Land-Grant University Research as a Driver of Progress in Agriscience

Simon Tripp, Martin Grueber, Alyssa Yetter, and Dylan Yetter

Abstract The agricultural industries of the United States are a vital part of our economy, as are the land-grant universities that are inextricably tied to those industries. Given this importance, NIFA engaged TEConomy Partners, LLC, to categorize and describe the broad range of R&D and associated extension activity undertaken by the land-grant university system and supported by NIFA funding. The analysis in this chapter provides this evaluation and categorization and compares Capacity and Competitive funded research projects to the larger body of published agricultural research. We find that, compared to overall publications, Capacity projects are more focused on production-oriented areas than basic sciences, while Competitively funded research has its largest focus in basic sciences. Additionally, a number of areas that are small or missing from overall publications are present in notably higher concentrations in Capacity projects. The focus areas of both Capacity and Competitively funded research projects follow the goals of the NIFA National Challenge Areas and the 2014 Farm Bill. Finally, we find evidence of substantial return on investment for both forms of funding.

Introduction

The US agricultural sector, together with the social and economic structures that sustain it, is fundamental to national well-being and economic performance.[1] Agriculture and associated industries are part of an economic and social ecosystem that consists of a complex web of actors and activities that serve specific functions

[1] In this chapter, for the sake of simplicity, the terms "agriculture," "agricultural sciences," and "agricultural industries" are considered to also embrace forestry, fisheries, and other natural resource-based industries that are of relevance to the work of the USDA, NIFA, and the nation's land-grant universities.

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and make possible the positive outcomes of the system as a whole. Because it is a knowledge-driven and technology-intensive science-based sector, the agricultural system is very much dependent on knowledge advancements, innovations, and the transfer of knowledge and technology from a highly active research and development (R&D) sector.

Agribusiness in the US economy is a high performer in terms of sustained growth in economic output and productivity. The increasing productivity of US agriculture, and the growth of the large-scale value-added industry chain that benefits from it, has not occurred by chance. Rather, it has resulted from the intense and deliberate application of scientific research and technological development across a broad range of disciplines and research challenges.

The ongoing success of US agriculture is a testament both to the sustained work of thousands of American scientists, technologists, and engineers researching and innovating solutions and to the millions of US farmers who deploy the solutions these researchers provide. It is important to recognize that, unlike many other industries, the primary production sector in agriculture, being made up of millions of small and midsize enterprises, has only a limited internal R&D capacity of its own. Instead, innovations and productivity increase predominantly depending on R&D and knowledge transfer from commercial agricultural input suppliers, the US Department of Agriculture (USDA) Agricultural Research Service (ARS), and America's unique system of land-grant universities (LGUs) and Cooperative Extension Services.

The common thread that runs through scientific, technological, and practice advancements, including in agriculture, is research. Basic and applied research in biological sciences, physical sciences, social sciences, and engineering and a broad suite of associated disciplines produce the knowledge and advancements upon which progress is made. Research is the fundamental engine that drives US economic progress and competitiveness, and research funding is the fuel for that engine. While American agriculture is an industry operated by millions (farmers, ranchers, foresters), and sustained by the innovations of thousands (in the R&D sector), it is critically important to note that it is financially supported in its foundational advancement by funding from a select few sources. This select group comprises private-sector industrial companies that develop applied technologies and solutions in terms of farm inputs and agricultural and processing equipment, the US Federal Government (most notably through the USDA and its National Institute of Food and Agriculture [NIFA]), state governments, commodity organizations, and nonprofit foundations.

After the private sector, the federal government is the next largest funder of agricultural and related research by a wide margin and is the primary funder of early-stage, exploratory research and applied agricultural research focused on specialty crops, livestock, and agricultural commodities specific to local geographies and production environments. Importantly, federally funded research also supports work in soils, water, ecological systems, workforce development, rural development, and other elements critical to the sustainability of the agricultural production ecosystem that do not attract significant commercial research.

In 2016 NIFA commissioned TEConomy Partners, LLC (TEConomy), to evaluate Capacity Funding (also known as Formula Funding) to land-grant universities and assess the productivity and impacts of this funding model. The full analysis provided to NIFA[2] assesses the types of basic and applied research programs funded under the Capacity Funding programs, the types of impacts being generated, the relevance of research to current and future national and state needs, and the strengths and weaknesses of the funding model using a set of existing federal and land-grant university datasets and a series of surveys administered to LGU leadership in colleges of agriculture, state experiment station systems, and extension services. This chapter and the one that follows it present a subset of the findings of the NIFA-TEConomy report. In this chapter, we describe the unique industry that is the twenty-first century American agriculture and the mission of the LGU system in support of it. This chapter then describes the methods and results of our analysis of (a) the areas of research output activity (as defined by publications volume and thematic content) in agriculture and related subjects overall and in comparison with NIFA Capacity and NIFA Competitive funding, (b) the fit of these research outputs with NIFA's National Challenge areas and the 2014 Farm Bill Priority Areas, (c) the financial leveraging of Capacity Funding, and (d) the return on investment of Capacity and Competitive Funding in terms of knowledge production.

Agriculture and the US Land-Grant System

Achieving large-scale gains in agricultural output and productivity is no easy task. Unlike almost every other industry, agriculture operates within a production environment that has substantial year-to-year and season-to-season variability. It is largely an outdoor industry dependent on weather and open to the pressures of naturally occurring diseases and pests. Factors both abiotic (rainfall, sunlight, frost, etc.) and biotic (plant and livestock diseases, crop-damaging pests, etc.) are variables that significantly affect production but cannot be assured in advance. New diseases are emerging, and existing diseases and pests are expanding in their geographic range, spurred in part by human activities and the reactions of the biosphere and climate to them. This dynamic production environment, and the challenges associated with it, represents a unique signature of the agricultural industry.

It is also the case, unlike most other manufacturing or technology industry sectors, that agriculture is almost entirely composed of small and midsize business enterprises in terms of primary production. Whereas the global automobile industry, for example, comprises circa two dozen or so major manufacturers, agricultural

[2] Simon Tripp, Martin Grueber, Dylan Yetter, Joseph Simkins and Alyssa Yetter. 2017. *"National Evaluation of capacity programs: Quantitative and Qualitative Review of NIFA Capacity Funding."* TEConomy Partners, LLC, for the National Institute of Food and Agriculture (NIFA). March 2017. Available online at https://nifa.usda.gov/sites/default/files/resource/NIFA Capacity Funding Review - TEConomy Final Report.pdf.

output in the United States alone stems from the work of 2.1 million individual farms. The US agricultural industry's national output is the net result of literally hundreds of millions of individual decisions made by farmers across their growing seasons, with those decisions having to take into account an exceptional number of variables, including weather, soil fertility, pathogens, pests, commodity prices, and global competition, among others, and the potential deployment of multiple technologies and solutions, such as specific crop varieties to use, livestock health products to employ, type of tillage to deploy, and capital investments in new farming equipment, to name just some.

The fact that American farmers and the R&D system that supports these farmers have *together* achieved the productivity increases shown on Fig. 1 in the face of the variable production environment and multivariate decision-making environment in which farmers operate is a splendid American success story, but one that goes under-recognized and underappreciated. The success of US agriculture is a testament to the determined and sustained work of many thousands of American scientists, technologists, and engineers developing and innovating solutions and to the millions of US farmers who deploy the solutions these researchers provide.

Because of US scientific research and scientific knowledge translated into practice, the nation's agricultural sector has become expert in doing more with less – working to deploy technologies and research-based solutions to produce increasing output from each existing acre of US agricultural land. Research-driven advancements in animal science, veterinary medicine, genetic marker-assisted livestock breeding, and advanced nutrition formulations, for example, have led to widespread

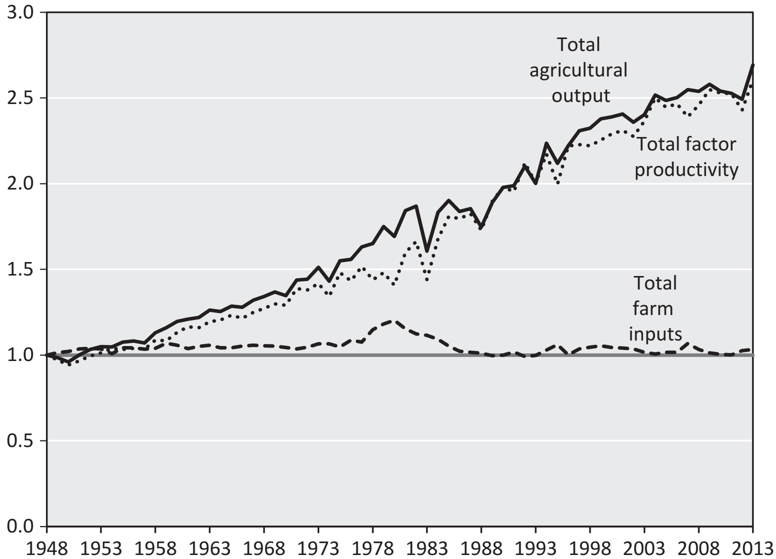

Fig. 1 US agricultural output, inputs, and total factor productivity index, 1948 = 1 (Source: USDA, Economic research service, agricultural productivity in the U.S. data as of December 2015)

gains in the output of the livestock and poultry sectors. Likewise, in crop agriculture, innovations in agronomic techniques, soil science, plant biology and breeding, molecular genetics, pest and disease management technology, and agricultural equipment engineering have led to similarly far-reaching increases in on-farm production. Today, revolutionary new technologies in biotechnology, genomics, precision equipment guidance, robotics, computerized decision support systems, and other technological fields are finding direct application in expanding agricultural production and efficiency. At the same time, rural sociologists, family and consumer science researchers, education and communication specialists, agricultural economists, and other academics and professionals have worked, and are working, to understand and sustain the economic and social fabric of rural, small town, and urban America that supports much of the progress in national farm, forest, and natural resource industries. In other words, research drives increasing productivity in agriculture and associated industries and works to sustain the societal, family, workforce, public policy, and other necessary pillars that support a sustainable agricultural economic ecosystem.

The federal government through the USDA both performs research, through its in-house ARS,[3] and funds research performed by other institutions, primarily academic institutions, across the United States. NIFA Capacity Funding and, to a lesser extent, Competitive Funding support a holistic land-grant-based R&D and extension ecosystem. This ecosystem, depicted in Fig. 2, comprises a complete continuum of R&D activity from basic inquiry, through applied and translational research, to piloting and field demonstration. The innovations and practical knowledge derived from R&D are disseminated through Cooperative Extension and land-grant technology transfer activities to those in production agriculture, industry, and society who can put this knowledge and innovation to work for the betterment of the US economy and society.

Of particular note is that this system is deliberately bidirectional. Communication of needs, challenges, opportunities, and innovations moves from the field to the researcher and from the researcher to the field. This NIFA-supported ecosystem (Fig. 2), rooted in the original vision for land-grant universities and Cooperative Extension, was envisioned, and subsequently evolved and refined, to provide a pragmatic feedback loop – assuring R&D activity is responsive to tangible needs and that novel innovations and findings are not only reported in academic journals but are proactively disseminated by Cooperative Extension activities for use in farms, industries, communities, and beyond.

The universe of potential research inquiry supported by NIFA is extremely diverse. Not surprisingly, there is a robust emphasis on work in support of enhancing and sustaining American production agriculture, forestry, and natural resource industries, but the activities undertaken extend far beyond core areas of agronomy, plant science, and livestock-related animal sciences. NIFA funding supports fundamental basic science inquiry in life sciences of relevance to better understand

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[3] The USDA Agricultural Research Service (ARS) has more than 2200 permanent scientists working on approximately 1100 research projects at more than 100 locations across the United States.

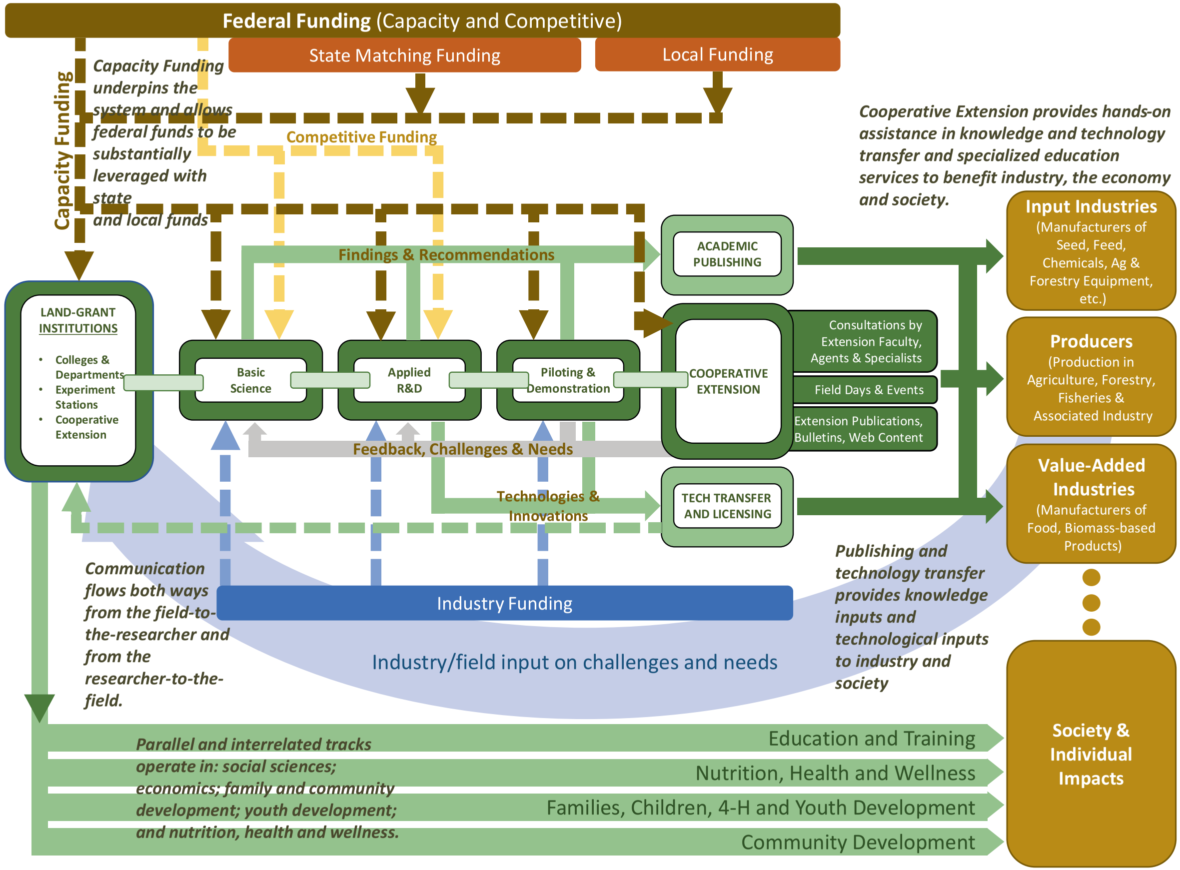

Fig. 2 Federal funding and the land-grant university research and cooperative extension ecosystem

life processes and mechanisms of action. Further, NIFA supports applied work in the value-added industries that work beyond the farm gate, across the supply chain, to provide US residents and global consumers with access to nutritious foods, health products, lumber and wood products, fibers, renewable bio-based fuels, chemical products, and materials. Because of the nationwide nature of agriculture and its associated value chain, the benefits these sectors provide are present in all states and US territories. Furthermore, NIFA supports research and extension activity that is focused on sustaining the rural families and small-town fabric that are crucial to the resiliency of these industry sectors.

Figure 3 depicts core areas of land-grant research activity identified by TEConomy in performance of this project and in previous engagements analyzing land-grant university and extension services impacts. The broad diversity of research activity, noted above, is graphically illustrated in this figure.

Currently, the federally supported land-grant university system is deployed in addressing a large-scale contemporary suite of complex and dynamic challenges and needs. The system is, for example, researching and extending into practice solutions across a range of domains, including, but not limited to, the following:

- Deploying traditional and state-of-the-art modern scientific tools and techniques to protect and improve both the yield and quality of agricultural crops and livestock
- Integrating advanced sensing, precision guidance, and metering technologies to maximize the efficient use of inputs to agriculture (such as water, fertilizers, and pesticides) and limit negative externalities associated with input use
- Developing advanced predictive modeling technologies, big data, and decision support systems to enhance the accuracy of agricultural decision making
- Exploring and developing new and enhanced sustainable biomass-based industries in the production of energy, fuels, materials, chemicals, and fibers
- Leveraging innovations and research findings to achieve rural development and enhanced economic and social opportunities for small towns, rural America, and metro areas engaged in value-added manufacturing using agricultural and natural resources
- Increasing the education, skills, and technical capabilities of the workforce to meet current and projected needs of the high-tech, high-productivity agricultural sector and value-chain industries

It should be recognized that advancements in these and other applied areas are built upon a platform of progress in fundamental, basic science knowledge that is the result of research undertaken predominantly at academic research institutions, including the land-grant universities. While basic sciences, including biological sciences, have experienced an explosion in discovery and knowledge in recent decades, there is still no shortage of fundamental research questions to be explored. Just in plant biology, for example, the American Society of Plant Biologists[4] notes the

[4]American Society of Plant Biologists. Unleashing a Decade of Innovation in Plant Sciences: A Vision for 2015–2025.

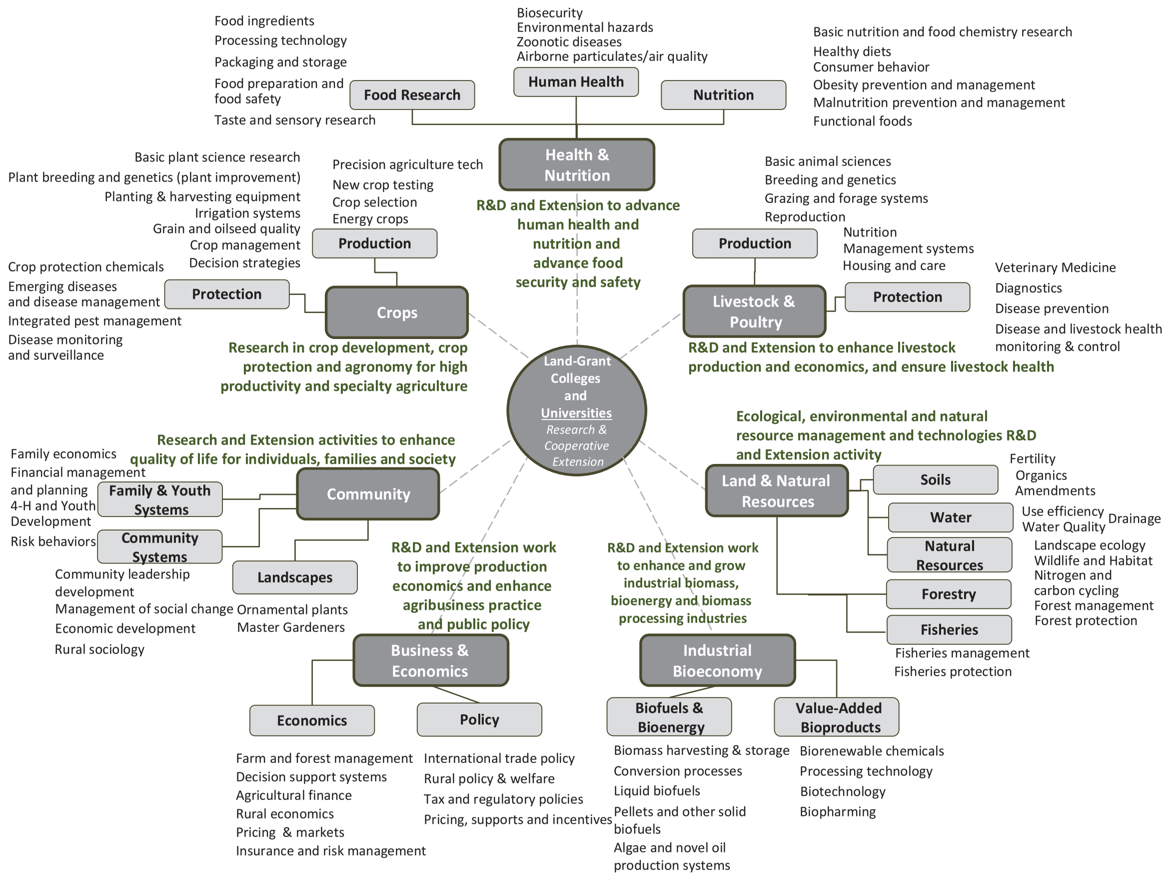

Fig. 3 An illustration of the varied scope of subject matter relevant to research and cooperative extension at land-grant colleges and universities

importance of advancing research in such fundamental areas as predicting plant traits from plant genomes in diverse environments; finding ways to assemble plant traits in different ways to solve specific challenges; discovering, cataloging, and utilizing plant-derived chemicals; and moving plant biology to a predictive science platform based on big data analytics. Basic science and applied science go hand in hand in terms of meeting grand challenges and opportunities in agriculture and associated areas of inquiry.

Our work for NIFA sought to categorize and describe the broad range of R&D and associated extension activity undertaken by the land-grant university system and supported by NIFA funding. It provides an evaluation and categorization of LGU research supported by NIFA Capacity and Competitive Funding in comparison to published agricultural research extant.

Data and Methods

With $0.85 billion currently going to Capacity Funding and $0.7 billion budgeted for NIFA-funded Competitive research,[5] it is important to examine, objectively, what outputs are occurring for the nation via USDA extramural funding of research and associated activities. To address this question, we analyzed data on academic publications and NIFA-funded project summary reports to examine quantitative metrics of research output activity.

Data

First, publication analysis is performed using Clarivate Analytics' (formerly Thomson Reuters) Web of Science™ database. The data used in this analysis include peer-reviewed journal articles, reviews, and conference proceedings papers. The dataset includes documents from 2010 through 2016 in all disciplines associated with agriculture, forestry, fisheries, and natural resources. A total of 123,790 records are included in the analysis. These data include all listed publications and do not provide details on the source of funds used for the research and accordingly are not limited to publications from research funded by NIFA. As such, they provide a baseline of the overall structure of the academic literature in agriculture and related disciplines, to which our subsequent analysis of NIFA-funded projects is compared. Second, for the analysis of NIFA Capacity and Competitive funded

[5] Competitive Funding includes the Agriculture and Food Research Initiative (AFRI), plus Mandatory Programs including the Specialty Crops Research Initiative (SCRI), Organic Agriculture Research and Extension Initiative (OREI), Beginning Farmers and Ranchers Development Initiative, Biomass Research and Development Initiative (BRDI), and smaller Competitive Programs.

projects, TEConomy was provided with annual datasets from the Research, Extension, and Education Project Online Reporting Tool (REEport), NIFA's grant reporting system, for the years 2010–2015. This consolidated dataset includes detailed descriptive information regarding the objectives, performance, and ongoing impacts of both Capacity and Competitive funded projects, including financial information regarding both NIFA funding (Capacity or AFRI or NRI Competitive Funding) and related state, local, and industry funding. Separate analyses are run for Capacity ($n = 19{,}791$) and Competitive funded projects ($n = 2299$).

Analysis

A real-text cluster analysis was performed on the full dataset using the OmniViz™ analysis system. The use of OmniViz™ cluster analysis allows the text of titles and abstracts of publications to be analyzed objectively, with no a priori categorization used. OmniViz™ uses real-text pattern-recognition algorithms to analyze the titles and abstracts of research publications, allowing for free association based on the usage of words and phrases rather than forcing clustering based on preselected keywords. Thus, there is no a priori bias to the clusters identified. This analysis also has the advantage of being well suited to identifying multidisciplinary research areas that are often difficult to identify in traditional academic disciplinary classifications. OmniViz™ cluster analysis results produce a classification system with a three-level hierarchy, shown in Fig. 4.

Our analysis is primarily descriptive in nature and details the topic areas of research in agriculture and related areas. The analyses proceed by first presenting the cluster segmentation of overall publications, followed by Capacity funded

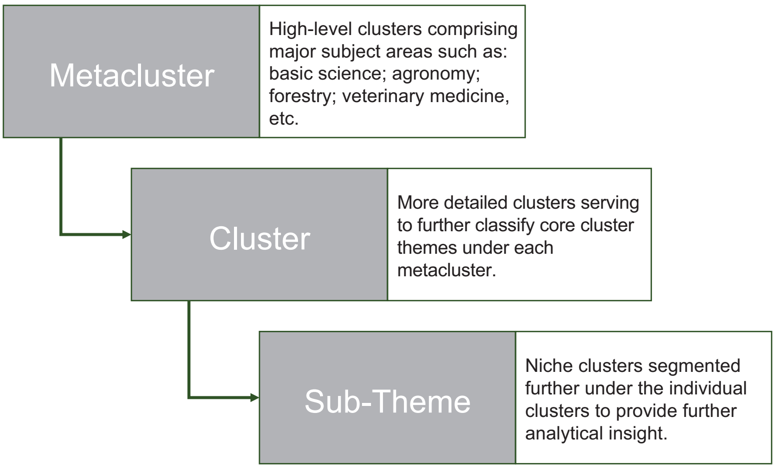

Fig. 4 Three-level hierarchy of OmniViz™ cluster analysis

projects and Competitively funded projects. Second, we compare the segmentation of Capacity projects to overall publications and compare Capacity and Competitively funded projects. Third, we assess the congruence of the clusters identified in Capacity and Competitively funded projects with the six NIFA National Challenge Areas and the six Priority Areas in the 2014 Farm Bill. Fourth, we utilize the REEport data to analyze the leveraging of Capacity Funding in terms of generating and matching other sources of public and private funding across cluster areas. Finally, we examine the return on investment, defined by publications output in the REEport data, across cluster areas.

Results

Publications

To first establish a baseline for the segmentation of agriculture, forestry, fisheries, and natural resources research, TEConomy performed a cluster analysis of the Clarivate Analytics *Web of Science*™ database for journal publications, articles, and conference proceedings papers in relevant disciplines. The cluster analysis produced 70 total clusters comprising 108,180 total publications (with 15,610 publications clustering into an "artifact" cluster not incorporated in the final analysis). The clusters were reviewed and provided with descriptive names for their content in a three-level hierarchy as summarized in Fig. 4. For the publication analysis, OmniViz™ identified 12 meta-clusters, 70 clusters, and 45 subthemes. In addition, Clarivate Analytics assigns a research area classification to each publication, and the percent segmentation for the highest order of this classification system is included herein also.

The results of the cluster analysis of the publications are presented in both graphical (Fig. 5) and tabular (Table 7, see appendix) forms. We find that agronomy and basic science are the largest of the meta-clusters, each with roughly 21% of the publications. For both of these meta-clusters, plant science is the largest cluster. In agronomy, the focus is on plant breeding and improvement, with corn being the single plant variety that makes up the largest subtheme. In basic science, the largest subthemes under the plant science cluster are stress resistance, physiology and morphology, and seeds, each with roughly 20% of the basic plant science publications. The third largest meta-cluster is veterinary medicine (18%), and its largest clusters are canine, infectious diseases, and equine publications.

Clarivate Analytics also assigns a research area classification to each publication, and the segmentation of classifications at the highest order of their classification system is shown in Fig. 6. This classification scheme is more rooted in traditional academic discipline names. Using this more traditional classification, we still see plant science and veterinary medicine as the most frequently published areas in the recent full literature of agriculture and related sciences.

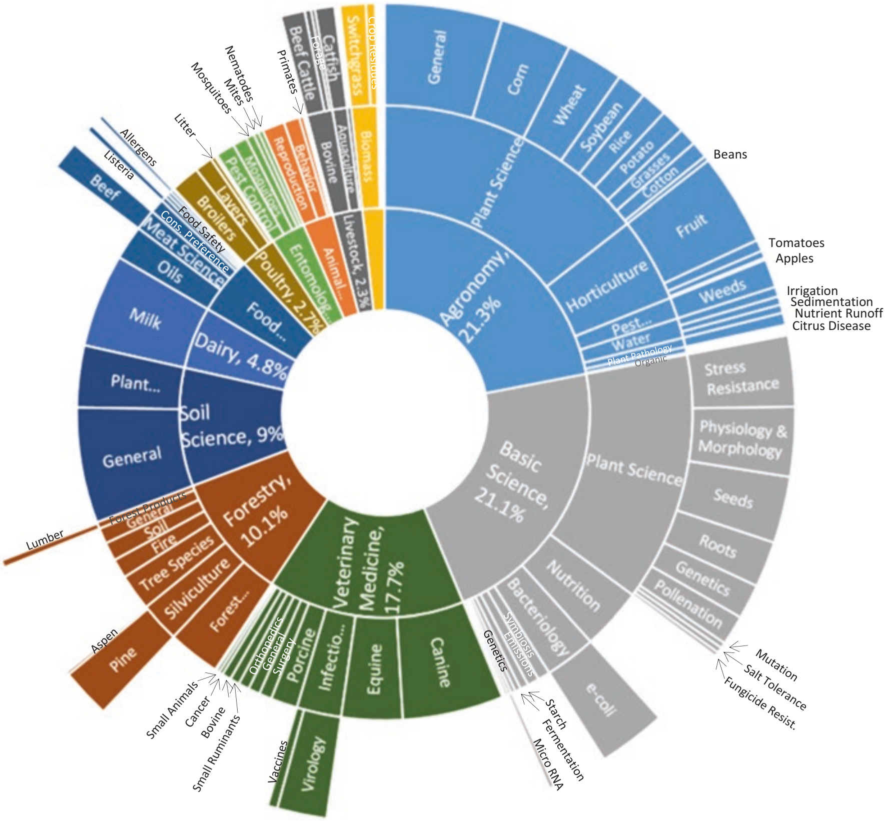

Fig. 5 Percentage segmentation of publications across key disciplines (OmniViz™ Cluster analysis of 108,180 publications)

Capacity Funded Projects

The analysis next turns to describing the segmentation of Capacity funded projects in the NIFA REEport data system. In total, the analysis covers 19,791 distinct Capacity funded projects. The results of the cluster analysis divide these projects into 10 meta-clusters, 55 clusters, and 44 subthemes. The results of the cluster analysis of the Capacity funded projects are presented in both graphical (Fig. 7) and tabular (Table 8, see appendix) forms. As in the overall publication analysis, the largest share of projects is in agronomy (36%), although pest management (27%) has a slightly larger share within this meta-cluster than plant breeding and improvement (25%), which is distinct from the overall patterns, where pest management is a relatively small share (5%). This is indicative of a general pattern in Capacity funded projects. While they are diverse, approximately two-thirds of Capacity funded projects (65.4%) demonstrate focus in "production"-oriented areas of R&D, including agronomy, animal science and livestock, forests and forestry, and fisheries and aquaculture. Other areas addressed include important health and welfare,

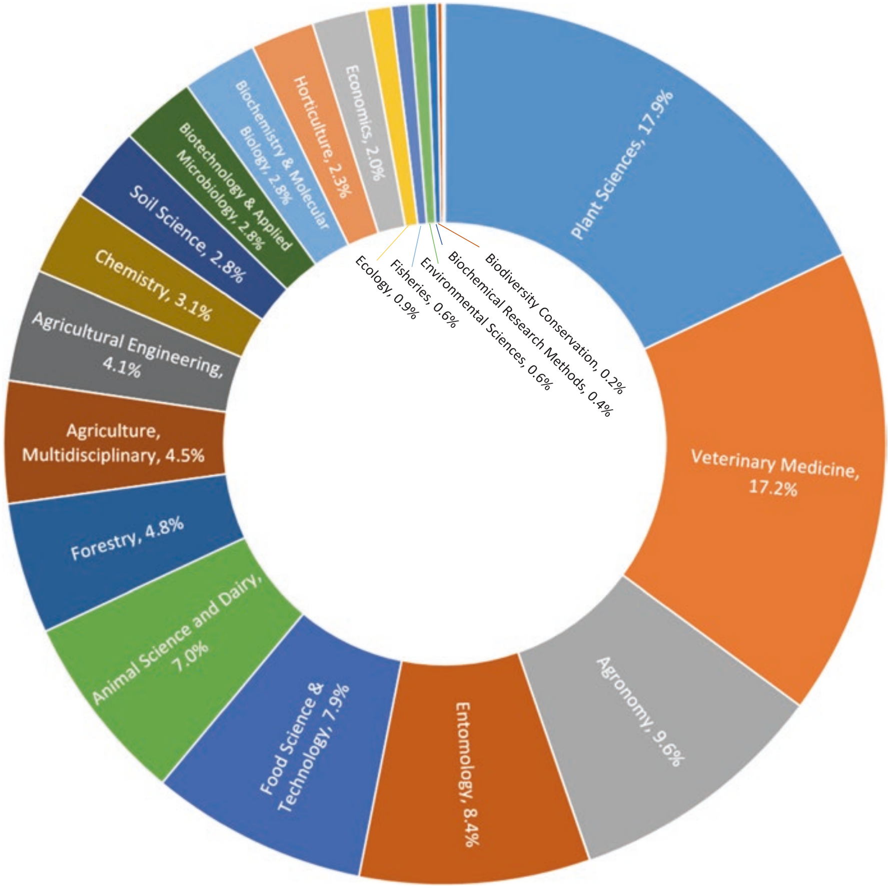

Fig. 6 Percentage segmentation using Web of Science™ classifications

family and youth, community development, and environmental domains. However, Capacity Funding is not only suited to the support of applied and translational research and extension projects. Among the 19,791 funded projects for 2000–2015, fundamental science (basic science) inquiry makes up 12.2% (2414 projects). These are quite focused in basic life sciences, with microbiology (72%) and genetics and genomics (11%) comprising the largest subclusters therein.

Comparison of Capacity Funded Projects and Overall Publications

It is evident that, in comparison to the *Web of Science*™ total agbioscience dataset**,** Capacity funded projects have several "signatures" in terms of focus:

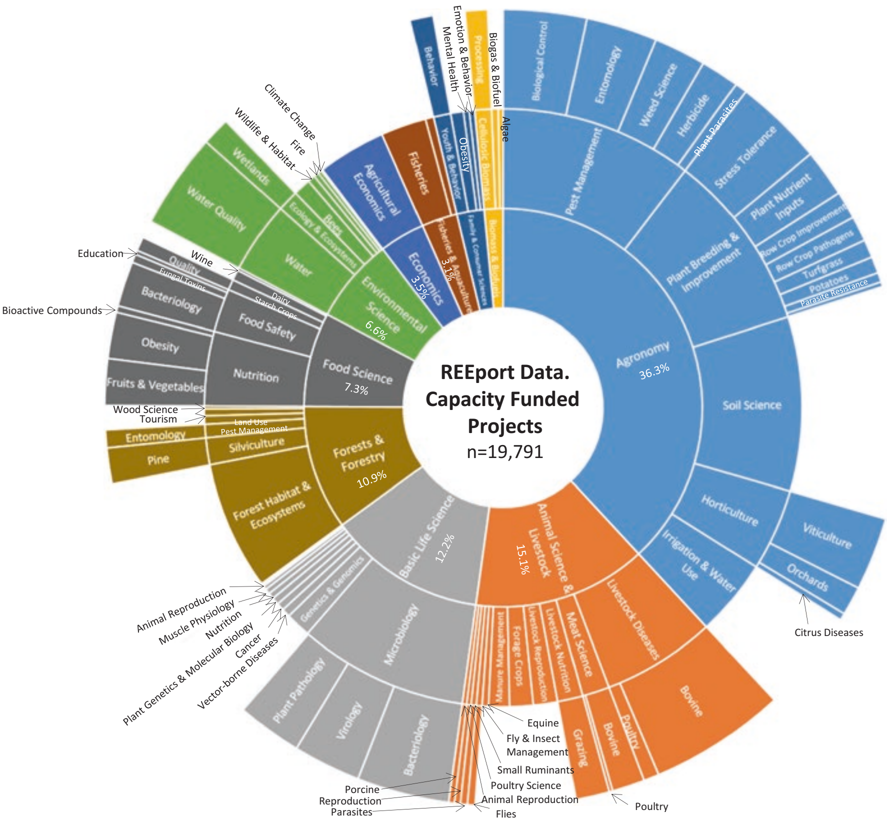

Fig. 7 Percentage segmentation of Capacity funded projects (REEport Data for 2010–2015) across meta-clusters, associated clusters, and subthemes (Data Table 8 in Appendix)

- Less emphasis on basic science projects. Basic science projects are 21.1% of all publications in the *Web of Science*™ dataset, whereas Capacity funded projects see 12.2% of projects clustered as basic science.
- Animal science and livestock research is more focused in the Capacity funded projects on animals used in production agriculture, and a separate veterinary medicine cluster is not evident (as it is in the full *Web of Science*™ dataset).
- A considerably larger emphasis on pest management as a theme, with 9.9% of total records in the Capacity funded analysis, versus just 1.1% in the *Web of Science*™ data.
- There is more emphasis in the Capacity funded projects on water as a research theme (7.7% of records across two clusters), as opposed to a 1% cluster in the *Web of Science*™ data.
- There is more emphasis in the Capacity funded projects on food science (7.3% of records), as opposed to 4.4% in the *Web of Science*™ data.
- A greater emphasis on biomass and biofuels in the Capacity records (3.1%) when compared with the *Web of Science*™ clustering (1.7%).
- A family and consumer science cluster (with 2.1% of records) and an economics cluster (3.5% of records) present under the Capacity Funding analysis that are

not distinct clusters in the *Web of Science*™ analysis. Similarly, fisheries and aquaculture has a Capacity funded cluster (2.8% of records), indicating an importance within Capacity funded activities above that observable in the overall literature.

It is also notable that agricultural engineering does not produce a distinct cluster in either of the cluster analyses, although Fig. 6 shows this discipline makes up 4.1% of the relevant *Web of Science*™ records. It is likely the case that this discipline's research is distributed within the cluster analysis into multiple clusters (e.g., irrigation, pest management, soil science, food science, etc.).

Overall, the comparison between the Capacity funded and *Web of Science*™ datasets illustrates a generally focused inquiry through Capacity projects on applied research – research focused toward current and emerging issues facing agriculture and natural resource sectors and communities.

Competitively Funded Projects

The REEport system also includes data on a total of 2299 NIFA Competitively funded projects. The results of the cluster analysis divide these projects into 9 meta-clusters, 30 clusters, and 11 subthemes (Fig. 8 and Table 9 in appendix). The largest area of Competitively funded projects is basic science, which takes up a quarter of these projects. Of the basic science projects, most are in basic plant science (33%), genetics and genomics (20%), microbiology (17%), and infectious diseases (17%). The prevalence of basic science in the Competitively funded projects is not to the exclusion of applied research projects. The meta-clusters of agronomy (21%), food science (11%), and animal science and livestock (11%) make up a large share of Competitively funded research and address problems including pest management, food safety, and vaccines.

Comparison of Capacity and Competitively Funded Project Meta-Clusters

Figure 9 presents a comparison of the results of the Capacity and Competitive funded projects clustering analysis. As would be expected, given the substantially larger numbers of records in the REEport data for Capacity funded projects (19,791) versus Competitive (2299), the Capacity cluster analysis produces more clusters and subthemes under each meta-cluster. The meta-clusters for each of the funding sources are similar, except for the absence of a fisheries and aquaculture cluster in the Competitive analysis, but they differ considerably in terms of the percent of the total records that each meta-cluster comprises for the respective funding types. The biggest differences can be observed in double the percentage emphasis on basic life science in the Competitively funded project universe when compared with Capacity funded projects and in significantly more Capacity funded projects focused in agronomy, which comprises plant breeding and improvement, pest management,

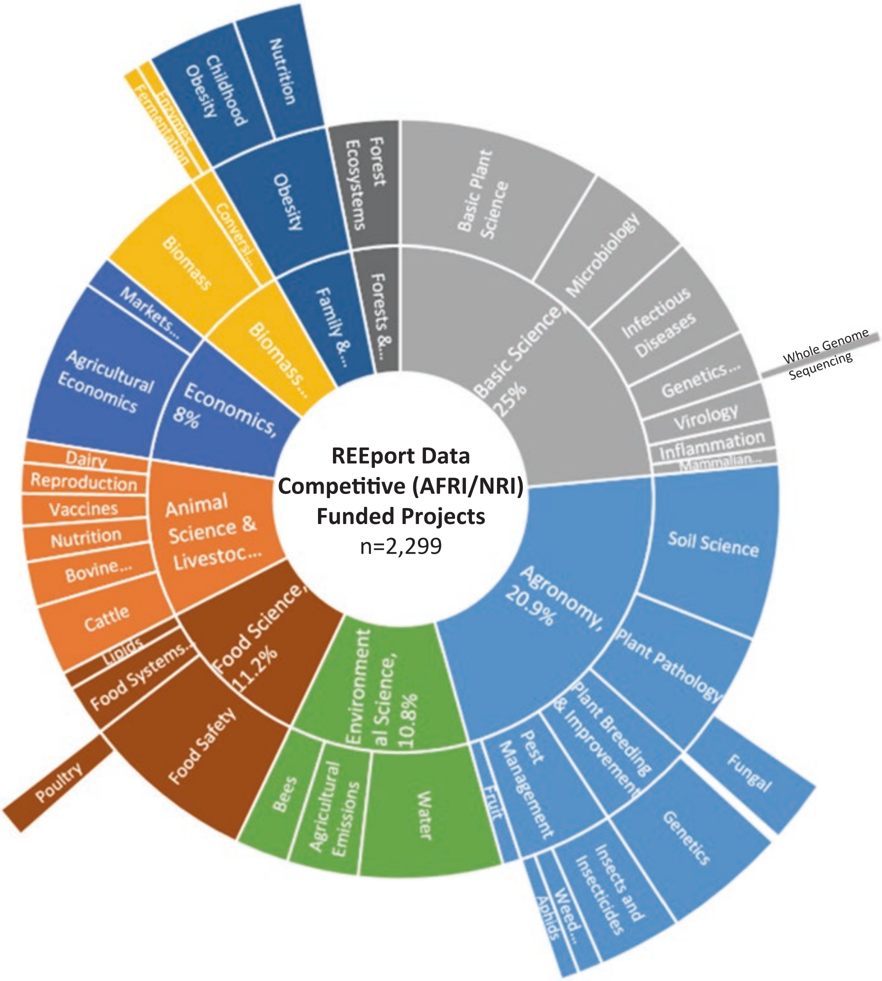

Fig. 8 Percentage segmentation of Competitive funded projects (REEport data for 2010–2015) across meta-clusters, associated clusters, and subthemes (Data Table 9 in Appendix)

soil science, horticulture, and irrigation and water use management. Animal science and livestock also has a greater emphasis in the Capacity funded portfolio than in the Competitive funded portfolio (15.1% and 10.9%, respectively). Forests and forestry as a percentage of the Competitive portfolio is more than three times smaller than under Capacity Funding, whereas several other meta-clusters show a higher emphasis in terms of Competitive Funding, including food science, environmental science, economics, biomass and biofuels, and family and consumer sciences.

NIFA Capacity and Competitive Funding demonstrate substantially different degrees of emphasis in terms of projects undertaken. Capacity Funding is more likely to focus on production agriculture-oriented research projects in agronomy, animal science and livestock, fisheries and aquaculture, and forests and forestry.

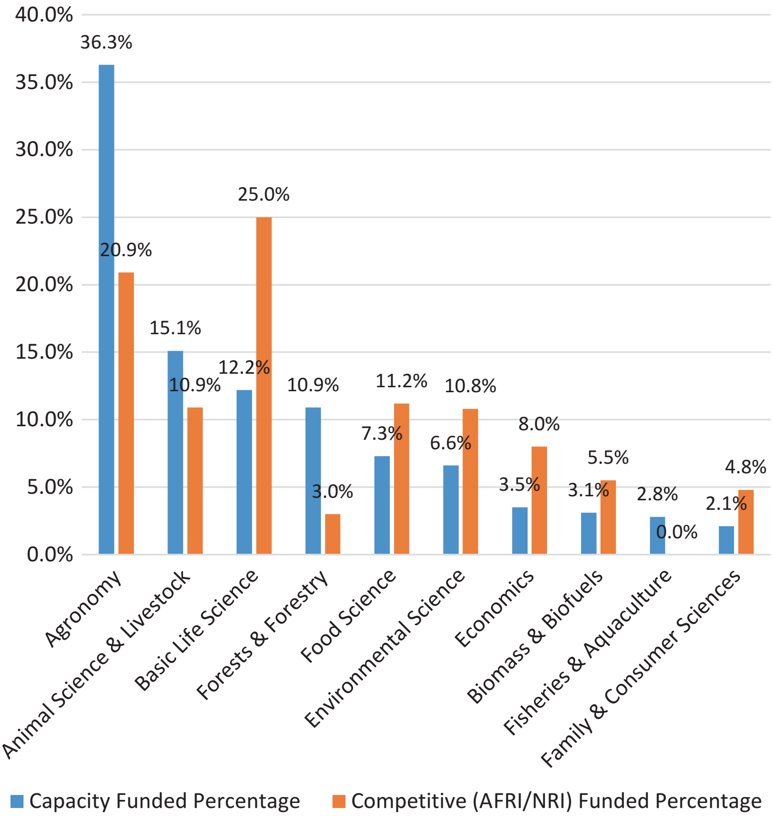

Fig. 9 Comparative percentage segmentation of Capacity and Competitive funded projects (REEport Data for 2010–2015)

This is a logical finding, given the ability of Capacity Funding to be focused on the particular needs of agricultural and natural resource industry needs, challenges, and opportunities at a state, regional, or local level. Competitive Funding skews more to an emphasis on basic life sciences, having double the emphasis here as seen in Capacity funded projects, and demonstrates marginally more emphasis on food science, environmental science, biomass and biofuels, economics, and family and consumer sciences.

Comparison of Capacity and Competitively Funded Project Meta-Clusters and Clusters on Six NIFA National Challenge Areas

In reviewing the cluster analysis of the respective portfolios of projects classified as either Capacity funded or Competitive funded, a comparison can be made of the alignment between these project portfolios and the six NIFA National Challenge

Areas. Table 1 lists both the Capacity funded and Competitive funded project meta-clusters and clusters and their relationship, in terms of likely subject matter, to each of the six NIFA National Challenge Areas.

As Table 1 illustrates, the majority of projects in both the Capacity funded (64.2%) and Competitive funded (59.1%) portfolios of work are relevant to the six NIFA National Challenge Areas combined. Capacity Funding shows a higher proportion of projects directed toward two of the challenges: food security, where it makes up almost half of the Capacity funded portfolio, and water. Competitive Funding sees a proportionately higher focus on the themes of climate variability and change, bioenergy, childhood obesity, and food safety. It should be noted that, in absolute project number terms rather than percent of projects, Capacity Funding has the higher total volume of work taking place across all of the National Challenge Areas except for climate variability and change.

Comparison of Capacity and Competitively Funded Project Meta-Clusters and Clusters on Six Priority Areas in the 2014 Farm Bill

The 2014 Farm Bill provides authority to NIFA to pursue programs in support of six congressionally identified priority areas. The Farm Bill priorities are summarized by NIFA as follows (Table 2)[6]:

These six Farm Bill priorities for NIFA can be compared to the results of the Capacity and Competitive NIFA funding REEport cluster analyses in order to produce an estimate of the projects undertaken by the land-grant universities relevant to these priorities. Table 3 lists both the Capacity funded and Competitive funded project meta-clusters and clusters and their relationship, in terms of likely subject matter, to each of the six 2014 Farm Bill priorities for NIFA.

As Table 3 illustrates, both Capacity funded (87.7%) and Competitive grant funded (88.2%) portfolios of work see the majority of projects as relevant to the six priority areas in the 2014 Farm Bill. Capacity Funding shows a higher proportion of projects directed toward the two challenges most directly focused on agricultural production: "animal health, production, and products" (16.4% of Capacity projects versus 10.8% of Competitive projects) and "plant health, production, and products" (36.7% of Capacity projects versus 29.1% of Competitive projects). The Competitive portfolio shows a higher proportion of projects focused on the post farm gate area of "food safety, nutrition, and health" (13.9% of Competitive projects versus 7.6% of Capacity projects). Overall, the Farm Bill priorities are addressed by almost nine out of every ten Capacity and Competitively funded projects.

[6] https://nifa.usda.gov/farm-bill-priorities

Table 1 Project meta-clusters and themes as identified in analysis of REEport system data on the six NIFA National Challenge areas

NIFA National Challenge	**Capacity funded** Meta-clusters (percent of total)	**Capacity funded** Clusters (percent of total)	**Competitive funded** Meta-clusters (percent of total)	**Competitive funded** Clusters (percent of total)
1. Food security	Agronomy (36.3%) Animal science and livestock (15.1%) Fisheries and aquaculture (2.8%)	Pest management (9.9%) Plant improvement (9.2%) Soil science (9%) Horticulture (4.2%) Irrigation and water use (4%) Livestock diseases (5.9%) Meat science (1.4%) Livestock nutrition (1.3%) Livestock reproduction (1.3%) Forage crops (1.2%) Manure management (1.1%)	Agronomy (20.9%) Animal science and livestock (10.9%)	Pest management (3.8%) Plant improvement (4%) Soil science (7.1%) Vaccines (1.3%) Animal nutrition (1.4%) Reproduction (1.2%) Dairy (2.3%) Cattle (2.8%) Bovine genetics (1.8%) Fruit (0.7%) Plant pathology (5.3%)
2. Climate variability and change	Environmental science (6.6%)	Climate change (0.2%)	Environmental science (10.8%)	Agricultural emissions (2.9%)
3. Water	Environmental science (6.6%) Agronomy (36.3%)	Water resources and quality (3.7%) Irrigation and water use (4%)	Environmental science (10.8%)	Water (5.8%)
4. Bioenergy	Biomass and biofuels (3.1%)	Cellulosic biomass (2.5%) Biofuels and biogas (0.3%) Algae and Phycology (0.3%)	Biomass and biofuels (5.5%)	Biomass (4.5%) Conversion processes (1%)
5. Childhood obesity	Food science (7.3%) Family and consumer sciences (2.1%)	Nutrition and obesity (1.8%) Obesity (0.7%)	Family and consumer sciences (4.8%)	Obesity (4.8%)
6. Food safety	Food science (7.3%)	Food safety (2.2%)	Food science (11.2%)	Food safety (8.4%)

	Capacity funded (percent of identified clusters focused on this area)	**Competitive funded** (percent of identified clusters focused on this area)
Food security	48.5%	31.7%
Climate variability and change	0.2%	2.9%[a]
Water	7.7%	5.8%
Bioenergy	3.1%	5.5%
Childhood obesity	2.5%	4.8%
Food safety	2.2%	8.4%
Total	64.2%	59.1%

[a]It should be noted that only some of the agricultural emission work would relate to climate change. Some of the projects under this category also examine odor mitigation or other emission factors (not all of which are gases)

Table 2 2014 Farm Bill priorities for NIFA

2014 Farm Bill priority area	NIFA description
Agricultural economics and rural communities	Prosperity and economic security for individuals and families, farmers and ranchers, business owners, and consumers are vital to a strong economy. The Farm Bill authorizes NIFA to continue to support programs that strengthen rural economies. NIFA's research, education, and extension programs help people make sound financial management decisions, discover new economic opportunities, develop successful agricultural and nonagricultural enterprises, take advantage of new and consumer-driven markets, and understand the implications of public policy on these activities
Agriculture systems and technology	The Farm Bill supports the development of advanced technologies to meet the complex agricultural challenges faced by the United States and countries throughout the world. Agricultural systems – both crop and animal – involve issues such as labor, marketing, finances, natural resources, genetic stock, and equipment. NIFA-supported projects address these issues as a system, rather than on an individual basis, because a holistic approach offers greater management flexibility, safer working conditions, and a sounder economy and environment
Animal health, production, and products	Animals are one of the most important aspects of agriculture in America. NIFA's investments in animal science have found new and better ways to advance animal production technology, enable the industry to respond to consumer demand, and advance human health and nutrition through better animal health and breeding. NIFA's animal-related programs – which include beef, dairy cattle, poultry, swine, sheep, goats, and aquaculture – encourage a multidisciplinary approach to research, education, and extension activities
Bioenergy, natural resources, and environment	NIFA integrates research, education, and extension expertise to address environmental and natural resource priorities. The agency's programs seek to develop the next generation of biofuels that will not only power machines but the American economy as a whole. Furthermore, these programs improve air, soil, and water quality, fish and wildlife management, and sustainable use and management of forests, rangeland, and watersheds and lead to a better understanding of how the changing climate affects agriculture
Food safety, nutrition, and health	Poor dietary choices, unhealthy lifestyles, foodborne illnesses, and the potential for terrorism and other attacks on the US food supply are national concerns. NIFA-funded programs help strengthen the nation's ability to address and reduce the negative effects of these concerns as well as issues related to food security and food science and technology
Plant health, production, and products	NIFA-funded plant and plant product programs provide better understanding of plants: how they grow, how to improve productivity, and how to use them in new ways. These programs reflect the diversity of plants and their uses around the world. NIFA also supports education programs, such as master gardeners and the extension program, which bring science-based information about growing plants to the public

Table 3 Comparing Capacity and Competitive (AFRI/NRI) funded project meta-clusters and clusters as identified in analysis of REEport system data on the six priority areas for NIFA in the 2014 Farm Bill

NIFA 2014 Farm Bill priority	**Capacity funded** Meta-clusters (percent of total)	**Capacity funded** Clusters (percent of total)	**Competitive funded** Meta-clusters (percent of total)	**Competitive funded** Clusters (percent of total)
1. Agricultural economics and rural communities	Economics (3.5%) Family and consumer sciences (2.1%)	Agricultural economics (3.5%) Youth and behavior (0.9%) Emotion and behavioral management (0.3%) Poverty and mental health (0.3%)	Economics (8.0%)	Agricultural economics (6.7%) Markets and pricing (1.3%)
2. Agriculture systems and technology	Not a specific meta-cluster but elements contained within multiple other meta-clusters and themes	Irrigation and water use (4%) Genetics and genomics (1.3%) Land use (0.4%)	Not a specific meta-cluster but elements contained within multiple other meta-clusters and themes	Agricultural emissions (2.9%) Genetics and genomics (5.0%) Food systems and access (2.0%)
3. Animal health, production, and products	Animal science and livestock (15.1%) Fisheries and aquaculture (2.8%)	Livestock diseases (5.9%) Poultry science (1.6%) Meat science (1.4%) Livestock nutrition (1.3%) Livestock reproduction (1.3%) Manure management (1.1%) Small ruminants (0.6%) Fly/insect management (0.3%) Equine (0.3%) Animal reproduction (0.2%) Fisheries (2.3%) Aquaculture (0.4%)	Animal science and livestock (10.9%)	Cattle (2.8%) Dairy (2.3%) Bovine genetics (1.8%) Nutrition (1.4%) Vaccines (1.3%) Reproduction (1.2%)
4. Bioenergy, natural resources, and environment	Biomass and biofuels (3.1%) Environmental science (6.6%)	Cellulosic biomass (2.5%) Biofuels and biogas (0.3%) Algae and phycology (0.3%) Ecology and ecosystems (1.1%) Climate change (0.2%) Water resources and water quality (3.7%) Fire management 0.3% Bees (0.9%) Wildlife and habitat (0.4%) Forest habitat and ecosystems (6.6%)	Biomass and biofuels (5.5%) Environmental science (10.8%)	Biomass (4.5%) Conversion processes (1.0%) Water (5.8%) Bees (2.2%) Forest ecosystems (3.0%)

(continued)

Table 3 (continued)

5. Food safety, nutrition, and health	Food science (7.3%)	Nutrition (3.8%) Food safety (2.2%) Obesity (0.7%) Dairy (0.5%) Wine (0.1%) Basic nutrition (0.3%)	Food science (11.2%)	Food safety (8.4%) Obesity (4.8%) Lipids (0.7%)
6. Plant health, production, and products	Agronomy (36.3%) Forests and forestry (10.9%)	Pest management (9.9%) Plant breeding and improvement (9.2%) Soil science (9.0%) Horticulture (4.2%) Silviculture (2.7%) Forage crops (1.2%) Wood science (0.2%) Basic plant genetics and molecular biology (0.3%)	Agronomy (20.9%)	Basic plant sciences (8.2%) Soil science (7.1%) Plant pathology (5.3%) Plant breeding and improvement (4.0%) Pest management (3.8%) Fruit (0.7%)
	⇩		⇩	
	Capacity funded (percent of identified clusters focused on this area)		**Competitive funded** (percent of identified clusters focused on this area)	
Agricultural economics and rural communities	5.0%		8.0%	
Agriculture systems and technology[a]	5.7%		9.9%	
Animal health, production, and products	16.4%		10.8%	
Bioenergy, natural resources, and environment	16.3%		16.5%	
Food safety, nutrition, and health	7.6%		13.9%	
Plant health, production, and products	36.7%		29.1%	
Total	87.7%		88.2%	

[a]Not a specific meta-cluster

Capacity Funding Leverage Identified in REEport Data

An advantage of the regional and local relevance of federal Capacity funded research is that state and local funders observe this local relevance and may then choose to provide additional matching financial support for the research and extension mission serving their state, county, or community. It could also be the case that the applied focus of much of the Capacity funded research portfolio holds appeal to commodity groups, agriscience companies, and other stakeholders to co-invest in land-grant R&D projects. The REEport data allow an evaluation of whether the opinions expressed by land-grant university leaders in a TEConomy survey that "the characteristics of work funded with federal Capacity Funding allows significant further leveraged funding to be raised" hold true.

REEport data indicate that a substantial amount of leveraged funding is indeed occurring and that these funds come from both public (state and local) and private (industry, foundations, commodity groups) funding sources. Table 4 summarizes funding data for the years 2010 through 2015 in aggregate, for each of the meta-cluster areas, identified through the cluster analysis of Capacity funded projects.

These data indicate that, across the ten Capacity funded meta-clusters, NIFA Capacity Funding totaled more than $1.64 billion with additional federal funding support of $3.2 billion over the 6-year period. The projects supported by this combined federal investment received a further $9 billion in funding from nonfederal sources, for a combined funding of activity in the 10 meta-clusters of almost $13.9 billion.

Clearly, this represents a significant overall leverage of federal funding for work in these meta-clusters equivalent to an additional $1.86 in funding being raised for every $1.00 in federal funding (Table 5). The meta-cluster achieving the highest leverage is agronomy with a ratio of $1 in federal funds leveraging an additional $2.30 in nonfederal funding. The lowest leverage is in basic life science, which is still a robust $1 to $1.32. This is to be expected, given the fundamental nature of research here having a less clear or assured path to applied relevance for key external funders like state agencies, industry, or commodity groups. It is important to note that even the nonindustry-oriented meta-clusters of family and consumer sciences achieve a robust level of leveraged external funding, with $1 in federal funding generating an additional $1.76 in external funds. The importance and pragmatic nature of federally funded work at the land-grant universities in agricultural sciences and associated disciplines are reflected in the universities being able to leverage these federal funds to generate significant additional funding.

Comparing Capacity and Competitively Funded Project Publication Return on Investment

Answering return on investment questions for academic research is never simple. There is a significant difference in how "return" might be defined, for example, between a basic science project that elucidates a biological process but produces no

Table 4 Capacity funded projects. NIFA funding and additional funds raised (2010–2015), $ millions

Capacity funded meta-cluster	A. Total NIFA funding	B. Other USDA funding	C. State appropriations	D. Self-generated funds	E. Industry funding	F. Other nonfederal funding	G. Other non-USDA federal funding	H. Total nonfederal funding (C + D + E + F)	I. Total federal funding (A + B + G)	J. Total funding (H + I)
Agronomy	$621.4	$328.9	$2228.2	$318.3	$647.2	$453.5	$635.1	$3647.2	$1585.4	$5232.6
Animal science and livestock	$280.7	$87.4	$917.8	$379.3	$179.1	$169.0	$443.1	$1645.2	$811.2	$2456.4
Basic life science	$176.8	$72.5	$700.8	$100.6	$207.6	$96.1	$590.8	$1105.1	$840.1	$1945.2
Biomass and biofuels	$57.3	$28.4	$180.0	$15.7	$50.1	$31.7	$96.2	$277.5	$181.9	$459.4
Economics	$47.3	$13.0	$138.9	$6.5	$15.5	$21.5	$33.0	$182.4	$93.3	$275.7
Environmental science	$90.0	$46.0	$336.8	$31.1	$62.7	$96.8	$177.7	$527.4	$313.7	$841.1
Family and consumer sciences	$18.3	$1.4	$60.4	$2.1	$8.5	$11.8	$27.4	$82.8	$47.1	$129.9
Fisheries and aquaculture	$49.4	$17.3	$139.3	$13.5	$27.1	$50.7	$86.3	$230.6	$153.0	$383.6
Food science	$117.7	$40.6	$361.3	$41.6	$140.1	$74.6	$168.6	$617.6	$326.9	$944.5
Forests and forestry	$184.8	$109.4	$448.2	$42.9	$80.0	$133.4	$196.2	$704.5	$490.4	$1194.9
Total	$1643.7	$744.9	$5511.7	$951.6	$1417.9	$1139.1	$2454.4	$9020.3	$4843.0	$13,863.3

Table 5 Capacity funded projects. External funds leveraged by federal funding (2010–2015)

Capacity funded meta-cluster	Total NIFA funding	Total nonfederal funding	Total, federal funding	Effective NIFA leverage	Effective federal leverage
Agronomy	$621.4	$3647.2	$1585.4	1 to 7.42	1 to 2.30
Animal science and livestock	$280.7	$1645.2	$811.1	1 to 7.75	1 to 2.03
Basic life science	$176.8	$1105.1	$840.1	1 to 10.00	1 to 1.32
Biomass and biofuels	$57.3	$277.5	$181.9	1 to 7.02	1 to 1.53
Economics	$47.3	$182.4	$93.2	1 to 4.83	1 to 1.96
Environmental science	$90.0	$527.4	$313.7	1 to 8.35	1 to 1.68
Family and consumer sciences	$18.3	$82.7	$47.1	1 to 6.09	1 to 1.76
Fisheries and aquaculture	$49.4	$230.7	$152.9	1 to 6.77	1 to 1.51
Food science	$117.7	$617.6	$326.9	1 to 7.03	1 to 1.89
Forests and forestry	$184.8	$704.5	$490.3	1 to 5.47	1 to 1.44
Total	$1643.6	$9020.4	$4842.7	1 to 7.43	1 to 1.86

commercial technology and say a soybean improvement project that produces a 5% yield increase in certain environmental conditions. Both are important, but they differ in their type of impacts. What both basic and applied research share in common is that research results produced by faculty at universities are likely to be published. Publishing activity may thus provide a baseline surrogate metric for productivity suitable for a high-level evaluation of academic research.

NIFA REEport data contain information on the source and amount of funding for each project. TEConomy's cluster analysis of REEport data for Capacity and Competitive funded projects thus allows for a comparison to be made for the highest-level meta-clusters that are present for both types of funded research. The results of the analysis (Table 6) show that across all areas of research, except forestry, Capacity funded research generates significantly higher volumes of publications per million dollars of federal funding when compared to Competitive Funding. Because of the leverage of Capacity Funds achieved through state and local sources, the federal government, for its share of the funding, receives a high return in terms of knowledge generated and disseminated through land-grant research.

It should be noted, however, that while the majority of all academic disciplines target research toward the generation of peer-reviewed academic publications, the work of the land grants recorded in Table 6 contains publications that are also geared toward agricultural producers, foresters, consumers, etc. that require information in a more concise form than the typical academic paper. For comparison purposes, therefore, care must be taken in comparing the Capacity and Competitive funded research coming via NIFA federally funded research as opposed to some other fed-

Table 6 Publications per $1 million in funding for Capacity and Competitive funded projects (REEport data for 2010–2015) across meta-clusters

	Publications per $1 M total Capacity and leveraged funds	Publications per $1 M in Competitive NIFA-AFRI (and previously NRI) funds	Difference between Capacity and Competitive funded publications per $1 M
Agronomy	12.78	4.90	+7.88
Animal science and livestock	9.96	7.60	+2.35
Basic science	9.14	5.27	+3.87
Biomass and biofuels	11.69	7.42	+4.27
Economics	16.95	4.78	+12.17
Environmental science	12.54	11.03	+1.51
Family and consumer sciences	16.23	3.44	+12.79
Food science	11.45	8.09	+3.35
Forests and forestry	13.08	13.71	−0.63

The same publication may show up multiple times across REEport years for multi-year projects. TEConomy manually removed these duplicates from the data to allow for accurate comparative analysis

eral funding agencies, such as, for example, the National Institutes of Health, where TEConomy's analysis of NIH REEport data finds circa 3.5 peer-reviewed publications generated per $1 million in NIH funding (using the same publication years).

Conclusions

Agriculture and related industries are one of the United States' great success stories. The sustained growth and productivity of these industries are made possible by the strong R&D sector in the United States. While industry is a vital part of this sector, the work of the LGUs and Cooperative Extension Services funded by the federal government through the USDA is critically important. Our evaluation of the Capacity Funding system provides a detailed picture of the ways in which federal funding is developing American science and agriculture.

Our examination of the Web of Science™ database indicates that, in overall publications volume in agriculture and related fields, agronomy, basic science, and veterinary medicine are the largest topic areas, with plant science being an important focus in the first two of these areas. The REEport data on the 20,000 Capacity Funding projects between 2000 and 2015 indicate that these projects are diverse but heavily focused on applied research areas, although not to the exclusion of basic sciences like microbiology. Compared with overall publications, however, Capacity projects are less focused on basic science and more focused on production-oriented areas and downstream value-added activities in food and biomass industries. This is evident in the example of animal research. While overall publications have a heavy focus on veterinary medicine, Capacity research does not have that emphasis but instead has a large focus on livestock health. Additionally, a number of areas that are small or missing from overall publications are present in notably higher concentrations in Capacity projects such as pest management, water, family and consumer sciences, and fisheries and aquaculture.

Competitively funded research in the REEport data has its largest focus area in basic science, which is double the proportion of Competitively funded projects as it is of Capacity funded projects. In comparison, Capacity Funding is much more focused on projects that promote agricultural production. Both Capacity and Competitively funded projects largely fit within the NIFA National Challenge Areas and the 2014 Farm Bill Priority Areas. Capacity funded projects are providing robust coverage of the six NIFA National Challenge Areas, with almost two-thirds of projects so focused. Emphasis, as expected, is not equal across the six, with major focus placed on food security and with 48.5% of projects focused on production agriculture. Water sees the second highest degree of emphasis in the Capacity funded project portfolio. NIFA-AFRI/NRI Competitive funds also see the majority of projects (59.1%) being classified in themes relevant to the six NIFA National Challenge Areas. In the case of Competitive funds, the allocation of projects across the six National Challenge Areas shows less percentage variation in Competitive project allocations. Both NIFA Capacity funded and NIFA Competitively funded portfolios see the vast majority of projects (almost nine out of every ten) being focused in areas specific to the 2014 Farm Bill priorities. Both funding methods therefore seem to be suited to developing research that targets our nation's goals.

Finally, we examined the leveraging of funds and return on investment of NIFA-funded research. All of the meta-cluster areas of Capacity projects leverage external funds. On average, each federal dollar brings an additional $1.86, for a total of almost 9 billion nonfederal dollars spent on Capacity projects between 2010 and 2015. Capacity funded projects have a strong return on investment when measured as publications per $1 million. In all areas but one, Capacity projects produced more publications per $1 million than Competitive projects, with the largest differences in family and consumer sciences, economics, and agronomy.

Appendix

Table 7 Percentage segmentation of publications across key disciplines (OmniViz™ cluster analysis of 108,180 publications)

Meta-cluster.	% of total	Theme	% of meta-cluster	% of total	Subtheme	% of theme	% of total
Agronomy	21.3%	Plant breeding/ improvement	65.5%	14.0%	General	31.8%	4.4%
					Corn	19.6%	2.7%
					Wheat	15.7%	2.2%
					Soybean	8.0%	1.1%
					Rice	7.3%	1.0%
					Potato	6.7%	0.9%
					Grasses	4.9%	0.7%
					Cotton	4.6%	0.6%
					Beans	1.4%	0.2%
		Horticulture	20.6%	4.4%	Fruit	80.2%	3.5%
					Tomatoes	10.0%	0.4%
					Apples	6.5%	0.3%
					Strawberries	1.8%	0.1%
						1.6%	0.1%
		Water	4.8%	1.0%	Irrigation	37.1%	0.4%
					Sedimentation	31.9%	0.3%
					Nutrient runoff	31.1%	0.3%
		Pest management	5.1%	1.1%	Weeds	100.0%	1.1%
		Plant pathology	2.2%	0.5%	Citrus	100.0%	0.5%
		Organic	1.4%	0.3%		100.0%	0.3%
		Mycology	0.4%	0.1%	Mushrooms	100.0%	0.1%
Basic science	21.1%	Plant science	60.3%	12.7%	Stress resistance	21.4%	2.7%
					Physiology and morphology	20.8%	2.6%
					Seeds	20.0%	2.5%
					Roots	13.8%	1.8%
					Genetics	10.5%	1.3%
					Pollination	8.9%	1.1%
					Mutation	1.7%	0.2%
					Salt tolerance	1.7%	0.2%
					Fungicide resistance	1.3%	0.2%
		Nutrition	14.9%	3.1%		100.0%	3.1%
		Bacteriology	12.3%	2.6%	e-coli	100.0%	2.6%
		Symbiosis	2.9%	0.6%		100.0%	0.6%
		Emissions	2.8%	0.6%		100.0%	0.6%
		Starch	2.0%	0.4%		100.0%	0.4%
		Fermentation	1.4%	0.3%		100.0%	0.3%
		Cell biology	1.0%	0.2%		100.0%	0.2%
		Basic genetics	0.8%	0.2%	MicroRNA	100.0%	0.2%
		Algology	0.7%	0.2%		100.0%	0.2%
		Biofilms	0.5%	0.1%		100.0%	0.1%
		Biochemistry	0.3%	0.1%		100.0%	0.1%

(continued)

Table 7 (continued)

Meta-cluster.	% of total	Theme	% of meta-cluster	% of total	Subtheme	% of theme	% of total
Veterinary medicine	17.7%	Canine	29.0%	5.1%		100.0%	5.1%
		Infectious diseases	28.0%	5.0%		54.4%	2.7%
					Virology	38.1%	1.9%
					Vaccines	7.5%	0.4%
		Equine	17.5%	3.1%		100.0%	3.1%
		Porcine	7.7%	1.4%		100.0%	1.4%
		Surgery	3.6%	0.6%		100.0%	0.6%
		General	3.3%	0.6%		100.0%	0.6%
		Orthopedics	3.1%	0.5%		100.0%	0.5%
		Small ruminants	2.8%	0.5%		100.0%	0.5%
		Bovine	2.6%	0.5%		100.0%	0.5%
		Cancer	1.0%	0.2%		100.0%	0.2%
		Small animals	0.9%	0.2%		100.0%	0.2%
		Ophthalmology	0.4%	0.1%		100.0%	`
Forestry	10.1%	Forest management	26.3%	2.7%		100.0%	2.7%
		Silviculture	25.1%	2.5%	Pine	74.6%	1.9%
						20.7%	0.5%
					Aspen	4.7%	0.1%
		Tree species	18.3%	1.9%		100.0%	1.9%
		Fire	9.8%	1.0%		100.0%	1.0%
		Soil	9.4%	0.9%		100.0%	0.9%
		General	7.9%	0.8%		100.0%	0.8%
		Forest products	3.4%	0.3%	Lumber	82.1%	0.3%
					Biofuel	17.9%	0.1%
Soil science	9.0%	General	65.1%	5.9%		100.0%	5.9%
		Plant nutrients	34.9%	3.2%		100.0%	3.2%
Dairy	4.8%	Milk	100.0%	4.8%		100.0%	4.8%
Food science	4.4%	Oils	39.7%	1.7%		100.0%	1.7%
		Meat science	24.6%	1.1%	Beef	100.0%	1.1%
		Consumer preferences	16.5%	0.7%		100.0%	0.7%
		Food safety	5.3%	0.2%	Listeria	100.0%	0.2%
		Food storage	4.3%	0.2%		100.0%	0.2%
		Alkaloids	4.1%	0.2%		100.0%	0.2%
		Peanuts	3.7%	0.2%	Allergens	100.0%	0.2%
		Nutrition	1.7%	0.1%		100.0%	0.1%
Poultry	2.7%	Broilers	53.6%	1.5%		100.0%	1.5%
		Layers	33.2%	0.9%		100.0%	0.9%
		Litter	8.4%	0.2%		100.0%	0.2%
		Turkey	4.8%	0.1%		100.0%	0.1%

(continued)

Table 7 (continued)

Meta-cluster.	% of total	Theme	% of meta-cluster	% of total	Subtheme	% of theme	% of total
Entomology	2.6%	Pest control	36.9%	1.0%		100.0%	1.0%
		Mosquitoes	28.2%	0.7%		100.0%	0.7%
		Mites	15.8%	0.4%		100.0%	0.4%
		Ticks	9.9%	0.3%		100.0%	0.3%
		Nematodes	9.2%	0.2%		100.0%	0.2%
Animal science	2.3%	Reproduction	48.5%	1.1%		100.0%	1.1%
		Behavior	34.5%	0.8%		100.0%	0.8%
		Primates	9.3%	0.2%		100.0%	0.2%
		Wildlife	4.4%	0.1%		100.0%	0.1%
		Nutrition	3.3%	0.1%	Probiotics	100.0%	0.1%
Livestock	2.3%	Bovine	58.1%	1.3%	Beef cattle	70.2%	0.9%
					Forage	18.4%	0.2%
					Grazing	11.4%	0.1%
		Aquaculture	33.0%	0.7%		100.0%	0.7%
		Manure management	8.9%	0.2%		100.0%	0.2%
Biomass and biofuels	1.7%	Biomass	78.6%	1.3%	Switch grass	73.6%	1.0%
					Crop residues	26.4%	0.4%
		Glycerol	7.4%	0.1%		100.0%	0.1%
		Biochar	7.2%	0.1%		100.0%	0.1%
		Anaerobic digestion	6.8%	0.1%		100.0%	0.1%

Table 8 Percentage segmentation of Capacity funded projects (REEport Data for 2010–2015) across meta-clusters, associated clusters, and subthemes

Meta-cluster	% of total	Theme	% of meta-cluster	% of total	Subtheme	% of theme	% of total
Agronomy	36.3%	Pest management	27.3%	9.9%	Biological control	32.3%	3.2%
					Entomology	27.8%	2.8%
					Weed science	20.3%	2.0%
					Herbicide	15.0%	1.5%
					Plant parasites	4.6%	0.5%
		Plant breeding and improvement	25.4%	9.2%	Stress tolerance	37.2%	3.4%
					Plant nutrient inputs	19.9%	1.8%
					Row crop improvement	11.6%	1.1%
					Row crop pathogens	10.6%	1.0%
					Turfgrass	7.6%	0.7%
					Potatoes	7.0%	0.6%
					Parasite resistance	4.0%	0.4%
					Grains	2.0%	0.2%
		Soil science	24.7%	9.0%		100.0%	9.0%
		Horticulture	11.6%	4.2%	Viticulture	67.0%	2.8%
					Orchards	26.6%	1.1%
					Citrus diseases	6.5%	0.3%
		Irrigation and water use	10.9%	4.0%		100.0%	4.0%
Animal science and livestock	15.1%	Livestock diseases	38.7%	5.9%	Bovine	89.8%	5.3%
					Poultry	10.2%	0.6%
		Poultry science	10.4%	1.6%		85.5%	1.3%
					Reproduction	14.5%	0.2%
		Meat science	9.3%	1.4%	Bovine	90.3%	1.3%
					Poultry	9.7%	0.1%
		Livestock nutrition	8.6%	1.3%	Grazing	100.0%	1.3%
		Livestock reproduction	8.2%	1.2%		100.0%	1.2%
		Forage crops	8.0%	1.2%		100.0%	1.2%
		Manure management	7.1%	1.1%		100.0%	1.1%
		Small ruminants	4.1%	0.6%		56.6%	0.3%
					Parasites	43.4%	0.3%
		Equine	2.2%	0.3%		100.0%	0.3%
		Fly and insect management	1.9%	0.3%	Flies	100.0%	0.3%
		Animal reproduction	1.5%	0.2%	Porcine	100.0%	0.2%

(continued)

Table 8 (continued)

Meta-cluster	% of total	Theme	% of meta-cluster	% of total	Subtheme	% of theme	% of total
Basic life science	12.2%	Microbiology	71.7%	8.8%	Bacteriology	40.8%	3.6%
					Virology	30.0%	2.6%
					Plant pathology	28.6%	2.5%
					Phages	0.6%	0.1%
		Genetics and genomics	10.7%	1.3%		100.0%	1.3%
		Vector-borne diseases	3.6%	0.4%		100.0%	0.4%
		Cancer	3.2%	0.4%		100.0%	0.4%
		Plant genetics and molecular biology	3.1%	0.4%		100.0%	0.4%
		Nutrition	2.5%	0.3%		100.0%	0.3%
		Muscle physiology	2.3%	0.3%		100.0%	0.3%
		Animal reproduction	1.5%	0.2%		100.0%	0.2%
		Molecular biology	0.8%	0.1%		100.0%	0.1%
		Biosensors	0.6%	0.1%	Nanotechnology	100.0%	0.1%
Forests and forestry	10.9%	Forest habitat and ecosystems	60.7%	6.6%		100.0%	6.6%
		Silviculture	24.4%	2.7%	Pine	52.0%	1.4%
						48.0%	1.3%
		Pest management	6.3%	0.7%	Entomology	100.0%	0.7%
		Land use	4.0%	0.4%		100.0%	0.4%
		Tourism	3.2%	0.4%		100.0%	0.4%
		Wood science	1.4%	0.2%		100.0%	0.2%
Food science	7.3%	Nutrition	52.5%	3.8%	Fruits and vegetables	46.9%	1.8%
					Obesity	46.5%	1.8%
					Bioactive compounds	6.6%	0.3%
		Food safety	30.7%	2.2%	Bacteriology	78.1%	1.7%
					Fungal toxins	14.7%	0.3%
					Education	7.2%	0.2%
		Starch crops	7.5%	0.5%	Quality	100.0%	0.5%
		Dairy	7.4%	0.5%		100.0%	0.5%
		Wine	1.9%	0.1%		100.0%	0.1%
Environmental science	6.6%	Water	55.9%	3.7%	Water quality	100.0%	3.7%
		Ecology and ecosystems	16.5%	1.1%	Wetlands	100.0%	1.1%
		Bees	13.6%	0.9%		100.0%	0.9%
		Wildlife and habitat	5.8%	0.4%		100.0%	0.4%
		Fire	3.9%	0.3%		100.0%	0.3%
		Climate change	2.9%	0.2%		100.0%	0.2%
		Emissions	0.8%	0.1%		100.0%	0.1%
		Environmental contaminants	0.5%	0.0%	Mercury and metals	100.0%	0.0%
Economics	3.5%	Agricultural economics	100.0%	3.5%		100.0%	3.5%

(continued)

Table 8 (continued)

Meta-cluster	% of total	Theme	% of meta-cluster	% of total	Subtheme	% of theme	% of total
Biomass and biofuels	3.1%	Cellulosic biomass	81.0%	2.5%		65.7%	1.7%
					Processing	34.3%	0.9%
		Biofuel and biogas	11.0%	0.3%		100.0%	0.3%
		Algae and phycology	8.1%	0.3%		100.0%	0.3%
Fisheries and aquaculture	2.8%	Fisheries	84.6%	2.3%		100.0%	2.3%
		Aquaculture	15.4%	0.4%		100.0%	0.4%
Family and consumer sciences	2.1%	Youth and behavior	42.0%	0.9%	Behavior	100.0%	0.9%
		Obesity	31.0%	0.7%		100.0%	0.7%
		Poverty and mental health	14.1%	0.3%		100.0%	0.3%
		Emotion and behavioral management	12.9%	0.3%		100.0%	0.3%

Table 9 Percentage segmentation of Competitive funded projects (REEport Data for 2010–2015) across meta-clusters, associated clusters, and subthemes

Meta-cluster	% of total	Theme	% of meta-cluster	% of total	Subtheme	% of theme	% of total
Basic science	25.0%	Basic plant science	32.7%	8.2%		100.0%	8.2%
		Genetics and genomics	19.8%	5.0%		53.5%	2.7%
						36.0%	1.8%
					Whole genome sequencing	7.0%	0.3%
						3.5%	0.2%
		Microbiology	17.4%	4.3%		100.0%	4.3%
		Infectious diseases	16.7%	4.2%		100.0%	4.2%
		Virology	6.3%	1.6%		100.0%	1.6%
		Inflammation	4.5%	1.1%		100.0%	1.1%
		Mammalian reproduction	2.6%	0.7%		100.0%	0.7%
Agronomy	20.9%	Soil science	34.0%	7.1%		100.0%	7.1%
		Plant pathology	25.2%	5.3%		63.6%	3.3%
					Fungal	36.4%	1.9%
		Plant breeding and improvement	19.0%	4.0%	Genetics	94.5%	3.7%
						5.5%	0.2%
		Pest management	18.3%	3.8%	Insects and insecticides	65.9%	2.5%
					Weed management	19.3%	0.7%
					Aphids	14.8%	0.6%
		Fruit	3.5%	0.7%		100.0%	0.7%

(continued)

Table 9 (continued)

Meta-cluster	% of total	Theme	% of meta-cluster	% of total	Subtheme	% of theme	% of total
Food science	11.2%	Food safety	75.5%	8.4%		71.1%	6.0%
					Poultry	11.3%	1.0%
						10.3%	0.9%
						7.2%	0.6%
		Food systems and access	18.3%	2.0%		100.0%	2.0%
		Lipids	6.2%	0.7%		100.0%	0.7%
Animal science and livestock	10.9%	Cattle	26.0%	2.8%		100.0%	2.8%
		Dairy	20.8%	2.3%		59.6%	1.3%
						40.4%	0.9%
		Bovine genetics	16.8%	1.8%		100.0%	1.8%
		Nutrition	13.2%	1.4%		100.0%	1.4%
		Vaccines	12.0%	1.3%		100.0%	1.3%
		Reproduction	11.2%	1.2%		100.0%	1.2%
Environmental science	10.8%	Water	53.4%	5.8%		100.0%	5.8%
		Agricultural emissions	26.5%	2.9%		100.0%	2.9%
		Bees	20.1%	2.2%		100.0%	2.2%
Economics	8.0%	Agricultural economics	83.6%	6.7%		100.0%	6.7%
		Markets and pricing	16.4%	1.3%		100.0%	1.3%
Biomass and biofuels	5.5%	Biomass	82.5%	4.5%		100.0%	4.5%
		Conversion processes	17.5%	1.0%	Fermentation	54.5%	0.5%
					Enzymes	45.5%	0.4%
Family and consumer sciences	4.8%	Obesity	100.0%	4.8%	Childhood obesity	56.8%	2.7%
					Nutrition	43.2%	2.1%
Forests and forestry	3.0%	Forest ecosystems	100.0%	3.0%		100.0%	3.0%