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Scope, characteristics, and use of the U.S. Department of Agriculture's intramural research

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Abstract This article presents for the first time a portrait of intramural research conducted by the U.S. Department of Agriculture (USDA). We describe the nature, characteristics, and use of USDA research based on scientometric indicators using patent analysis and three bibliometric methods: publication analysis, citation analysis, and science mapping. Our analyses are intended to be purely descriptive in nature. They demonstrate that USDA maintains several core scientific competencies and its research is much broader than and reaches well beyond traditional agricultural sciences for which it is best known. We illustrate the current status, recent trends, and clear benchmarks for planning and assessing future USDA research across an array of scientific disciplines.

Keywords Agriculture · Intramural research · Research benchmarking · Research output · USDA · Federal research · Education · Extension

JEL Classification Q16 · O32 · O38

Mathematics Subject Classification (2000) 94A17 · 94A99

Introduction

The U.S. Department of Agriculture (USDA) is the federal executive department responsible for developing and executing U.S. federal government policy on farming, agriculture, and

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The views expressed here are the authors' and do not necessarily represent the policies or views of the United States Department of Agriculture.

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food. It aims to meet the needs of farmers and ranchers, promote agricultural trade and production, work to assure food safety, protect natural resources, foster rural communities and end hunger in the United States and abroad. Science is at the foundation of USDA's many and varied functions including administrating various multi-billion dollar social programs like the Supplemental Nutrition Assistance Program, formerly known as Food Stamps, managing agricultural and conservation programs, and protecting and managing the nations national forests. Numerous products developed and research undertaken by USDA have had and continue to have impact on the everyday lives of people throughout the world. Examples include the active ingredient in most insect repellents, DEET; mass-produced penicillin; and trans-fat research that provided the basis for current food labeling in the United States.

Expressing and evaluating the depth and breadth of USDA research competencies is critical to ensure that the science is relevant and that resources are directed to areas of greatest impact. Scientific output cannot be well captured by a single metric, because it is not unidimensional; however, scientometric methods can shed light on the nature of scientific activity of a particular university, organization, or government agency. This article uses scientometric methods as well as patent analysis to examine depth, breadth, and use of USDA research. Although the work presented here is descriptive without delving into policy questions of "what" and "why," it provides a critical element of the basis for monitoring progress and directing resources in the future.

Scientometric analysis is the quantitative study of the innovation system; it is based primarily on bibliometric and patent indicators (Pouris and Pouris 2009). Bibliometric indicators and patent analysis possess several unquestionable strengths that have resulted in their universal use. They are highly reliable because they are well defined and unambiguous. They enable detailed categorization, which allows the study of individual scientific and technological fields and subfields. Because unique entities can be studied with the same methodology, they make organizational and international comparisons possible.

Although many articles have been published on various aspects of U.S. and agricultural science contributions, no quantitative study of USDA intramural research efforts exist to date. We use bibliometrics to provide useful insights into the breadth and reach of USDA research as well as patent analysis to demonstrate applications of that research. Another goal of this work is to propose a benchmark and framework for evaluating USDA research going forward. This benchmark assessment of research outputs also can provide the basis for measuring research productivity for example, in terms of research outputs per dollar invested or per scientist year.

The rigorous and well-established scientometric methods used to measure, analyze, and characterize science also can be applied to evaluate research performance (Price 1975). Such methods are critical for evaluating publicly funded research programs because effective outcomes of research for the public good are essential. Declining and highly constrained budgets require policy makers and research institutions to more carefully evaluate their research portfolios. Portfolio decisions need to be made on the basis of merit and research productivity. Those portfolios can be evaluated in terms of research quantity and quality, but also can reveal the organization of research by indicating research outputs by field, and indicate new and emerging research patterns and directions. Science and technology indicators (STI) exist in a variety of forms (e.g., research expenditures, scientist years, number of new PhD's). The U.S. National Science Foundation's annual Science and Engineering Indicators (NSF-S&E 2008) present a collection of measures that provide a snapshot of U.S. research capacity by field and sector and compares the United States to the rest of the world. Scientometrics is an STI that provides a quantitative means for evaluating research by assessing research publications and patents as a reflection of research output. Both measures (citation analysis and patent citation) are not without their flaws and challenges, but they provide an objective measure of research output and a fairly rigorous accounting of the research landscape. The U.S. government must direct its science resources in targeted and complex ways that push existing science capacity to new limits and thus a baseline snapshot and firm knowledge of research competencies are required.

Some science indicators point to a leveling off of U.S. science contributions on a global scale and in fact, a loss of ground. Over the last decade total numbers of citations to U.S. scientific articles published and the world's total citations have dropped by 50 and 53%, respectively (King 2004). The United States falls below the United Kingdom, China, India, the smaller Scandinavian countries, Israel, the Netherlands, and Switzerland in the ratio of citations to GDP (King 2004). The center of gravity of the world system of science is changing; its axis appears to be moving from North America to Europe and now to Asia (Leydesdorff 2006).

Delving more deeply into U.S. contributions, we examine specifically how the USDA contributes to science that addresses many of the great challenges facing the United States and the world. In addition to addressing environmental, human health, and other global challenges for which USDA's science and policies exist, advances in science are critical contributions to economic growth as well (Solow 1957; Griliches 1990).

Finally, a critical aspect of science policy is to assess how public science investments address public policy goals (i.e., how do they address specific predefined outcomes). Most publicly funded research—and agricultural research in particular—is designed to address problems the public faces and for which the private sector either doesn't have the incentive or capacity to address. Typically research cannot directly impact desired outcomes; there are often too many uncontrollable factors that can mitigate the impact of scientific discoveries (National Academies 2008). But certain research outputs—discoveries and new knowledge—must be had to be able to move to the right direction. Ideally scientometric analyses, such as the present one, can provide a basis for assessing if a research agency is moving toward desired outcomes.

Agricultural research in the United States

The multidisciplinary field of agricultural sciences provides a means to address how to feed the world's population and how to alleviate and prevent problems affecting human health and the environment. Agricultural research has been shown to be a socially productive activity and public agricultural research has been shown to have high social rates of return with estimates averaging 45% (Fuglie 2007). In the United States, as in most western developed countries, agricultural research is an activity shared by the public and private sectors in terms of financing and performing.

As the United States seeks to enhance knowledge-based aspects of its economy, science, engineering, and related technological activities are recognized as key drivers. Agriculture is a key contributor to U.S. economy-wide productivity growth. Agriculture represents only 1.8% of U.S. GDP but from 1970 to 2000 made an oversized contribution of 12% of to overall U.S. productivity growth (Jorgenson et al. 2008). U.S. public agricultural R&D has accounted for about half of all agricultural productivity growth since 1950 (Shane 1998), but the contribution of public agricultural investment to overall agricultural R&D has declined since the mid-1980s.

On a national scale, industry has been the primary performer of R&D in general since the early 1950s and has become the primary funder of R&D since 1980, surpassing the federal government in that role. Exhibiting the same trend, private spending on agricultural

R&D overtook public spending in the early 1980s and now represents a little better than half of all agricultural R&D investments. In 2006 the United States' investment in public agricultural research was $5.0 billion and comprised federal (58%), state (27%), and other (15%) contributions (U.S. Department of Agriculture Current Research Information System 2009).

USDA ranks sixth among federal agencies in total federal R&D investment, not including investments in education or extension/outreach. USDA's share of federal research has shrunk over the past two decades from about 5 to 3.5–4% (3.5% of federal basic research and 3.9% of federal applied research) (NSF 2008). With regard to the composition of research investments across the federal government, investments in life-sciences research dominate at USDA and HHS. Social science investments are small in all agencies.

USDA science addresses a wide range of issues; most of the USDA efforts are focused in life sciences (>80%) and within that the largest share is focused on animal and plant production systems. Social sciences make up a much smaller proportion of USDA efforts.

USDA science investments are viewed in three functions: research, education, and extension. The science agency budgets are about 3% of USDA's total budget, which is considerably less than U.S. agencies that share similar missions. The USDA science budget is allocated predominantly (over three-fourths) to research and development, split fairly evenly between basic and applied. Education represents less than 5% of the science agency appropriations for education programs (not counting experiential education that occurs in other programs. Approximately 15% of appropriations are devoted to extension activities through the Cooperative Extension System, which is the department's primary mechanism for science engagement with the public.

USDA science investments also can be viewed by the manner (mechanism) by which they are invested, which includes intramural (work carried out by scientists who are directly employed by USDA) or extramural (through contracts, grants, and agreements with non-USDA organizations such as universities). The realm of research conducted through USDA's primary intra- and extramural programs is organized by various functional categories that address agriculture and allied sciences, food and nutrition, and forestry. Research topics addressed in these broad categories span natural resources and environment; plants and their systems; animals and their systems; agricultural, natural resource, and biological engineering; food and non-food products: development, processing, quality, and delivery; economics, markets, and policy; human nutrition, food safety, and human health and well-being; and families, youth, and communities. In addition, UDSA science addresses methods and procedures to monitor, track and evaluate preprocessed and processed food products; methods to monitor and evaluate disease in plants and animals; and issues related to the distribution and consumption of foods by various populations.

Data and methods

In this study we focus on three bibliometric approaches to provide an objective profile of USDA's intramural scientific research: (1) publication analysis, (2) citation analysis, and (3) science mapping. In addition to these bibliometric analyses, we assessed the quality of journals in which USDA intramural research is published by examining impact factors of journals in which recent (i.e., 2008) USDA articles were published. Finally, we provide a brief review of the use of patents by USDA and how trends in patenting compare to trends in publication of USDA research.

Publication and citation analysis

Publication analysis has proven a valuable means for developing science indicators and for characterizing science profiles of nations, governments, public and private institutions, and scientific disciplines (King 2004; Adams and Griliches. 1996; Pouris and Pouris 2009). Moreover, citation analysis is used to assess the merit of original published research and to determine impact of specific articles, authors, and publications. Citation analysis involves examining a publication's referring documents and in this case, we are using citation analysis to assess the merit and determine the use or impact of a science entity, specifically USDA intramural research. The raw data for the bibliometric study were derived from Scopus, the largest abstract and citation database of peer-reviewed literature and web sources. Scopus was selected as the data source because it provides broad coverage of scientific, technical, medical and social sciences literature, reflecting the broad nature of USDA's intramural research.

A straight publication counting method was used to count USDA-authored articles. The objects of study were fields and subfields of USDA research and the basic unit used for counting was USDA-authored articles as identified by contributing authors. In the straight counting method, individual publications were categorized into various scientific fields or subfields by assigning them to the field of science identified by the contributing author(s) for submission to the journal and categorized by Scopus subject area. The average count of a single article is 1.56 because it may be categorized by Scopus into one or more subject areas.

Articles that cited the original USDA-authored articles identified by the method described above were assigned to fields using Scopus subject designation. This designation served as an indicator of how other researchers use the published USDA research.

Mapping science

Science mapping is a relatively new scientific discipline that has evolved from the explosion of rigorous data available in digital form (e.g., publications, patents, grants) and has been embraced by key institutions concerned with managing knowledge and conducting relevant research. For example, eight key Institutes of the National Institutes of Health (NIH) have mapped their scientific expertise and use this information to inform decision making and define institutional strategy. Until the current study, mapping of science competencies has not been undertaken for USDA.

Using citation data for 16,000 peer-reviewed journals represented in Scopus over a 5-year period, publications were categorized into subject areas. All articles published in 2008 were identified and using the most highly cited articles, a co-citation analysis was performed to group references into article clusters that represent specific areas of research.[1] The process results in approximately 80,000 clusters that represent specific areas of research. Articles published in the past 5 years were then assigned to clusters by looking at their references. Each of the clusters is assigned to a discipline (554 in total) and a subject area (13 in total). The clusters were placed around the wheel of science according to their assigned discipline. Only clusters in which USDA has a large relative market share are

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[1] Co-citation analysis and science mapping was developed courtesy of SciVal Spotlight©, Elsevier B.V.

selected for inclusion in creating competencies. They are grouped together based on USDA's unique publication history by looking at how articles from the USDA are shared between these clusters. This creates distinctive groups of clusters. Based on a combination of metrics measured against each of the groups, they are labeled either as distinctive competencies or emerging competencies. The competencies are plotted on the map based on the subject clusters that make up the competency. The competency is drawn as a circle with a line for each subject cluster.

The ordering of fields around the circle is based on a meta-analysis of 20 existing science maps. Circular maps enable visualization of interdisciplinary research and places an equal value on all lines of research.

Impact factors of referenced journals

Impact factors were examined for journals in which 3,836 USDA-authored agriculture-specific articles were published in 2008. Impact factor values were obtained from individual journal self-description and correspond to 2008 Thomson Reuters Journal Citation Reports (JCR). The impact factor of a journal is calculated by dividing the references cited in 1 year by the number of citable articles published in the same journal over the previous 2 years. This ratio is published annually in Thomson Reuters JCR. Impact factors have been used to "clarify the significance of absolute citation frequencies" (Thomson 2009), and as a result its applications have gained great significance in the world of academia (Monastersky 2005). Historically, impact factors have been the most widely used tool for evaluating the quality of a journal and thus the merit of the contributing authors and research (Opthof 1997; Vinkler 2007).

Patent analysis

As another measure of the quantity and quality of USDA research, trends and categories of USDA patents were assessed using information from the U.S. Patent and Trademark Office (USPTO). The use of patenting is not the primary means of knowledge transfer used by USDA but it is an important component of the science profile (Heisey et al. 2006).

For purposes of patent analysis, we are using patents assigned by the USPTO to the Secretary of Agriculture, a measure of patents awarded for USDA intramural research. The USPTO examines claims on the basis of established criteria: subject matter, utility, novelty, non-obviousness, and definiteness (42 U.S.C. 2181 (a); Fordis and Sung 1995).[2]

Results and discussion

Research output

In terms of absolute output, USDA has published a continually increasing number of articles per year over time. Numbers as derived from data indexed in Scopus range from a total of 4,208 articles in 1995 to 9,582 articles in 2008 implying a 6% average annual growth in the number of articles per year or approximately 400 published articles.

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[2] In the current analysis we focus on publications counts and citations and limit our analysis of patents to patent count and the class of patents held by the USDA.

Based on straight publication counts, agricultural and biological research has consistently represented between 41 and 44% of USDA's published intramural research output during the period 1995–2008 and in fact the trend extends back further in time, suggesting that the majority of USDA's intramural research work resides in the area of agricultural and biological research (Fig. 1). This should be no surprise because USDA's main research focus has been directed to these sciences since its inception (Huffman and Evenson 2006). This area of research includes specific topics such plant breeding and crop development, cultivation systems, animal breeding and nutrition, and other related fields.

The second two dominant areas of research in terms of output are (1) environmental sciences and (2) biochemistry, genetics, and molecular biology, each representing about 10–13% of published research output (Fig. 1).

USDA primarily performs "problem-solving" research, and does it within a well-developed infrastructure and established institutional framework. As such, there is relative constancy of the proportion of published research outputs associated with the different

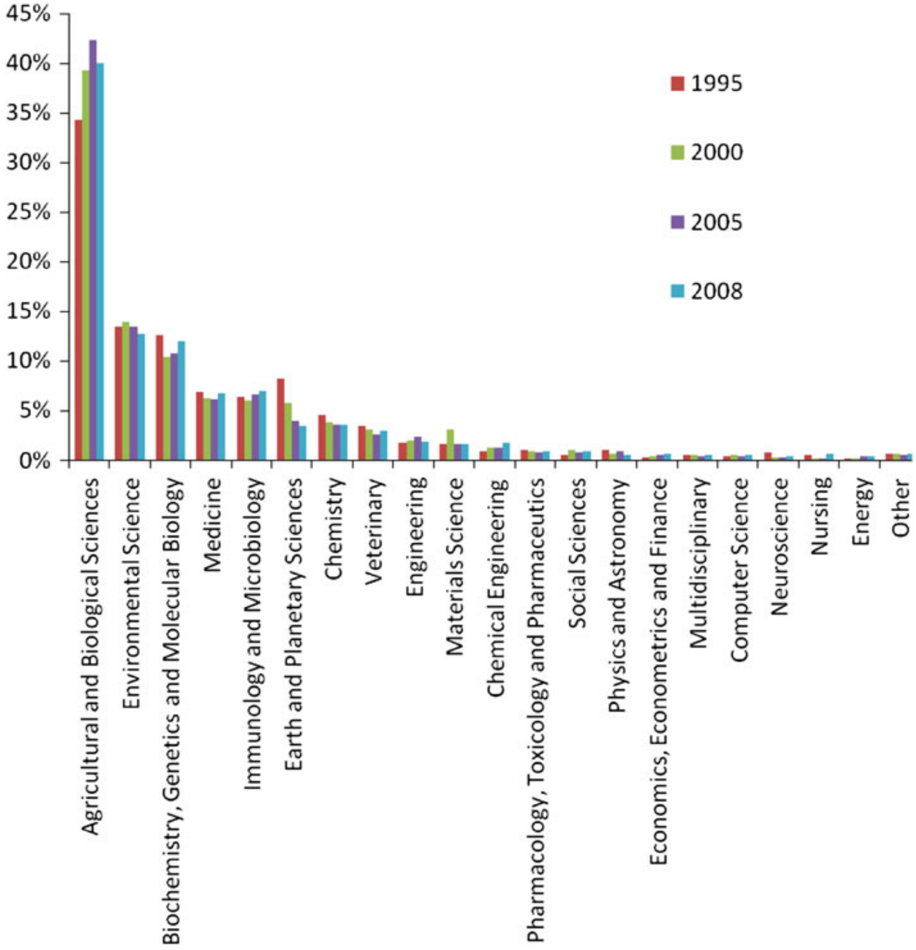

Fig. 1 Distribution of USDA intra mural research publications by field, selected years

topic areas. This constancy or apparent stability may be a reflection of the basic nature of this type of research—namely that much of the research is foundational; it is research that continues to explore and advance knowledge along specific areas of science.

Initially in this study, USDA research output was analyzed solely based on the fields (i.e., journals) in which it was published as described above. The challenge associated with this approach is that each scientific journal is classified into a major field despite the fact the journal articles and the journals themselves are progressively covering a wider array of disciplines that are not reflected in a single field classification. To better illustrate science capabilities, multidisciplinary work, and interrelationships among fields based on research output, a map of USDA science was assembled, which provides a unique “fingerprint” of USDA’s research.

Areas of USDA science strengths are identified in the science map (Fig. 2) derived from co-citation analysis. The position and size of circles reflects areas of science and relative outputs. As indicated by the size and placement of circles on the map, USDA’s strength, relative to science globally, is clearly in the biological and earth sciences (lower right-hand portion). USDA also has a noticeable strength in health, which includes the disciplines of nutrition and infectious disease where most of USDA’s contributions are found. Smaller circles reflect areas where USDA may need to leverage resources.

The clusters of circles along the edge of the circular map and fewer circles toward the middle of the map indicate that the majority of USDA’s research is strongly discipline-

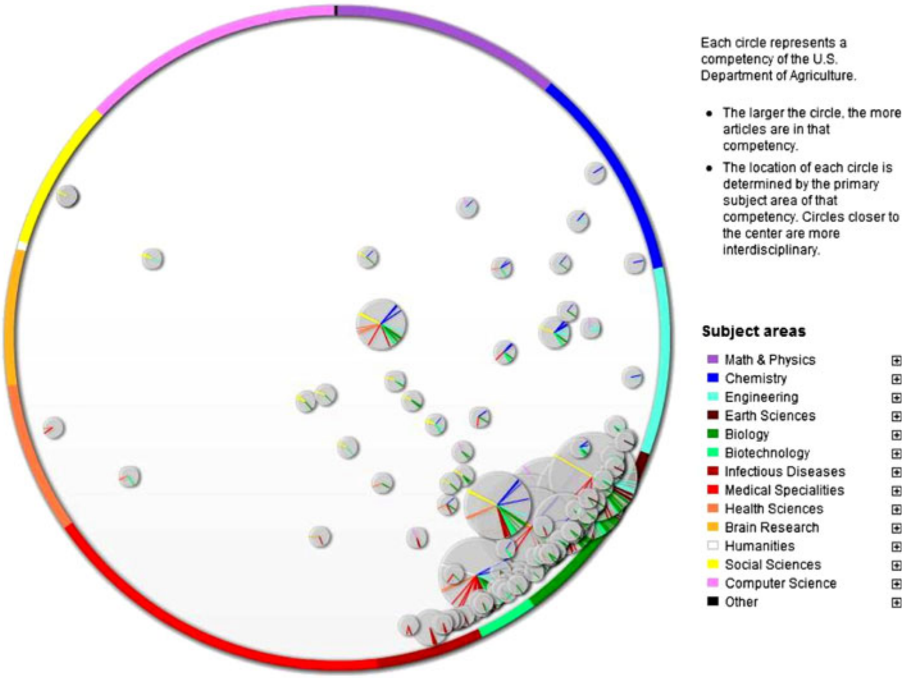

Fig. 2 Map of USDA intramural research published during 2003–2008 illustrating the multidisciplinarity (*number of circles in the map*), interdisciplinarity (*nearness of the circles to the center of the map*), distribution (*location of circles around the map*), and depth (*size of circles of map*) of USDA science. *Source*: SciVal Spotlight, 2011. Permission to reproduce granted by Elsevier B.V. SciVal Spotlight. 2011. http://www.spotlight.scival.com

based, and less is interdisciplinary (researchers from multiple disciplines engaged in creating and applying new knowledge as they work together as equal stakeholders in addressing a common challenge) in nature. Nevertheless, much of USDA's research is multi-disciplinary (researchers from several different disciplines, but not necessarily integrated at the outset to work on a common problem).

Patenting of USDA research

The USDA patents inventions (both utility and plant patents) as a means of technology transfer. The goals of intellectual property management and technology transfer by the USDA and other Federal agencies are to transfer the benefits of public research to the public and potential users, fulfilling agency mission, and influencing the direction of technology development. These goals are different from those of the private sector which are primarily to provide a means to capture the returns on investment in R&D. The USDA uses patents to license technologies through exclusive and nonexclusive arrangements. The degree of exclusivity is considered for the purpose of developing a means for most successfully expanding the commercialization of a technology.

The Secretary of Agriculture is the assignee for patents held by the USDA. Most USDA patents and other intellectual property arrangements including Cooperative Research and Development Agreements, Plant Variety Protection Certificates, and licenses are managed through an Office of Technology Transfer (OTT).

Table 1 indicates the types of patents held by the USDA as classified by the USPTO standard classification system. The USPTO uses a system of classification to categorize patent by class and subclass. This system of standardization permits patent examiners and filers to more easily identify patents by their characteristics (USPTO 2009).

Most of the USDA patents, over 50%, are biological or plant patents. Of the 500 patents awarded to the USDA between 1996 and 2005, patents under class 435, chemistry and molecular biology and microbiology, represent nearly 24% of patents held. Classes 424 and 514, bio-affecting and body treating composition, 514 represent the next 26%. Other patents relate to mechanical devices and process inventions.

The number of patents awarded to the UDSA is relatively small and has not grown appreciably over time (Fig. 3). While the number of USDA patent awards has grown very slightly over time, the pattern of growth has not been like patenting by universities and the private sector over this same time period.

Heisey et al. (2006) suggest that the use of patenting by the USDA has not come at the expense of scientific publication—the primary means of USDA knowledge dissemination. While there was modest growth in patents over the period, the number of patents awarded averaged 54 per year while the number of publications averaged 4,000 per year. Also, comparing publication and patent counts per scientist staff years from 1990 to 2003 Heisey et al. showed similar growth rates for the two measures.

In sum, several observations are made from USDA patent analysis. First, there are far fewer patents than publications produced during a single time period. The USDA uses a highly selective process for determining which technologies to patent and chooses relatively few compared to private firms or many other research organizations. There were only 500 patents awarded during 1996–2005 while there were roughly 120,000 articles published during this period confirming the notion that USDA uses publications as its primary means of technology transfer. Second, the USDA prefers patents as a means of technology transfer for certain types of technology. Some technologies that may not be fully captured with a publication and may require a patent to ensure the technology is not

Table 1 Distribution of USDA patents by USPTO patent classifications

Class	Number of patents by class	Percent of patents in class (%)	Patent class
435	119	23.8	Chemistry: molecular biology and microbiology
424	99	19.8	Drug, bio-affecting and body treating compositions[a]
514	33	6.6	Drug, bio-affecting and body treating compositions[a]
800	27	5.4	Multicellular living organisms and unmodified parts thereof and related processes
Plant	21	4.2	Plant patents
426	20	4.0	Food or edible material: processes, compositions, and products
536	11	2.2	Organic compounds—part of the class 532–570 series
524	11	2.2	Synthetic resins or natural rubbers—part of the class 520 series
73	10	2.0	Measuring and testing
554	8	1.6	Organic compounds—part of the class 532–570 series
530	8	1.6	Chemistry: natural resins or derivatives; peptides or proteins; lignins or reaction products thereof
119	7	1.4	Animal husbandry
43	7	1.4	Fishing, trapping, and vermin destroying
504	6	1.2	Plant protecting and regulating compositions
324	6	1.2	Electricity: measuring and testing
436	4	0.8	Chemistry: analytical and immunological testing
428	4	0.8	Stock material or miscellaneous articles
8	4	0.8	Bleaching and dyeing; fluid treatment and chemical modification of textiles and fibers
568	5	1.0	Organic compounds—part of the class 532–570 series
564	3	0.6	Organic compounds—part of the class 532–570 series
525	3	0.6	Synthetic resins or natural rubbers—part of the class 520 series
449	3	0.6	Bee culture
242	3	0.6	Winding, tensioning, or guiding
210	3	0.6	Liquid purification or separation
209	3	0.6	Classifying, separating, and assorting solids
206	3	0.6	Special receptacle or package

[a] This Class 514 is considered to be an integral part of Class 424 (see the Class 424 schedule for the position of this Class in schedule hierarchy). This Class retains all pertinent definitions and class lines of Class 424

captured for exclusive use by a private firm. USDA may also choose to patent and license out a technology to encourage additional investment for scale-up and commercialization. A licensee is granted exclusive (or nonexclusive) rights to capitalize on the technology and will thus have the incentive to make the additional investments to bring the technology to market. Finally, the last observation is that the USPTO patent classification system and Scopus subject areas do not map into one another neatly. However, casual observation suggests that most USDA patents are related to the subject areas (i) agricultural and biological sciences and (ii) biochemistry, genetics, and molecular biology, which is consistent with the number and percentage of published articles.

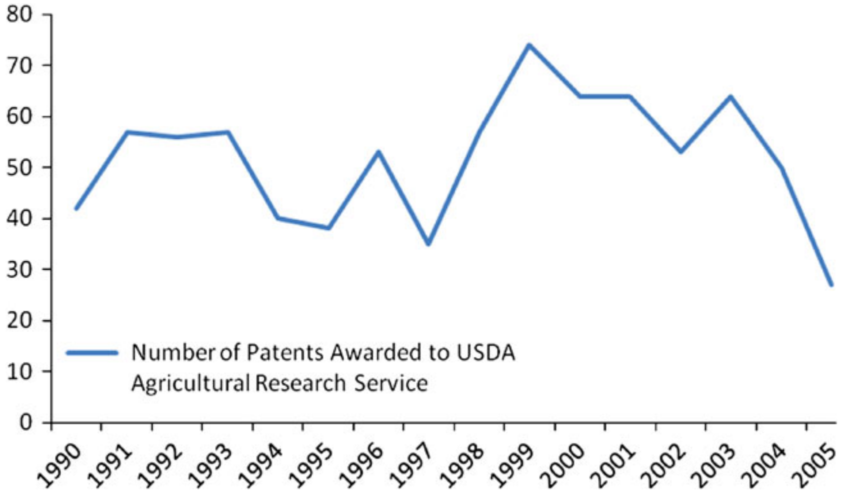

Fig. 3 Number of patents awarded annually to the U.S. Department of Agriculture, 1990–2005. *Source*: Heisey et al. (2006) and U.S. Department of Agriculture (2009)

Research quality

Hoeffel (1998) states that in each specialty the best journals are those in which it is most difficult to have an article accepted, and these are the journals that have a high impact factor. Impact factors of journals in which USDA research is most commonly published range from <0.1 to >9.0. The average impact factor of the top ten journals comprising approximately 23.5% of USDA intramural research publications in 2008 is 1.45, which is slightly lower than the average impact factor of the top ten "high impact" agricultural journals (1.879; Thomson Reuters Sci-Bytes 2008; Table 2). While the majority of USDA's research is published in journals that have impact factors of 2.0 or less, it is

Table 2 Impact factors of top ten journals publishing USDA research in 2008

Journal	Percent of total 2008 publications	Impact factor
Journal of Agricultural and Food Chemistry	3.38	2.562
Plant Disease	3.04	0.670
Crop Science	2.67	0.610
Horticultural Science	2.47	0.522
Forest Ecology and Management	2.33	2.110
Journal of Economic Entomology	2.10	1.201
Agronomy Journal	1.99	1.532
Transactions of the ASABE	1.87	1.040
Journal of Animal Science	1.82	2.123
Journal of Environmental Quality	1.79	2.098
Average		1.45

Table 3 Number and distribution of articles published by USDA authors and the number of articles citing USDA publications

Subject areas[a]	USDA authored articles—published in 2005		Articles citing USDA articles (2005–2008)	
	Number of articles	Percent of total	Number of articles	Percent of total
Agricultural and Biological Sciences	**3,696**	**43.6**	**35,156**	**32.5**
Biochemistry, Genetics and Molecular Biology	**942**	**11.1**	**16,686**	**15.4**
Environmental Science	**1,173**	**13.8**	**11,973**	**11.1**
Medicine	**539**	**6.4**	**11,003**	**10.2**
Immunology and Microbiology	**579**	**6.8**	**9,622**	**8.9**
Chemistry	*310*	*3.7*	*4,385*	*4.1*
Earth and Planetary Sciences	*342*	*4.0*	*3,976*	*3.7*
Veterinary	*229*	*2.7*	*3,695*	*3.4*
Pharmacology, Toxicology and Pharmaceutics	*73*	*0.9*	*1,975*	*1.8*
Chemical Engineering	*108*	*1.3*	*1,785*	*1.7*
Engineering	*204*	*2.4*	*1,727*	*1.6*
Materials Science	143	1.7	980	0.9
Social Sciences	72	0.8	933	0.9
Nursing			772	0.7
Physics and Astronomy	75	0.9	619	0.6
Neuroscience			595	0.6
Multidisciplinary			584	0.5
Energy	39	0.5	426	0.4
Computer Science			367	0.3
Economics, Econometrics and Finance	51	0.6	294	0.3
Psychology			190	0.2
Health Professions			137	0.1
Business, Management and Accounting			116	0.1
Mathematics			95	0.1
Decision Sciences			30	0.0
Arts and Humanities			28	
Dentistry			25	
Total	8,485	100.0	108,174	100.0

Retrieved from Scopus, March 2009

[a] Scopus subject area designations

important to note that 0.7% of USDA's research in 2008 was published in the Proceedings of the National Academy of Sciences, a journal with an impact factor of 9.38.

In addition to examining impact factors of journals in which USDA research is routinely published, citation analysis was used to provide an indication of the use of USDA's intramural research by virtue of how often it is cited and by the variety and types of users. Table 3 presents the number and distribution of USDA-authored articles published in 2005 and corresponding number and distribution of citings of these articles, reflecting areas of science where USDA research is being used.[3] In 2005, the total number of USDA-authored articles was 8,485. These USDA-authored articles were cited collectively 108,174 times between 2005 and mid-2008. Agricultural and biological science articles received the greatest number of citations representing 32.5% of all cited USDA published research. Biochemistry, genetics, and molecular biology articles were cited the second most at 15.4% followed by environmental science at 11.1%. Medicine and immunology, and microbiology also are highly cited at 10.2 and 8.9% respectively. Agricultural and biological sciences are the most highly cited areas of USDA research and further biochemistry, genetics and molecular biology are leading fields in biotechnology and the sources of most modern advances in the life sciences. An unexpected result was the strong use of USDA intramural research areas of medicine and health through immunology and microbiology. Environmental science also appears to have a relatively significant role reflecting the level of effort USDA science contributes to natural resources management.

Table 3 shows how USDA research is used based on citation evidence. We define USDA's perceived strengths as the five disciplines presented in bold in the table. They are: agriculture and biology; biochemistry, genetics, and molecular biology; environmental science; medicine; and immunology and microbiology. This somewhat broad coverage of topics represents 78% of research cited by scientist and about 80% of USDA's published materials and as such is viewed as the mainstay of USDA science. The next group (italics) includes chemistry, earth and planetary sciences; veterinary; pharmacology, toxicology, and pharmaceutics; chemical engineering; and engineering, represents 16% of cited articles. The remaining areas (normal text) cover nearly 6% of citings. Together these two groups, as defined by users, represent 94% of research cited by researcher of which nearly 60% is outside of the traditional agricultural sciences.[4]

Indicators of use: defining value of USDA intramural research

Citations counts provide a good indicator of the use of research output. Articles that are highly cited clearly have a greater impact on science than those that are rarely cited. Taking the notion of "use" one step further, here we utilize a measure that quantifies the relative value of USDA intramural research as derived from use indicators. We use an indicator designed to reflect the extent to which articles are used relative to the size of literature produced within a particular subject area, the citation per publication (CPP). The CPP is a kind of efficiency measure in that it suggests how useful the research is relative to all other research published in the area. The CPP is calculated as the ratio of the number of citations during a period of time to the volume of publications produced by the entity in question within a subject area.

$$\mathrm{CPP}_{it} = \frac{\left(\sum_{t=1}^{T} C_{\mathrm{it}}\right)}{P_{i1}}, \tag{1}$$

where C_{it} are the number of citations for subject i in period t, which are summed over T years, and P_{i1} are total published article in subject i in period 1. For example, in the

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[3] This study focuses on publications from 2005 and citations received during the 2005–2008 period. Looking at the distribution of research output over 28 subject areas over a 10-year time frame we found very little change in the relative contributions of each subject area to overall output. We are confident that this period is very representative of USDA's research output.

[4] Below we further develop the notion of core competencies.

Table 4 CPP by subject area of USDA 2005 intramural research publications and average CPP for publications from all sources 2005

Subject area	USDA CPP by subject area	Average CPP by subject area[a]
Agricultural and Biological Sciences	9.5	4.5
Biochemistry, Genetics and Molecular Biology	17.7	13.4
Environmental Science	10.2	6.6
Medicine	20.4	8.7
Immunology and Microbiology	16.6	12.5
Chemistry	14.1	7.3
Earth and Planetary Sciences	11.6	7.9
Veterinary	16.1	4.5
Pharmacology, Toxicology and Pharmaceutics	27.1	8.0
Chemical Engineering	16.5	5.1
Engineering	8.5	2.9
Materials Science	6.9	4.3
Social Sciences[b]	9.3	3.0

[a] *Source*: Thomson Reuters Journal Citation Reports® (2009)

[b] The USDA CPP for Social Science is the average for their Economics and Social Sciences CPPs

subject area of Agricultural and Biological Sciences, during the period from 2005 to 2008 the USDA received 35,156 citations for its 3,696 authored articles published in 2005 (Table 3). The CPP for Agricultural and Biological Sciences for USDA during this period is 9.5, implying that for every article published there were on average 9.5 references.

For the total number of articles published by USDA in 2005 (Table 3), the CPP is 12.7 implying that on average, for each article produced by the USDA, other researchers referenced articles 12.7 times. Agriculture and biological research, the primary subject area for USDA, represented over 43% of articles produced by USDA authors but only 35.5% of articles cited by researchers. The CPP for agriculture and biological research was 9.5, less than the overall average for USDA.[5,6] Biochemistry, genetics, and molecular biology ranked second in percentage of articles cited (15.4%) but had a higher CPP of 17.7. Medicine which represents only 6.4% of articles published in 2005 and 10.2% of articles cited had a CPP 20.4.[7]

Table 4 presents CPPs for USDA intramural research publications that represent a little over 90% all USDA publications and average CPPs by subject area from all published sources as derived from Thomson Reuters Journal Citation Reports (2009). When USDA CPPs are compared to CPPs from all sources, in general USDA's are higher. This is not

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[5] There are areas such as health professions and business management, where nonUSDA authors have cited USDA research but for which USDA authors have not designated as such.

[6] We assume the appropriate period of time for references to meaningful accumulate following any given year of publication is roughly 3 years. With the exception of seminal articles, the scientific value of an article takes a year or two to be discovered and then typically peaks at 3 years (Price 1980).

[7] Pharmacology, Toxicology, and Pharmaceutics has a very impressive CPP of 27.1 because the small number of articles published in 2005 (73) have 1,975 citations. Four of the top cited USDA authored articles within this subject area were published in *Science* and *Proceedings of the National Academy of Sciences of the United States of America*, which tend to be highly-cited journals.

surprising in certain fields where USDA has an obvious interest and mission to serve. Agricultural and biological and veterinary sciences are areas in which USDA is a key contributor to knowledge generated in these areas. The CPP for USDA's medicine research is higher than the average. USDA has significant programs in nutrition and other related research, which for purposes of analyses are categorized under medicine. USDA CPPs in pharmacology, toxicology and pharmaceutics are significantly higher than the average, not because these areas are a primary focus of research for USDA, but because USDA published a small number (relative to the field) of very high impact articles during this time period, which also indicates the broad reach of USDA research into other disciplines. USDA has a relatively high CPP in social sciences because a portion of its intramural research is conducted by the Economic Research Service, which is devoted to producing social and economic research. These data represent only a snap shot in time: 1 year of publications and 3 years of citations. Looking at additional time periods may seem warranted; however, we examined the distribution of articles published by subject area over a ten-year time period and found little variation in the distribution of subject areas addressed.

By combining both quantitative and qualitative information, the CPP's provide an interesting perspective. For example, the CPP for social sciences is similar (9.3) to that of agricultural and biological sciences (9.5) while social science publications represented less than 1% of USDA publication in 2005.[8] These indicators are informative and may be useful for making research funding allocation decisions, but should be done so with caution. We argue above that these indicators are a reflection of the value of this research (i.e., they reflect how desirable this published research is relative to how much is produced). To the extent the CPPs reflect a return on investment in research, then a high CPP would indicate an area of research for which additional investment would be warranted.[9] But caution is imperative because while the CPP indicates the value of a line of research to users, it does not reflect the capacity of the organization to produce or sustain the line of research. Below we present an augmented measure that reflects the value of the research and the strength and capacity of the organization to undertake it.

USDA intramural research capacity

The CPP described above combines information on publication quantity and quality derived from publication counts and numbers of citations. Using these two indicators (publication output and citation analysis) concurrently with the CPP, a view of USDA's research capacity is demonstrated. Figure 4 shows the distribution of publications, the citations received, and the associated CPPs by subject area. The percentage of the number of articles produced by subject area reflects the capacity by the agency (e.g., agricultural and biological sciences are clearly areas of strength for the intramural USDA research program). That fact is reflected by both the number of articles produced and how often the research is cited in other publications. In terms of the percent of publications and citations, the subject areas of biochemistry, genetics, and molecular biology and the area environmental science are also clearly important areas of USDA research strength and capacity.

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[8] While it was determined Scopus was the most complete source for bibliometric information for the life, physical and social sciences, social science information may be somewhat underrepresented. Scopus has updated its accounting of social science publications since this article was written.

[9] Clearly those decisions are beyond the scope of this paper; these indicators are presented merely as additional information to aid decision-making.

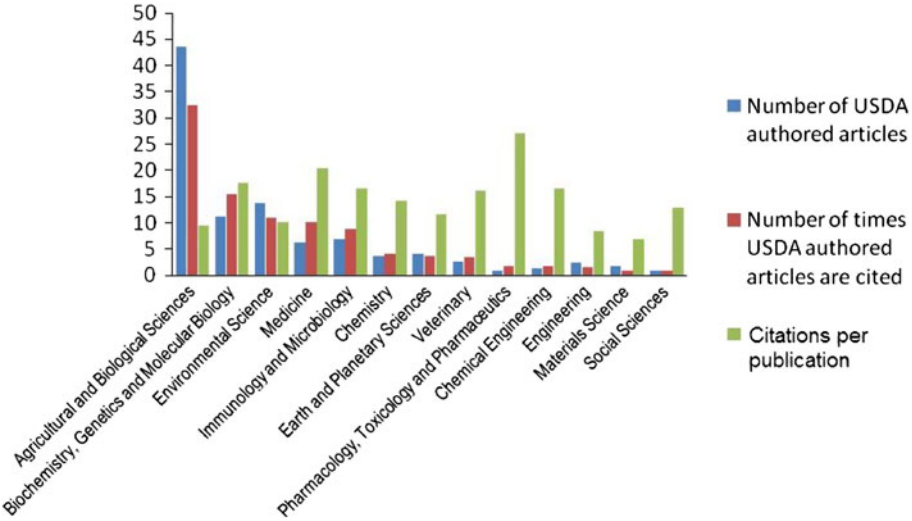

Fig. 4 USDA intramural research capacity: distribution of numbers of USDA published articles, numbers of citations, and CPP as an indicator of use by subject area

USDA intramural research core competencies

Core competencies reflect the strength and capacity of an organization to produce a highly valued good (or service) relative to other providers. An organization has a core competency in a subject area where they are very competent in producing a highly valued good. As a public sector entity, the USDA has to compete for public research dollars. Also, the USDA intramural research program is part of the larger national food and agricultural research system which includes the Land Grant university (LGU) system and other academic institutions. The LGU system is essentially the extramural part of the USDA research system because of the substantial support received by the USDA. As such it is important for the USDA to consider core competencies of its intramural research relative the extramural capacity. In short, when asked what research should be undertaken by either the intramural or extramural part of the system, it is critical to know the core competencies of the intramural component.

To develop a measure of core competencies we begin by creating a citation-weighted CPP. Citation weights adjust the CPPs upward or downward to reflect the extent a subject area is valued by users relative to all other areas of research.[10] Citation weights are calculated as the share of the number of citations in a subject area of total citation counts. Figure 5 is the citation weighted CPP for the key subject areas. The index is calculated as:

$$\mathrm{WCPP}_{it}^{C} = \frac{\sum_{t=1}^{T} C_{it}}{\sum_{i=1}^{M} \sum_{t=1}^{T} C_{it}} \times \frac{\sum_{t=1}^{T} C_{it}}{P_{i1}}, \tag{2}$$

for T periods and M subject areas. The index is normalized to the citation weighted value of the agricultural and biological sciences index value—so all other index values are relative

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[10] A publication weighted CPP also was calculated reflecting production capacity. The citation weighted CPP is considered more meaningful because it reflects the value of the research.

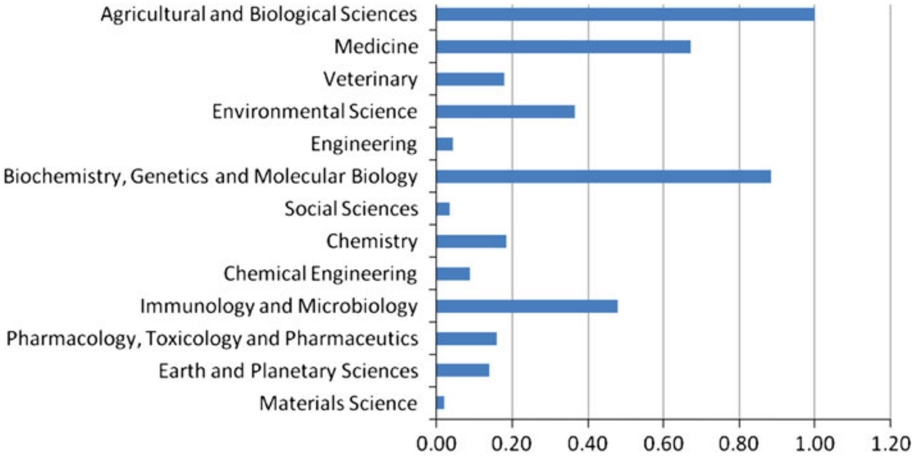

Fig. 5 USDA intramural research strengths: citation-weighted citation per publications (WCPP^C), 2005–2008

to the agricultural and biological index. The purpose of this weighting is to provide a sense of "importance" to the CPP measures (i.e., the impact actual users place on the efficiency aspect of the CPP measure). Agricultural and biological sciences appear as a very significant part of the USDA intramural research portfolio both in terms of numbers of publications and numbers of citations, but the CPP is 9.5 which is below the mean of 12.5, suggesting its use value is below average. Conversely pharmacology, toxicology and pharmaceutics had a high CPP but low number of publications and citations. So while researchers clearly use and value USDA research in the area of pharmacology, it seems inappropriate to term it core competency of USDA. By weighting the CPPs by their relative citation share, the significance of the CPP to overall use of USDA intramural research becomes more apparent.

The citation weighting of the CPP provides a picture of USDA intramural research strengths as a function of use across all areas of research. Agricultural and biological sciences are clearly strengths, as are biochemistry, genetics and molecular biology. By employing the citation weighting, agricultural and biological sciences moves from the a 11th ranked CPP to first place WCPP^C. Biochemistry is stable moving from an CPP third to a second place WCPP^C and medicine moves from second to third. Immunology does not change but environmental science moves from a tenth place CPP to fifth place WCPP^C. These results complement the science map presented earlier by indicating the growing and evolving importance medicine and related research have within the USDA intramural research program. When looking just at the citation ranking, medicine was in fourth place but by including the impact of the CPP medicine rises to third. Environmental science falls from a third ranked CPP to fifth place WCPP^C while it was in tenth place when ranked solely by the CPP. For some areas where their citation weight was low (i.e., a subject that appeared important because of its CPP, was not used by many of overall users), their relative position does not change very much.

We believe that combining the impact and value of research reflected by the CPP and the citation weight provides a useful measure of research strengths. However, some authors argue that making comparisons such as these across disciplines may be inappropriate

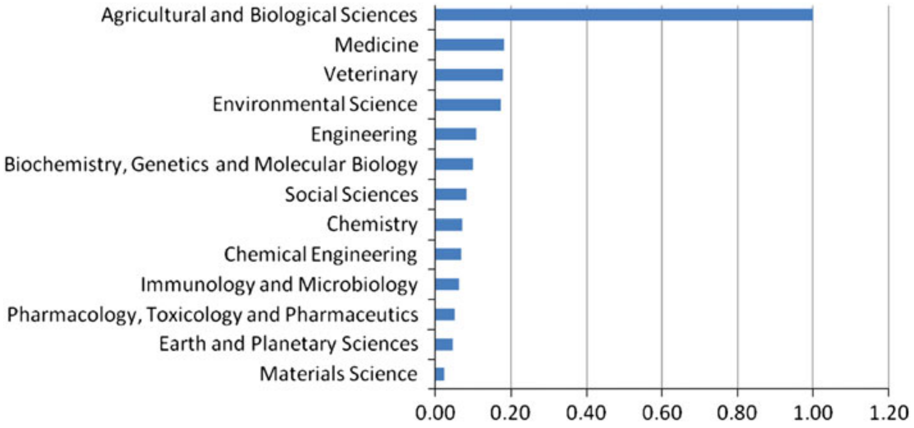

Fig. 6 USDA intramural research core competencies: CPPs standardized to account for differences in average citation rate across disciplines

because of introducing biases resulting from different subject-area citation rates (King). For example, journals of medicine and microbiology have much higher citation rates (8.7 and 16.4, respectively) compared to economics and business (3.1) and engineering (2.8) (Thomson Reuters 2008). We correct for this potential bias by incorporating average subject area citation rates in the adjusted CPP. By essentially deflating reported or nominal citation rates we are able to standardize the CPPs across subject areas making them directly comparable.

Defining the average subject area citation rate as ρ_{it}, then the standardized citation rates by subject area are $\tilde{C}_{it} = C_{it}/\rho_{it}$. The average subject area citation rate adjusted index is calculated as:

$$\mathrm{WCPP}_{it}^{\tilde{C}} = \frac{\sum_{t=1}^{T} \tilde{C}_{it}}{\sum_{i=1}^{M} \sum_{t=1}^{T} \tilde{C}_{it}} \times \frac{\sum_{t=1}^{T} \tilde{C}_{it}}{P_{i1}}, \tag{3}$$

When citation weighted CPPs are adjusted for average citation rate within specific fields of science (Scopus subject categories), core competencies can be demonstrated (Fig. 6). These competencies are based on specific research strengths of USDA in a particular field of research which provide the fundamental basis for the provision of added value (as defined by adjusted citation weights).

When adjusted citation-weighted CPPs are compared to unadjusted citation-weighted CPPs (Figs. 5, 6), notable observations are made in the relative ranking of subject categories. One thing that does not change with adjustment for average citation rate within a field is the prominence of agricultural and biological sciences as the USDA's primary intramural research core competency; however, several changes do take place with adjustment.[11] First, the status of medicine among the mix of USDA's intramural research competencies increases and is second to agricultural and biological sciences. A dramatic change in position of veterinary sciences as a core competency is seen with a third-place ranked position. The two other fields rounding out the top five core competencies are environmental science and engineering. Like veterinary medicine, engineering was not in

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[11] Index is normalized such that all subject areas are compared to agricultural and biological sciences.

the top five before making adjustments for average subject-area citation rate. When adjusted, the categories of immunology and microbiology as well as biochemistry, genetics, and molecular biology drop out and engineering moves into the top five research competencies.

Although the measure of research competencies we define here appears to be valid, some caveats exist. Goldstein and Spiegelhalter (1996) suggest that three areas need to be carefully considered when assessing research rankings as we have attempted here.

Source data can contain inherent biases and they can be inadequate. Bibliometrics must be used carefully for social sciences and humanities research evaluation because of the apparent differences in the way this research is reported and tracked (Science-Metrix 2004). For example, social sciences appears to be underrepresented in the Scopus framework used in the present analysis and economics is reported separately; however, Scopus is the most comprehensive database for the mix of life, physical, and social sciences.

It is imperative that statistical analysis and presentation be appropriate and that confounding factors be addressed. Techniques for adjustment of outcomes, as we have attempted here, are crucial to address the potentially skewed nature and uncertainty in the presentation of results. If appropriate adjustments are not made, or if data are not analyzed thoroughly, erroneous rankings can be generated, as we have demonstrated with early calculations in our analyses.

Finally, interpretation of results should be approached with a good understanding of the data and methods used to generate those results. Interpretation of rankings based solely on citations, without careful treatment as we have carried out here to standardize these rankings, can lead to invalid conclusions.

Summary and conclusions

Over the past 15 years, results of USDA's intramural research have been published consistently throughout a wide range of disciplines, demonstrating tremendous breadth. Over that same period USDA total annual publications have grown continually. Considerable depth also exists as indicated by the volume and proportion of total publications. Proportionally, agricultural and biological research dominate USDA's intramural research output, followed by environmental sciences, biochemistry, genetics, and molecular biology. These areas of research are considered foundational to discovery and innovation in agriculture and other related areas.

While an analysis of output is meaningful, the changing nature of science begs for a more dynamic approach to assessing research strengths, which is accomplished by mapping USDA's intramural science and performing citation analysis. Mapping USDA's intramural research competencies provides a sense of major research strengths and emerging competencies. Again, USDA's major strengths relative to science globally is in biological and earth sciences; however, a clearer picture of emerging competencies in medicine (nutrition and infectious disease) begins to appear when USDA science is mapped. In addition, an appreciation for the extensive multi-disciplinary and limited interdisciplinary nature of USDA science can be had. Citation analysis provides evidence that USDA clearly maintains five key areas of strength: agriculture and biological science; biochemistry, genetics and molecular biology; environmental science; medicine; and immunology and microbiology.

Research strengths are meaningless unless they are valued. In this study we use an index of CPP as a metric for establishing the relative value of USDA research. Combining information on publication quantity and quality in various subject areas of USDA research, significant value is placed on USDA's research in medicine (CPP of 20.4) and pharmacology (27.1); whereas, research in agriculture and biological sciences exhibits a modest CPP (9.5). USDA's research in the field of medicine is identified through science mapping as an emerging strength and this apparent strength is substantiated by its high CPP. To rely on only the CPP as an indicator of value can be misleading because it does not account for relative importance of the research. Establishing relative importance of research with respect to other research subject-area output produced by the USDA can elucidate core research competencies.

Citation-weighted CPPs provide an accurate indicator of core competencies (or relative importance) of USDA's research because they include measures of strength, value, and capacity. When weighted, agriculture and biological sciences is clearly the USDA' s core competency. While the top five core competencies identified by weighted CPPs are the same as those identified by citation analysis, the relative importance of those areas is different in the two analyses. Medicine is ranked 4 out of 5 in a straight citation analysis, but ranks 3 out of 5 when its citation-weighted CPP is determined, so clearly, medicine (nutrition and disease-related) research is a core competency. On the other hand, environmental sciences research at USDA, falls from a third ranked CPP to fifth place citation-weighted CPP while it was in tenth place when ranked solely by the CPP, which might call attention to the need to further evaluate those areas of research.

The current assessment provides a benchmark of the existing USDA intramural science competencies. Looking at the array of disciplines that are represented by the number of articles published in the various fields provides an indication of the existing breadth and depth of USDA science and a technological forecast of research strengths by revealing new or emerging knowledge areas. Performing the same analysis in the future and observing a change in the disciplines represented will provide an indication of how USDA science evolves or responds to changing demands on science.

With the clearly defined benchmark of USDA intramural research described here, the routine use of knowledge management tools such as bibliometrics and patent analysis will help to enable cross-disciplinary information transfer, reveal unproductive overlap and duplication, unrealized complementarity, gaps, and opportunities. It will facilitate collaborations to help establish research priorities and provide opportunities for researchers to think systematically about the state of their field and the contribution of their research. The use of these methods can support monitoring of funding and research developments over time, evaluation of funding strategies for different programs.

While the current effort is a first attempt to apply scientometric techniques to USDA science, much work is needed to advance and enhance this type of work. This study provides a benchmark for evaluating the rate and direction of future USDA science, but it is only a first step. The current analysis looks at a significant proportion of the USDA science landscape through bibliometrics and patent analysis. Going forward it would be beneficial to interlink these research output metrics to provide a more comprehensive look at USDA intramural research. An even greater challenge lies with providing a similar assessment of the extramural component of the public agricultural research system—a component funded in part through the USDA and other public funds greatly in excess of the funds allocated to intramural research. While our first attempt provides a "vertical" (unlinked) snapshot of the intramural research outputs—publications and patents—developing a "horizontal" (interlinked) assessment across both the intramural and extramural parts of the U.S. public agricultural research system will greatly enhance public science policy decision-making.

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