettle *et al.*, 2007). Though these authors use a broader category which includes the agricultural productivity oriented research we are focused on here, the results are applicable. This reflects declining trends in U.S. agricultural R&D expenditures which are much lower than they should be given the social rate of return realized (Alston *et al.*, 2009).

Figure 2: Historical and projected non-price induced TFP improvements



Source: (Goettle *et al.*, 2007)

Reductions in publicly funded agricultural R&D imply reduced competitiveness of U.S. agriculture and its exports, and potentially serious impacts on global agricultural growth, food security and environmental quality.

Within the United States, a reduced rate of increase in spending on productivity-enhancing and productivity-maintaining research may be expected to increase both average prices for locally produced agricultural commodities and the variance in those prices. Maintenance research is especially important for price stability. It addresses threats to productivity associated with pests and pathogens that may be unintended consequences of productivity-enhancing research. For example, any reduction in crop-genetic diversity resulting from productivity-enhancing research might increase crop vulnerability to new pests or pathogens (Piesse & Thirtle, 2010). But Van de Wouw et al., based on a survey of the literature, concluded that while there is likely an initial reduction of diversity during the transition from farmer selection of cultivars to scientific plant breeding, subsequently the effects on genetic diversity are neutral. Nevertheless,

reducing research which is required to maintain productivity—especially in plant breeding, plant pathology, and entomology—may increase consumer price variability, by increasing pest or pathogen-induced variability in supply. This same effect may be expected to reduce the competitiveness of U.S. agriculture, and so reduce U.S. agricultural exports.

Stagnation of U.S. agricultural R&D spending has consequences for other countries which are more difficult to predict, but are potentially of much greater concern. There are two main points at issue. One is the implication of agricultural R&D spending for TFP growth, given projected population increases and increasing demand for industrial uses including biofuels. Declining yield growth in major food crops as a result of declining public investment in TFP-enhancing agricultural R&D is argued to threaten world food security (Nin Pratt & Fan, 2010). While the focus of that paper is public investment in agricultural R&D in developing countries and the Consultative Group on International Agricultural Research (CGIAR), there is historically a close link between agricultural R&D in the United States and productivity growth elsewhere.

Most developing countries, and almost all low income countries, have relied heavily on the results of publicly funded agricultural productivity oriented R&D in the United States (and a few other developed countries) (Pardey *et al.*, 2006; Alston *et al.*, 2009). The main private sources of agricultural R&D are located in the same developed countries, and similarly benefit from spillover effects from publicly funded agricultural R&D in those countries. Given trends in publicly funded agricultural R&D in developing countries, it follows that stagnation in public agricultural R&D in the United States has potentially significant negative implications for future food security in those countries, and especially in the low-income countries where food security is currently at risk.

The second concern is that if yield growth does not keep up with population growth and demand for biofuels, meeting the food needs of an increasing world population and mandates for increased biofuels will require the continued expansion of farmlands. Over the last fifty years, agricultural production growth in developed countries has been met through intensification of existing activities. In developing countries, there has been some increase in land used for agricultural production (Table 4), but Fuglie also reports in the same paper robust agricultural output growth of about 3% per year in those countries from 1970-2006. This means that agricultural output more than tripled over this time period. A majority of output growth in developing countries came either from use of inputs other than land, TFP growth, or both, and only a small fraction came through use of increasing amounts of land. It will be important to continue funding the research which generates increases in TFP to maintain this favorable outcome since little sustainably productive land remains available for cultivation, urbanization will require more of the 70% of fresh water now used for agricultural production, and it is important to minimize additional fertilizer use.

Table 4: Total agricultural land 1961 and 2005

Region	Total agricultural land (millions of hectares)		
	1961	**2005**	**% change**
Developed countries	1,276	1,194	−6
Developing countries	2,596	3,109	20
Former USSR countries	622	633	2
World	4,494	4,936	10
Quality adjusted (millions			
Developed countries	504	515	2
Developing countries	926	1,270	37
Former USSR countries	334	316	−5
World	1,765	2,101	19

Source: (Fuglie, 2008)

In the absence of total factor productivity gains, the growth of agricultural production on what are now non-agricultural lands would accelerate. This would involve conversion of increasingly marginal land, with concomitant declines in yields and increased negative environmental impacts; accelerated biodiversity loss (Sachs *et al.*, 2009); increasing greenhouse gas emissions (Pachauri & Reisinger, 2007); and growing risks of emergent zoonotic diseases from the expanding contact zone between people and wildlife (Piesse & Thirtle, 2010; Jones *et al.*, 2008).

Increased agricultural productivity can be environmentally friendly when it reduces the absolute amount of resources needed to produce increasing quantities of food and other agricultural products. The late Nobel Laureate Norman Borlaug made the case as follows: "…thanks to agricultural productivity increases made possible through research and new technology development since 1990, an area greater than all the land in the 26 states east of the Mississippi River, has been spared for other uses. Imagine the environmental disaster that would have occurred if hundreds of millions of environmentally fragile acres, not suited to farming, had been ploughed up and brought into production. Think of the soil erosion, loss of forests and grasslands, and biodiversity, and extinction of wildlife species that would have ensued!" (Alston et al. 2010). Similar implications for environmental impact can be projected for failing to continue to increase agricultural productivity enhancing research going forward.

The 2010 GAP report (Global Harvest Initiative, 2010) estimates that the increase in global TFP needed to meet the food demands of the growing world population is 1.75% per year, up from the current rate of 1.4%. Since it takes years to realize the returns to research investments, increases in both public and private sector R&D funding is needed now. Given the U.S. role in overall global agricultural productivity, this emphasizes the need to reverse the downward trend in both public and private real investments in agricultural productivity enhancing research in the U.S. immediately. The long lag times in getting on-the-ground production following initial research funding means that we cannot afford to back off funding the research, even for a short time.

Environmental benefits are substantial and largely unvalued

The trends described above deal with the impact of R&D on the more efficient production of foods, fuels and fibers and the resulting environmental benefits, but there is a growing appreciation that land committed to agriculture can generate an array of additional benefits (Millennium Ecosystem Assessment, 2005). These include, for example, watershed protection, habitat provision, carbon sequestration, erosion control, and recreation. All of these have social value. In some production systems the monetary value of these benefits is greater than the value of the foods, fuels and fibers that are the primary outputs of agriculture. For an example outside the U.S., a recent assessment of the benefits derived from tropical forests found that the value of water management or control and climate change mitigation (carbon sequestration) were each larger than the sum of all timber and non-timber products yielded by such forests (TEEB, 2009). Another example in the U.S. is the role played by Catskill farmers in utilizing best management practices in order to assure the supply of clean water to New York City's reservoirs with a value in excess of the conventional farm products they produce.

While measures of agricultural productivity do not yet include non-traditional outputs in estimates of either input productivity or total factor productivity, they will be required in the future to ensure that these socially important outputs are considered. Just as we now have measures of the effect of R&D expenditures on the production of foods, fuels and fibers, we will need measures of the effect of R&D expenditures on the other ecosystem benefits supported by effective agricultural land management practices. For example, research increasing crop nutrient-use efficiency could reduce nutrient escape from agricultural production if it fully compensates for any increased application rates needed to produce higher yields. Increasing ecosystem benefits will involve institutional and policy intervention as well as increased research. Much research relevant to ecosystem benefits will have direct implications for agricultural productivity, producer incomes and meeting societal goals.

Markets exist for some of these ecosystem benefits, such as recreation and tourism, but not for many others. Markets are already developing for carbon sequestration and watershed protection services (Engel *et al.*, 2008; Wunder *et al.*, 2008), for example, and there are a number of near-market schemes for habitat protection on private lands that generate income for farmers. For example, biodiversity offset and compensation programs in the United States already generate payments of $1.5-$2.4 billion annually (Madsen *et al.*, 2010). Additional research is needed to better understand institutional and incentive systems related to agricultural contributions to these societal goals and in some cases to agricultural productivity.

Recommendations

We recommend at least a 25% increase in the annual growth rate of funding of agricultural productivity enhancing research and extension, while also funding other topics currently included in the agricultural research budget.

Doubling of agricultural production by 2050 is needed to satisfy expected demand growth for agricultural products to feed the world's population while also providing the fuel and other industrial products required. As argued in the GHI report starting from FAO numbers, this means that agricultural total factor productivity needs to grow by at least 25% faster than is currently the case while holding agriculture's environmental footprint constant. Assuming that the TFP growth rate has the same relationship as to past public funding growth, agricultural productivity enhancing research funding must also grow at least 25% faster than currently is the case. This growth needs to be in addition to the funding devoted to the wide range of environmental services we rely on from agricultural lands and other research topics currently commanding more than 40% of the agricultural research and development funding and deserving continued growth.

Increasing agricultural productivity enhancing research is critical to:

- the U.S generating sufficient agricultural productivity growth to be able to maintain its competitiveness in global markets without degrading the environment,
- food security domestically, and international food security through U.S. agricultural exports, and
- developing countries increasing their own agricultural productivity growth through adopting or adapting U.S. research results, in addition to funding their own R&D.

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Report Developed by the NAREEE Advisory Board - Agricultural Productivity and Agricultural Research Work Group

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