Agriscience Innovation at Land-Grant Universities, Measured by Patents and Plant Variety Protection Certificates as Proxies

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Abstract One of the major metrics of innovation in agriscience is intellectual property. Land-grant university innovation is documented as intellectual property in two main ways: patents and Plant Variety Protection certificates. To evaluate the innovation generated by NIFA Capacity Funds, TEConomy Partners, LLC, examined the patents and PVP certificates received by LGUs during a 7-year period (2010–2016). The results indicate substantial innovation occurring in LGUs. LGUs generated 4% of total patenting in agriculture and related fields in the study period. When broadened to include patents that cite prior LGU work, LGUs influence up to one in six patents in agbiosciences in the United States. Even higher impacts of LGUs are found in PVP certificates. Between 2010 and 2016, an average of 14% of PVPs were awarded to LGUs. This analysis further demonstrates that LGUs patent in cutting-edge applications of biotechnology and associated life and physical sciences. In PVPs, LGUs generated intellectual property in many crops that were not experiencing IP generation from other sources. Overall, we conclude that university-based research, especially research at LGUs, plays a substantial role in the US agriscience innovation ecosystem.

Introduction

Intellectual property (IP) generation is one important output of federal Capacity and Competitive funded research projects, and thus examining patenting and other IP protection activity is useful for assessing the innovation impact of federally funded research. R&D at universities may result in novel innovations that may be protected

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for the university via patenting, administered through the US Patent and Trademark Office or via Plant Variety Protection (PVP) certificates administered by the US Plant Variety Protection Office. Like peer-reviewed scientific publications, the generation of a patent or a PVP certificate is a testament to unique and impactful research results. The National Institute of Food and Agriculture (NIFA) mission areas related to agriculture, food supply, public health, nutrition, natural resources, etc. may be served not only by generating new knowledge and recommendations rooted in research and reported in publications but also by the generation of new innovations that have value when implemented as commercial technologies. Patents and PVP certificates can thus serve as a proxy measure for innovation. It should be noted, however, that these are imperfect measures in that the land-grant service ethos can also result in multiple innovations being released to the field without patent or other IP protections ever being sought. Patent data should be seen, therefore, as underestimating the total universe of technological innovation occurring.

Researchers examining the underpinnings of innovation have demonstrated the use of patents as an intermediary metric that identifies novel innovations with links to federal R&D investment, and thus patents may be used as proxies for "translatable innovation."[1,2] Evaluating innovation impact via patents also allows for the usage of forward citations as a proxy measure for the downstream "forward innovation" that results from new patented innovations generating follow-on advances in related technological areas that effectively build upon the knowledge or technology contained within the referenced patents. Although not all land-grant institution patents or PVP certificates will originate from resources provided through NIFA or other USDA funding, the overall portfolio of innovation activity produced at these institutions can serve as an approximation for the types of innovation being funded by Capacity Programs given their role as major sources of research support at these institutions for agriculture and associated disciplinary work.

Data and Methods

Using patent data published by the US Patent and Trademark Office (USPTO), it is possible to profile the innovation areas that have indirect linkages to NIFA Capacity Funding programs.[3] The indirect impact of Capacity Programs on innovation can be

[1] Kalutkiewicz, Michael J., and Richard L. Ehman. 2014. *Patents as proxies: NIH hubs of innovation*. Nature Biotechnology, June 2014.

[2] Grueber, Martin, and Simon Tripp. 2015. *Patents as Proxies Revisited: NIH Innovation 2000 to 2013*. Battelle Technology Partnership Practice. March 2015.

[3] Direct attribution to NIFA Capacity Funding cannot be systematically identified since one of the few ways to capture direct linkages through documentation is the use of the government interest field included on patents that provides any recognition or attribution to government funding support used in creating the IP described in the patent. Patents where the government interest field includes references to funding support from NIFA and other USDA programs demonstrate a direct attribution back to these funding sources, but feedback from land-grant universities indicates that this form of documentation is not used consistently enough for analysis.

profiled through examining the portfolio of IP being generated at land-grant universities, because they are the primary recipients of Capacity Funding. Patents tied to land-grant institutions can be identified by the holders of the IP documented in patents, called assignees. Assignees can include multiple institutions and combinations of private and public entities. Additionally, many patents cite the prior art established in existing patents in documenting new discoveries. Important IP that fundamentally advances the state of technology or science in an area will likely be cited by many other patents which use the initial discovery as the basis for downstream innovation. In examining the scope of land-grant university appearances in cited references for US patents in agbioscience areas, the indirect impact of Capacity Program support for past research at these institutions can be highlighted for its foundational role in follow-on industry and academic innovation. Accordingly, our analysis of patents includes two sets of patents. First, we identify patents based on a land-grant institution being listed as an assignee. Second, we identify patents with a land-grant institution patent cited in prior art references. By using both sets of patents, we capture the downstream innovation of the work in Capacity Funding program areas and the subsequent downstream innovation that may be rooted in original LGU-performed research.

Analysis of patents and forward citation of patents is performed using the Clarivate Analytics "Thomson Innovation" patent database. To capture the innovation activity related specifically to NIFA mission objective areas, detailed patent classes were used to identify relevant technologies and products with applications in agricultural sciences and associated fields. The US Patent and Trademark Office Cooperative Patent Classification (CPC) system assigns each patent a specific numeric major patent "class" as well as supplemental secondary patent classes which detail the primary technology areas being documented by the patented IP. These classes are assigned to patents by dedicated classification staff who examine the documented IP's key focus and end uses. By combining relevant patent classes across the wide array of agricultural science-related activity, these class designations allow for an aggregation scheme that identifies broad technology themes specific to the technology areas that are part of NIFA's key mission. We grouped these relevant US-invented patents into broader agbioscience patent class groups to allow an analysis of innovation trends. The data used in this analysis include all issued US patents from 2010 to 2016 within the set of key patent classes identified by the analysis team at TEConomy Partners LLC (TEConomy). Appendix A provides a listing of the patent classes and class groups that were used in this analysis as "agriculture and related sectors" and how they are grouped into major technology themes.

A second set of data is additionally used to examine the innovative products of capacity funding, via LGUs, Plant Variety Protection (PVP) certificates. Plant breeders may protect their intellectual property not only through patenting but also through PVP certificates, which protect plant varieties for 20 years. Using the USDA Agricultural Marketing Service Scanned Certificates database of issued PVP certificates, we compiled a database of all issued PVPs between 2010 and 2016. The database lists the name of the applicant for the PVP, which allows us to identify which PVPs are the result of research done at a LGU. These data permit us to capture a metric of innovation additional to the analysis of patents.

Results

Dynamics of Land-Grant University Patenting Activity

There were 24,462 total US patents granted in the agriscience class areas shown in Appendix A from 2010 through 2016. Of these patents, 950 (4%) listed land-grant institutions as one of the original assignees and 3911 (16%) listed land-grant institutions in their prior art references. This level of LGU patenting represents a significant component of national innovation activity given the highly concentrated nature of institutions generating innovation in this space. The top five patenting entities in agbiosciences are corporations, and these five together account for almost 26% of all patents generated during this period. In this context, the cumulative patenting impact of land-grant university innovation supported by Capacity Funding can be thought of as roughly equivalent to one of the major agbioscience companies in the United States.

Figure 1 shows growth trends for the analyzed patent groups between 2010 and 2016. Overall US patenting in agbioscience classes (solid line) rose significantly over this period, increasing by 77%. Land-grant university patenting (dashed line), however, increased at a slower rate, growing by 37% over the same period. However, land-grant patenting activity did increase sharply after 2012 and has exhibited consistent annual growth since then, despite declines in overall patenting volume.

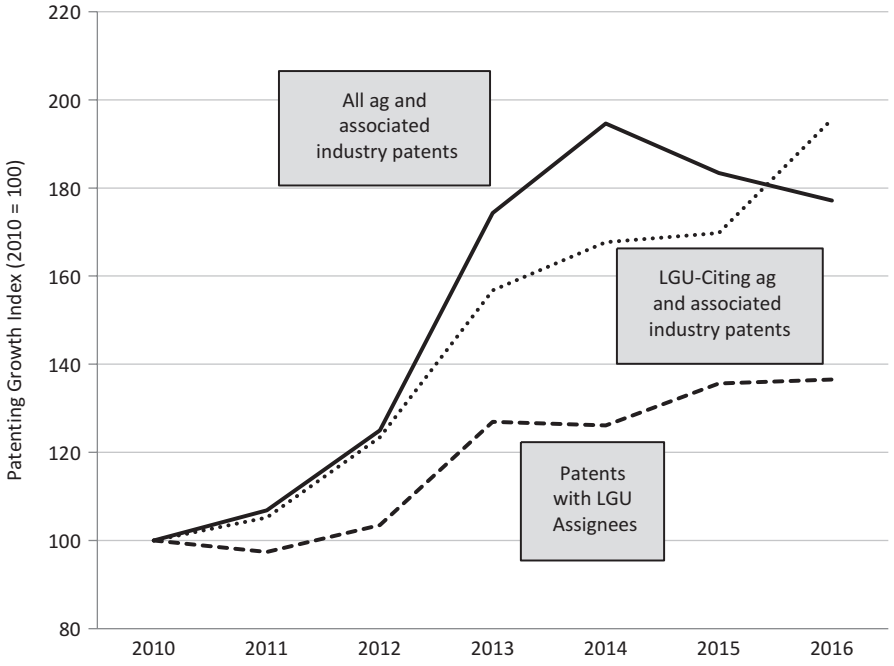

Fig. 1 Patenting trends by land-grant universities and all entities, 2010–2016

Finally, patents citing land-grant patents (dotted line) saw a 95% increase over this period, with no periods of decline. This highlights the benefit of ongoing Capacity Funding support in maintaining a consistent base of innovation despite year-to-year fluctuations in broader trends.

Viewing patent totals solely in terms of their final assignee does not capture the numerous patents where land-grant researchers contributed to technologies that were ultimately assigned to private industry and other institutions besides the land-grant universities. It is challenging to trace all inventors listed on patents back to work produced during their tenure at land-grant or non-land-grant institutions, but it is possible to examine the citation impacts of patents that have been assigned to land-grant institutions as an indication that innovative IP produced there was used as the basis for other downstream technologies.

Figure 2 shows the proportion of total agbioscience patents that cite land-grant-assigned patents in their documentation of new IP from 2010 to 2016. Patents supported by Capacity Funding programs appear to play a significant role in generating downstream innovation by private industry and other institutions. From 2010 to 2016, land-grant university-assigned patents in agriculture and related industry areas were cited by 16% of all US patents generated, with a peak of approximately one in every six patents citing prior land-grant work in 2016.

Capacity Funding programs serve as key supporting mechanisms for innovation activity at land-grant universities, and recent patenting demonstrates a significant impact on the country's stock of associated innovation. Many additional patents, especially those generated as a result of collaborative university and extension inter-

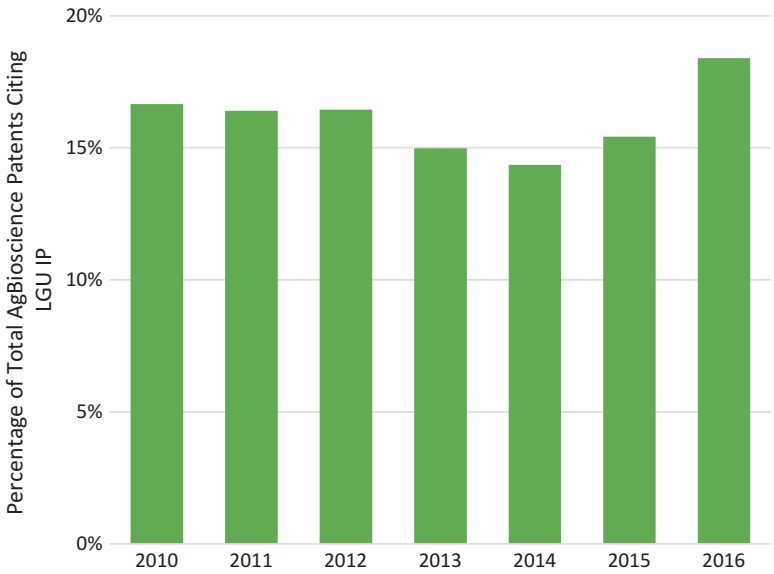

Fig. 2 Percentage of total US agriculture and associated sector patents citing Land-grant university assigned patents, 2010–2016

actions with agriculture industry firms, are not able to be definitively captured through examination of historical patent data, and the innovative footprint of land-grant institutions in the patenting landscape is likely significantly larger. In other words, the data presented herein are likely quite conservative.

Key Areas of Patenting Impact

The patents generated by the land grants display several major innovation focus areas. These serve to highlight the innovation themes across land-grant institutions in terms of driving cutting-edge agricultural science and the importance of continued federal funding support for research. Figure 3 shows the percentages of the land-grant patenting portfolio (blue bars) across broad agriculture and associated sector areas as compared with total US percentages (green bars). The yellow bars indicate the percent of all patents citing LGU-originated patents.

Relative to total US trends (green bars), land-grant university patenting (blue bars) is more concentrated in enzymes, fertilizers, and other agricultural chemicals, genetic engineering, and microbiology. New plant varieties and cultivars make up a large proportion of both the land-grant and national patenting portfolios, which is unsurprising given the end product of much agbioscience innovation is directed toward creating new crops that have improved disease resistance and favorable growth and yield traits. However, technologies that are perceived as more traditionally agriculture centric like agricultural machinery and planting processes and

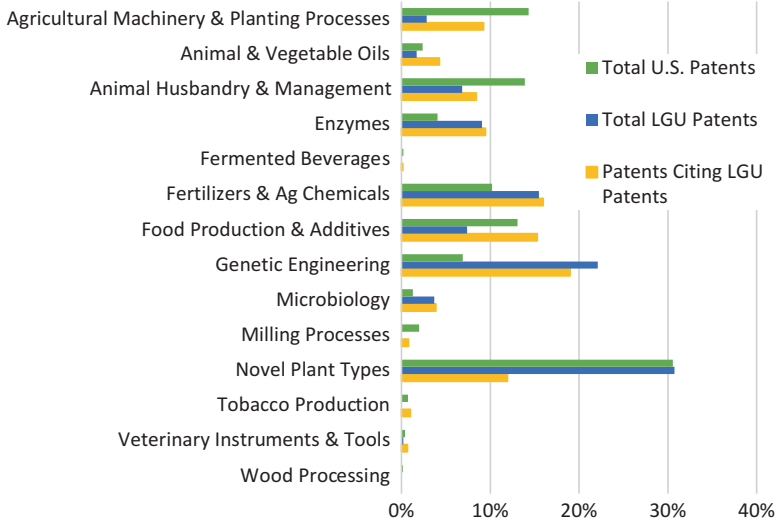

Fig. 3 Agriculture and associated sector patent Portfolio composition of Land-grant institutions and total United States, 2010–2016

animal husbandry and management are more highly concentrated in private industry at the national level, indicating that NIFA funding programs are supporting more cutting-edge science and applications in next-generation agricultural biotechnology as opposed to basic agricultural infrastructure. Land-grant institution patenting appears to be more specialized around the processes and techniques that help form the foundation of key agbioscience technology fields such as genetically engineered organisms, biologically derived agricultural compounds, and chemicals for use in agriculture. Several detailed technology applications of these fields represented in land-grant patenting portfolios are listed in Table 1.

Another way of viewing areas of specialization in land-grant patenting is through their forward innovation impact. As noted above, forward citations from later patents that cite the IP documented in land grants' agriculture and associated areas indicate the impact that the documented technologies have on furthering the pace of innovation. Often, distinct bursts in innovation, as measured by forward citations, can be traced back to critical IP documented in a select few patents that initially documented groundbreaking new research,[4] making forward citation impact a good indicator of the value of a patent's IP. Figure 4 shows both

Table 1 Examples of detailed technology areas represented in specialized agriculture and associated sector patenting areas for land-grant institutions

Broad area	Examples of detailed technology applications present in land-grant patenting activity
Enzymes	More efficient and cost-effective biofuel production Synthesis of bioproducts and organic compounds via enzymes and other hosts Delivery vectors for disease resistance in plants or animals
Fertilizers and other agricultural chemicals	Biorepellents and environmentally compatible pesticides Improved fungicide compounds Biofilm and bacterial growth inhibitors Improved delivery of biocides (via technologies like coated nanoparticles) and antimicrobial coatings and surfaces Toxicity-minimizing fertilizers and growth enhancers Pest insect attractants
Genetic engineering	Transgenic plants and animals Engineered disease/pest resistance and environmental tolerance Precision breeding and improved yields for improved food production Genetically modified organisms for biofuel production and bioreactors
Microbiology	Genetically modified animal disease strains and growth media Livestock stem cell lines and applications in improving animal health Transgenic algae and other beneficial microorganisms

[4] Huang, Yi-Hung, Ming-Tat Ko, Chun-Nan Hsu. 2014. "Identifying Transformative Research in Biomedical Sciences," *Technologies and Applications of Artificial Intelligence*, Volume 8916 of the series *Lecture Notes in Computer Science*, November 2014.

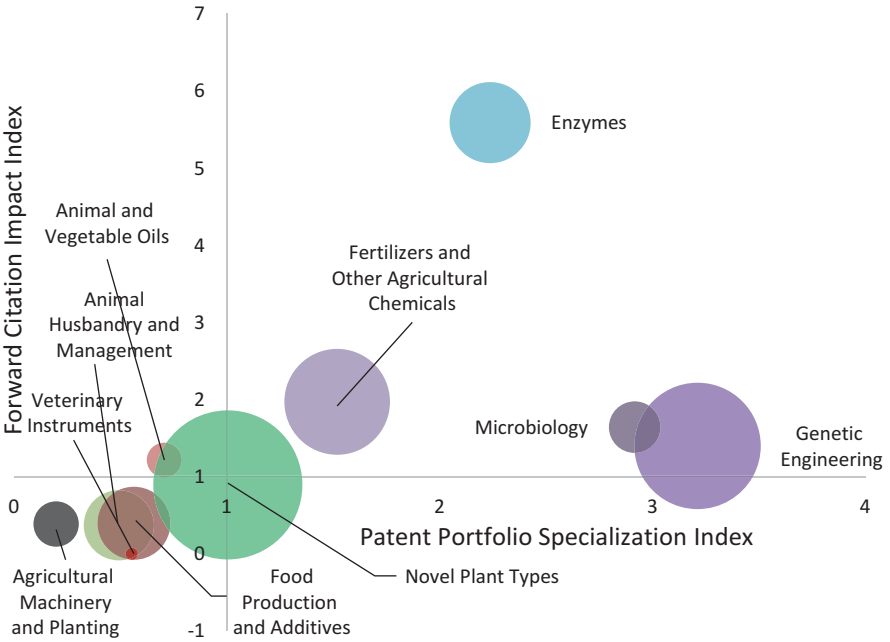

Fig. 4 Specialization and forward citation impact indices of land-grant institution-assigned patents in agriculture and associated areas, 2010–2016, relative to national trends

the specialization and forward citation impact of land-grant institution-assigned patents relative to national patenting trends across broad agricultural and associated science and technology categories.

As seen in Fig. 4, land-grant university agriscience patenting in genetic engineering, microbiology, and enzyme applications is both highly specialized and has high forward citation impact relative to national trends. In particular, patents documenting enzyme applications in agriculture and associated areas had a citation impact almost six times higher than that of the United States, indicating that the IP developed by land-grant institutions in this area has generated significant downstream innovation activity. Fertilizers and other agricultural chemicals also had above-average specialization and forward citation impacts relative to national trends. More traditional agricultural innovation in food production and additives, animal husbandry and management, and veterinary instruments and tools were all below average for land grants relative to total US patenting, with novel plant types being about the same as the wider United States in terms of its role in the land-grant patent portfolio. These areas of specialized and highly innovative impact partially speak to the changing nature of modern agricultural science, where advanced biotechnology serves as much of the basis for new technologies but, more importantly, highlights the advanced nature of land-grant

universities' innovation activity supported by federal funding programs. The innovations being generated by land-grant institutions are clearly focused around next-generation applications for agriculture, and the role of Capacity Funds in driving the research activities that produce those outcomes is thus an important piece of the ongoing evolution of the wider US agricultural sciences field.

Land-Grant University PVP Certification

There were a total of 3824 PVP certificates granted between 2010 and 2016, 488 of which were applied for by land-grant institutions. The percentage of PVP certificates granted to LGUs varies year to year, with a peak of 20% in 2016, averaging 14% over 7 years in our data. Together, this places the land-grant institutions as the third largest recipient of PVP certificates in this period, after Pioneer Hi-Bred International, Inc. (with 32% of PVPs), and Monsanto Technology, LLC (with 22% of PVPs). The next largest recipient after LGUs is Syngenta Crop Protection (with 8% of PVPs).

Figure 5 presents the proportion of PVPs granted for each of the 113 types of crops. Crops with less than 1% share of the total are combined in the "Other" category. Of the remaining 14 most prevalent crops, soybeans and field corn have the largest number of protected varieties, each with more than one quarter of the total. Common wheat, potatoes, and cotton are the next three most prevalent varieties.

Figure 6 presents the data split by applicant type. Again, all crop types with less than 1% share are combined in the "Other" category. This comparison indicates that there is both specialization and overlap in the crops developed by LGUs and other institutions and companies. Of the ten most prevalent crops for both groups, five are shared (common wheat, soybean, potato, perennial ryegrass, and Kentucky bluegrass). However, of these shared crops, none make up a similar proportion of PVPs. For example, while soybeans make up almost a third of non-LGU PVP certificates, they are only 3.6% of LGU certificates. It is also notable that there are many plants that are only prevalent in one of the two pie charts. While field corn is almost one third of non-LGU certificates, it is not present in the LGU certificates.

Although some crops have varieties being developed both in and out of the land-grant system, others are more exclusive. Indeed, of the 113 crops in the data, 68 had varieties only developed by non-LGU institutions, and 18 had varieties only developed by LGUs. The remaining 27 crops had varieties developed by both LGUs and others. Table 2 presents all crop types with 50% or more of their PVP certificates received by LGUs. Of these crops, rice, peanuts, and oats have the most protected varieties (all between 30 and 40). These crops represent ones in which LGUs have specialization and a substantial amount of protected varieties. Of the crops that are 100% LGU, none have more than four certified varieties.

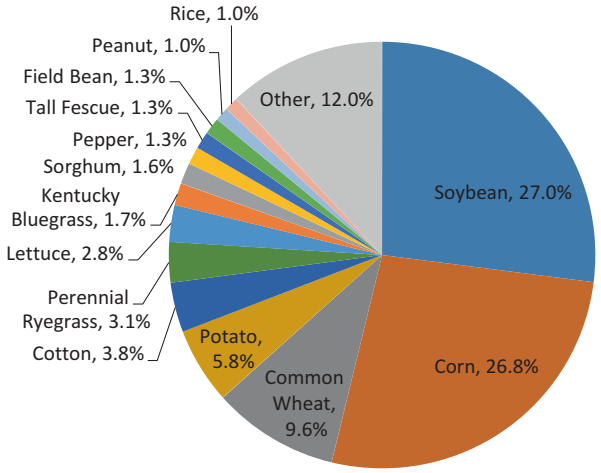

Fig. 5 Crop prevalence in PVP certifications

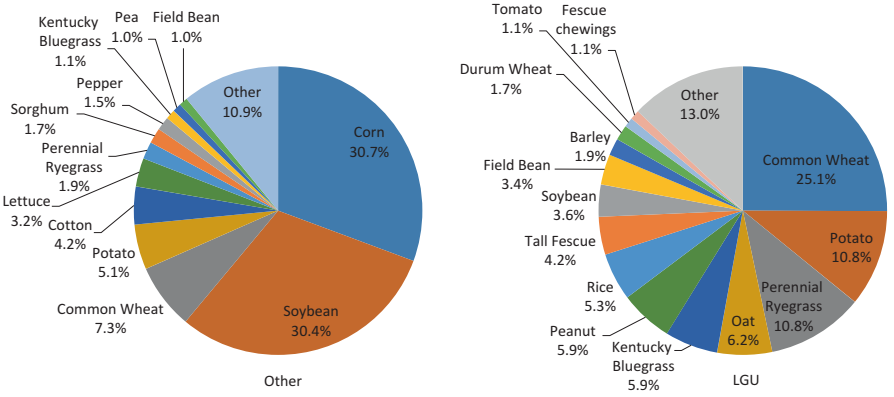

Fig. 6 Comparison of crop prevalence in LGU and other PVP certifications

Conclusions

Analysis of intellectual property data provide an accepted proxy for evaluating innovation levels occurring at universities. In agriscience, it is land-grant universities that are the primary academic research institutions engaged in research and associated IP development, in part because of their ability to receive and leverage federal NIFA Capacity Funds. Analysis of patents and patent forward citations shows LGUs generating 4% of total patenting in these fields in the 7-year period (2010–2016). However, the impact of land-grant innovation is more wide-ranging, influencing up to one in every six patents (as defined through patent citations) in agbiosciences in the United States. In terms of Plant Variety Protection certificates, the direct impact of the LGUs is even higher than in patenting, with an average of

Table 2 Crops with 50% or more of PVP certifications by land-grant institutions

Crop	Others(%)	LGU(%)
Wheat, durum	50	50
Ryegrass, annual	50	50
Bent grass, creeping	50	50
Flax	50	50
Onion	50	50
Fescue, hard	40	60
Fescue, chewings	38	63
Rice	36	64
Peanut	28	72
Oat	12	88
Bean, lima	0	100
Beet	0	100
Meadow-foam	0	100
Mustard, india	0	100
Bent grass, colonial	0	100
Clover, red	0	100
Clover, white	0	100
Crotalaria, sunn	0	100
Arugula	0	100
Asparagus	0	100
Bahia grass	0	100
Clover, arrowleaf	0	100
Corn, sweet	0	100
Fescue, creeping	0	100
Mustard, white	0	100
Rape, winter	0	100
Switchgrass	0	100
Wheat, club	0	100

14% of PVPs being awarded to LGUs between 2010 and 2016. Patenting in agriculture and associated fields at the LGUs is particularly focused around cutting-edge applications of biotechnology and associated life sciences and physical sciences. Areas that are particularly strong include fertilizers and other agricultural chemicals, genetic engineering, and novel plant types, together with enzymes and microbiology. In PVPs it is found that LGUs demonstrated IP generation in 18 crops that did not generate PVPs from other sources, and the LGUs innovated in 27 crops that others also worked in. Overall, it can be concluded that university-based research, especially research at LGUs, plays a substantial role in the US agriscience innovation ecosystem.

Appendix A: CPC Patent Classes Used in Patent Analysis

Table 3 Mapping of CPC classes to broad agbioscience areas

Broad agbioscience area	CPC class number	Description
Agricultural machinery and planting processes	A01B	Soil working and agricultural machinery
	A01C	Planting, sowing, and fertilizing processes
	A01D	Harvesting and mowing
	A01F	Threshing, baling, cutting, and produce storage
	A01G	Horticulture, forestry, and watering
Animal husbandry and management	A01K	Animal husbandry and breeding
	A01L	Animal shoeing
	A01M	Catching and trapping animals
Veterinary instruments and tools	A61D	Veterinary instruments, tools, or methods
Food production and additives	A01J	Manufacture of dairy products
	A21B	Baking equipment
	A21C	Dough processing
	A21D	Baking additives, products, and preservation
	A22B	Animal slaughtering
	A22C	Meat, poultry, and fish processing
	A23B	Food preservation
	A23C	Downstream dairy products
	A23D	Edible oils and fats
	A23F	Coffee and tea
	A23G	Cocoa products and other candies
	A23J	Protein compositions for foodstuffs
	A23K	Animal feedstocks
	A23L	Foods or foodstuffs not covered by other classes
	A23N	Machines for treating harvested plants
	A23P	Shaping or working of foodstuffs
Fertilizers and other agricultural chemicals	A01N	Preservation, biocides, pest repellants/attractants, growth regulators
	C05B	Phosphatic fertilizers
	C05C	Nitrogenous fertilizers
	C05D	Other inorganic fertilizers
	C05F	Other organic fertilizers
	C05G	Fertilizer mixtures and additives
Animal and vegetable oils	C11B	Producing and refining animal and vegetable oils
	C11C	Secondary fats, oils, or fatty acids obtained from processing
Milling processes	B02B	Preparing grain and fruit for milling
	B02C	Specific milling processes
Novel plant types	A01H	New plants and processes for obtaining them

(continued)

Table 3 (continued)

Broad agbioscience area	CPC class number	Description
Tobacco production	A24B	Manufacture or preparation of tobacco
Wood processing	B27L	Removing bark and splitting wood; manufacture of wood stock, veneer, shavings, fibers, or powder
Fermented beverages	C12C	Beer brewing
	C12G	Preparation of wine and other alcoholic beverages
	C12H	Pasteurization, sterilization, purification, clarification, and aging of alcoholic beverages
Enzymes[a]	C12N (part)	Preparation and compositions of enzymes, proenzymes, or carrier-bound or immobilized cells
Genetic engineering[b]	C12N (part)	Mutation or genetic engineering substances (DNA or RNA), vectors, and host organisms
Microbiology[b]	C12N (part)	Microorganisms, spores, undifferentiated animal or plant cells, tissues, and culture media, viruses, and bacteria

[a]Patent classes that document areas related to microorganisms, plant and animal cell lines, and genetic engineering techniques often do not distinguish between human biomedical and agricultural applications for the end use of the IP listed and many times have multidisciplinary innovation impacts across human and agricultural biotech areas, making attribution of new technologies directly to agricultural biotechnology difficult. For these classes, expert review of all US patents generated for the analysis period was conducted to determine those that had agricultural biotechnology contexts for inclusion

[b]Grueber, Martin, and Simon Tripp. 2015. *Patents as Proxies Revisited: NIH Innovation 2000 to 2013*. Battelle Technology Partnership Practice. March 2015