United States Department of Agriculture

Economic Research Service

Administrative Publication Number 082

February 2020

Developing Automation and Mechanization for Specialty Crops: A Review of U.S. Department of Agriculture Programs

A Report to Congress

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United States Department of Agriculture

Economic Research Service
www.ers.usda.gov

Recommended citation format for this publication:

Astill, Gregory, Agnes Perez, and Suzanne Thornsbury. February 2020. *Developing Automation and Mechanization for Specialty Crops: A Review of U.S. Department of Agriculture Programs: A Report to Congress*, AP-082, U.S. Department of Agriculture, Economic Research Service.

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Abstract

At $64.7 billion, specialty crops comprised one-third of U.S. crop receipts and one-sixth of receipts for all agricultural products in 2017. Relative to other crops, many specialty crops are more dependent on agricultural labor for production, harvesting, and processing. Title VII, Section 7610 of the Agriculture Improvement Act of 2018 includes a request to identify programs of the U.S. Department of Agriculture (USDA) that accelerate the development and use of automation or mechanization in the production or processing of specialty crops. USDA has six such programs in the Agricultural Marketing Service (AMS), the Agricultural Research Service (ARS), and the National Institute of Food and Agriculture (NIFA) that funded $287.7 million (nominal) towards 213 projects from 2008 to 2018. USDA has three programs in Rural Development (RD) that funded $3.4 billion toward 280 projects from 2010 to 2018 to support the digital infrastructure needed for adoption of automation or mechanization. Each program is designed differently to achieve unique objectives: funding for specialty crop automation or mechanization projects is only a subcomponent of each program identified. The diverse purposes, origins, oversight, and funding mechanisms of these programs have implications for how research areas are prioritized and funded.

Keywords: specialty crops, mechanization, automation, technology, machinery, machine learning, data analysis, mechanical harvesting, processing, precision agriculture, remote sensing, drones, sensors

Acknowledgments

We thank Rich Derksen, USDA Office of the Chief Scientist, for facilitating collaboration between ERS and other USDA agencies; Carly Borgmeier of USDA, Agricultural Marketing Service; Joseph Munyaneza and Tim Rinehart of USDA, Agricultural Research Service; Angelica Van Goor of USDA, National Institute of Food and Agriculture; and Joseph Gilson of USDA, Rural Development for providing inventories of programs and projects related to automation or mechanization in specialty crops, example project highlights, and descriptions of program objectives, authorities, and funding mechanisms; Travis Minor and Jennifer Bond, ERS, for helpful reviews; Carol Ready for editing and Cynthia A. Ray for designing.

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What Is the Issue?

At $64.7 billion, specialty crops comprised one-third of U.S. crop receipts and one-sixth of receipts for all U.S. agricultural products in 2017. Many specialty crops are labor-intensive in production, harvesting, or processing. For example, harvest for many specialty crops requires workers to accurately distinguish ripe and unripe fruits and vegetables and gently pick, sort, or package the fruit or vegetable by hand without damage. A long-term decline in the supply of farm labor in the United States encourages producers to select less labor intensive crops, invest in labor-saving technologies, and develop strategies to increase labor productivity. Title VII (Research, Extension and Related Matters) of the Agriculture Improvement Act of 2018, includes a request in Section 7610 to review programs of the U.S. Department of Agriculture (USDA) that affect the production and processing of specialty crops to be utilized by the Secretary of Agriculture to develop and implement a strategy to accelerate the development and use of automation or mechanization in the production or processing of specialty crops.

What Did the Study Find?

USDA has six programs in the Agricultural Marketing Service (AMS), the Agricultural Research Service (ARS), and the National Institute of Food and Agriculture (NIFA) that, among other objectives, support the development and use of automation or mechanization in the production and processing of U.S. specialty crops. From 2008 to 2018 these AMS, ARS, and NIFA programs funded $287.7 million (nominal) toward 213 projects to develop and enhance the use of automation or mechanization in specialty crop production and processing. Projects covered a broad spectrum of technologies, including job aid/machinery automation, machine learning/data analysis, mechanical harvesting/processing, precision agriculture, remote sensing/drones, and sensors.

Funding amounts, projects, and technology categories are listed in a program inventory contained in an attachment to this report. Each identified program is designed differently to achieve unique objectives, although each program identified addresses the development and use of automation or mechanization in specialty crops in some form. The diverse purposes, origins, oversight, and funding mechanisms of these programs carry implications for how research

areas are prioritized and funded. For example, some programs are focused specifically on specialty crops while others include a broader set of agriculture sectors. In many cases, the structure of the program precludes determining whether demand for program funding exceeded funds available.

USDA has three programs in Rural Development (RD) that support the infrastructure needed for adoption of automation or mechanization. The programs in RD were targeted toward rural infrastructure that supported or enabled the automation or mechanization technologies to function. From 2010 to 2018, RD funded $3.4 billion (nominal) toward 280 digital infrastructure projects that facilitate the use of automation or mechanization in specialty crop production and processing.

Projects in the inventory represent multiple stages of research from the development of component parts, to working prototypes, to field trials, to integrated commercial technologies. Information on the extent of technology adoption was not available. Ultimately, adoption will depend on economic and behavioral factors unique to individual producers. For example, adoption of a new harvester technology that requires orchard redesign, while labor-saving, may not be feasible in the short run. Likewise, in an industry with a limited number of potential users or tight profit margins, returns on investment in research and development may seem low.

Going forward, new Federal programs may provide other funding opportunities to accelerate the development and use of automation or mechanization in the production or processing of specialty crops. For example, the Agriculture Improvement Act of 2018 authorized $50 million annually from fiscal year (FY) 2019 to FY 2023 for a 5-year pilot program: Agriculture Advanced Research and Development Authority (AGARDA). Funding must be appropriated before awards can be made. This program aims to achieve multiple objectives, with priority to projects that accelerate the advanced research and development of qualified products and projects that address critical research and development needs for technology for specialty crops, or that prevent, protect, and prepare against intentional and unintentional threats to agriculture and food.

How Was the Study Conducted?

With the help of the USDA Office of the Chief Scientist, ERS researchers worked with national program managers at USDA agencies to develop an inventory of projects and programs that directly accelerate the development and use of automation or mechanization for specialty crops between 2008 and 2018. With project timelines ranging from 1 to 5 years depending on the program and agency, the time period covers multiple rounds of project funding with enough time for early projects to have yielded results. Projects were assigned to one of six categories to describe areas of research: job aid/machinery automation; machine learning/data analysis; mechanical harvesting/processing; precision agriculture; remote sensing/drones; and sensors.

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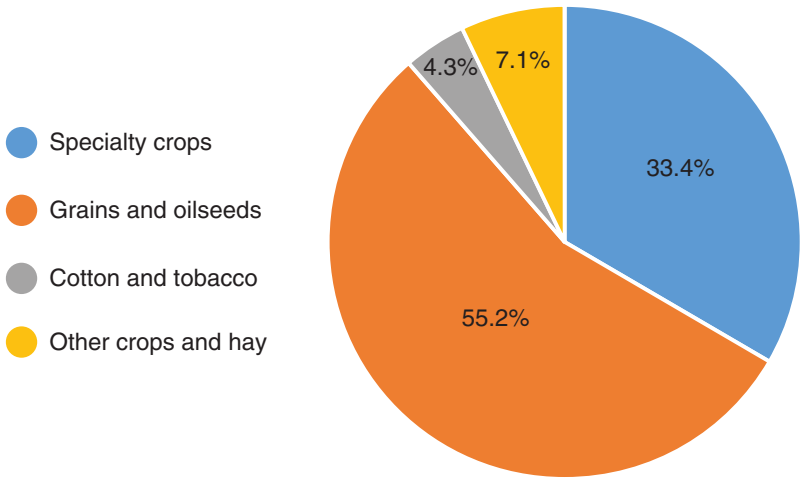
Background

Specialty crops (fruits, vegetables, tree nuts, horticulture, and nursery crops including floriculture) comprise a substantial share of the value of U.S. farm crops. In 2017, the total farmgate value of sales for these crops is estimated at $64.7 billion, accounting for one-third of the total market value of U.S. agricultural crops sold at farmgate or one-sixth of all U.S. agricultural products sold (USDA, National Agricultural Statistics Service, 2017). Of the total farmgate sales for specialty crops, $28.5 billion was attributable to fruits and tree nuts. A further $19.8 billion was generated through sales of vegetables and melons (including sweet and regular potatoes). Horticultural products grown in the United States in 2017 (nursery, greenhouse, floriculture, sod, and Christmas trees) add a further $16.5 billion in sales.

Compared to other crops, specialty crop production typically produces high-value output from relatively small areas of land: fruit, tree nut, vegetable, and melon production comprised nearly one-quarter of farmgate sales using only 3 percent of the total harvested crop land. Many specialty crops are also labor-intensive, requiring harvest workers to accurately distinguish ripe and unripe fruits and vegetables and to gently pick, sort, or package the fruit or vegetable by hand without damaging it. A long-term decline in the supply of farm labor in the United States continues to encourage producers to select less labor-intensive crops, invest in labor-saving technologies, and develop strategies to increase labor productivity (Zahniser et al. 2018).

Figure 1
Specialty crop share of total U.S. Crop farmgate sales, 2017



Sources: USDA, Economic Research Service Calculations based on USDA, National Agricultural Statistics Service Census of Agriculture, 2017

USDA has six programs in AMS, ARS, and NIFA that directly accelerate the development and use of automation or mechanization in the production and processing of U.S. specialty crops, and three programs in RD that facilitate the adoption of automation or mechanization (Table 1). Some programs are broader in coverage and include research on other crop and/or livestock sectors as well as specialty crops. In all the programs identified, automation or mechanization for specialty crops is one area of focus among multiple focus areas, even when they are all directed toward specialty crop sectors.

Between fiscal years 2008 and 2018, the programs identified by AMS, ARS, and NIFA funded $287.7 million (nominal) toward 213 projects to develop and enhance the use of automation or mechanization in specialty crop production and processing (Table 2). Projects covered a broad spectrum of technologies including job aid/machinery automation, machine learning/data analysis, mechanical harvesting/processing, precision agriculture, remote sensing/drones, and sensors (Table 3). Outputs from these projects include stakeholder outreach events/workshops, conference papers, journal articles, and newly available technologies (prototypes and/or working applications). Projects included a wide variety of specialty crops including almonds, apples, avocados, beets, blueberries, broccoli, cabbage, carrots, cauliflower, celery, cherries, chestnuts, chickpeas, chili peppers, citrus, cranberries, currants, elderberry, table and wine grapes, hazelnuts, hops, lettuce, maple syrup, mushrooms, nursery crops, olives, onions, ornamentals, pecans, peaches, pears, peas, peonies, pistachios, potatoes, pumpkin seeds, raspberries, sod, strawberries, sweet corn, sweet potatoes, tea, tomatoes, and walnuts.

The programs in RD were targeted toward rural infrastructure that supported or enabled the automation or mechanization technologies to function. From 2010 to 2018, RD funded $3.4 billion (nominal) toward 280 digital infrastructure projects that facilitate the use of automation or mechanization in specialty crop production and processing.

Table 1
USDA Programs Used To Accelerate the Development and Use of Automation or Mechanization in the Production or Processing of Specialty Crops

Agency	List of Programs
Agricultural Marketing Service (AMS)	Specialty Crop Block Grant Program
Agricultural Research Service (ARS)	National Program (305) Crop Production
	National Program (306) Product Quality and New Uses
National Institute of Food and Agriculture (NIFA)	Specialty Crops Research Initiative
	Small Business Innovation Research
	Agriculture and Food Research Initiative
Rural Development (RD)	Community Connected/Reconnect Grants
	Farm Bill Broadband Program
	Telecommunications Infrastructure Program

Source: Based on list provided by lead contacts from USDA's Agricultural Marketing Service, Agricultural Research Service, National Institute of Food and Agriculture, and Rural Development.

Table 2

Funding for USDA Programs Used To Accelerate the Development and Use of Automation or Mechanization in the Production or Processing of Specialty Crops, FY 2008 to FY 2018 (Nominal $)

	AMS	ARS	NIFA
Job Aid/Machinery Automation	1,728,425	19,752,000	12,088,409
Machine Learning/Data Analysis	536,120	31,836,000	7,280,422
Mechanical Harvesting/Processing	1,968,176	9,926,000	19,640,170
Precision Agriculture	1,689,152	65,201,000	44,423,450
Remote Sensing/Drones	2,717,851	25,543,000	7,606,663
Sensors	3,904,240	26,120,000	7,721,427
Total	12,543,966	176,378,000	98,760,541
Share of total funds	2%[a]	1%[b]	3%[c]

[a]AMS share of all specialty crop (SC) research funding going to automation or mechanization (M&A) in SC.
[b]ARS share of all agriculture research funding going to M&A in SC. However, using only the share of SC research funding going to M&A in SC is 60 percent in FY 2018.
[c]NIFA share of all SC research funding plus some other agricultural research funding going to M&A in SC.
FY = fiscal year.

Source: Based on data provided by USDA's Agricultural Marketing Service (AMS), Agricultural Research Service (ARS), National Institute of Food and Agriculture (NIFA). See the accompanying project inventory for individual projects.

Table 3

Number of Projects Supported by USDA Programs Used To Accelerate the Development and Use of Automation or Mechanization in the Production or Processing of Specialty Crops, FY 2008 to FY 2018

	AMS	ARS	NIFA
Job Aid/Machinery Automation	20	1	10
Machine Learning/Data Analysis	5	1	5
Mechanical Harvesting/Processing	32	2	11
Precision Agriculture	13	6	32
Remote Sensing Drones	22	1	12
Sensors	30	2	8
Total	122	13	78

FY = fiscal year.

Source: Based on data provided by USDA's Agricultural Marketing Service (AMS), Agricultural Research Service (ARS), National Institute of Food and Agriculture (NIFA). See the accompanying project inventory for individual projects.

Agricultural Marketing Service, USDA

Program Overview and Purpose

The Agricultural Marketing Service (AMS) manages a variety of services to establish the quality and availability of agricultural products for U.S. consumers and market opportunities domestically and internationally for U.S. agricultural producers (AMS, 2019). Support for rural America and the Nation's agricultural sector is provided, in part, through a variety of AMS-managed competitive and non-competitive grant programs, including the **Specialty Crop Block Grant Program (SCBGP)**. The SCBGP is a non-competitive grant program, which provides formula funds to State departments of agriculture to enhance the competitiveness of specialty crops. Legislative authority is provided under section 101 of the Specialty Crops Competitiveness Act of 2004 (7 U.S.C. § 1621 note) and amended under section 10107 of the Agriculture Improvement Act of 2018, Public Law 115-343 (the Farm Bill).

USDA-AMS may encourage, but does not have the authority to require, specific project types. Priorities for funding and project selection are determined at the State level through State departments of agriculture in consultation with specialty crop stakeholders. The 2018 Farm Bill amended the program to highlight that research and development assistance programs relevant to specialty crops are eligible activities.

Project Criteria

Through the SCBGP, funds are made available for State departments of agriculture to enhance the competitiveness of specialty crops. Applicants are encouraged to develop projects pertaining to: enhancing food safety; improving capacity of entities in the specialty crop distribution chain; investing in specialty crop research, including a focus on conservation and environmental outcomes; developing new and improved seed varieties; pest and disease control; increasing nutrition knowledge and consumption of specialty crops; improving efficiency and reducing costs; and sustainability. Projects funded under this program must demonstrate an ability to enhance the competitiveness of specialty crops, benefit more than one product or organization, and have demonstrable performance measures. Three examples are included in Appendix A.

Coverage

From FY 2008 to FY 2018, AMS funded $597 million (nominal) to the SCBGP, of which $12.5 million (or 2 percent) addresses measures to develop automation or mechanization in specialty crops. AMS receives from each State department of agriculture the number of applications for projects they received and the number they funded, but such information is not specific to automation or mechanization.

Crops

Specialty crops under this program include fruits, vegetables, tree nuts, cut flowers, nursery crops, ornamentals, and all other horticultural crops grown in any of the 50 States, District of Columbia, and five U.S. territories (American Samoa, the Commonwealth of the Northern Mariana Islands, the Commonwealth of Puerto Rico, Guam, and the U.S. Virgin Islands).

Opportunities To Accelerate the Development and Use of Automation or Mechanization in Specialty Crops at USDA-AMS

The SCBGP covers multiple research areas prioritized by individual State departments of agriculture around priorities determined to best suit State needs. At the Federal level, trade-offs in priorities are unavoidable as States seek to achieve multiple objectives and tailor objectives to more localized needs (see Cattaneo et al. (2006) for a discussion of trade-offs in objectives for conservation programs). For example, the 2018 Farm Bill establishes the Agriculture Advanced Research and Development Authority (AGARDA) pilot program. One AGARDA priority for awarding grants and entering into contracts, cooperative agreements, or other transactions is "critical research and development needs for technology for specialty crop production." While not directly addressed to SCBGP, AGARDA priorities may encourage project selection decisions among the States.

AMS recently implemented an evaluation plan consisting of eight outcomes—with associated indicators and subindicators—in order to report on the measurable outcomes of the SCBGP at a national scale. Each project within a State application must select at least one of those eight outcomes measures and indicators. By collecting, aggregating, and reporting performance data across all States and territories, AMS (2015) plans to share the impact of the SCBGP with all stakeholders, including the Office of Management and Budget (OMB), Congress, the agricultural community, and the general public.

AMS is currently in the process of revisiting these measures based on guidance included in the 2018 Farm Bill. As the SCBGP grant awards have a 3-year performance period, FY 2016-awarded projects will submit their Final Performance Reports in December 2019.

Agricultural Research Service, USDA

Program Overview and Purpose:

The Agricultural Research Service (ARS) examines research questions related to the biological, biochemical, physiological, and epidemiological factors impacting agricultural production (ARS, 2019). ARS also studies the impact of technologies on these agronomic factors. ARS research is organized into National Programs (NPs) that coordinate research and communication across four theme areas. Two national programs, **NP 305 and 306**, relate to automation or mechanization and are organized under the Crop Production and Protection and Nutrition, Food Safety/Quality theme areas, respectively.

ARS research is authorized by the Department of Agriculture Organic Act of 1862 (7 U.S.C. 2201 note); Act of June 29, 1935 (7 U.S.C. 427); Agricultural Marketing Act of 1946, as amended (7 U.S.C. 1621 note); Food and Agriculture Act of 1977 (P.L. 95-113), as amended (7 U.S.C. 1281 note); Food Security Act of 1985 (P.L. 99-198) (7 U.S.C. 1281 note); Food, Agriculture, Conservation, and Trade Act of 1990 (P.L. 101-624) (7 U.S.C. 1421 note); Federal Agriculture Improvement and Reform Act of 1996 (FAIR) (P.L. 104-127); and Agricultural Research, Extension, and Education Reform Act of 1998 (P.L. 105-185). A broad inventory of agricultural technologies developed or funded by USDA (not limited to specialty crop automation or mechanization) has been published by the Office of Technology Transfer in ARS (USDA, 2019a).

Project Criteria

The objectives of research projects funded under ARS National Programs 305 and 306 are derived from statutory language, specifically the "Purposes of Agricultural Research, Extension, and Education" set forth in Section 801 of Federal Agriculture Improvement and Reform (FAIR) Act. In general, funded projects must strive to enhance the global competitiveness and long-term productivity of U.S. crops, increase economic opportunities, or aid in risk management and/or safety. Projects funded under NP 305 are evaluated based on their potential to increase cropping efficiency, productivity, quality, marketability, and protection of annual, perennial, greenhouse, and nursery crops while maintaining or enhancing worker safety and environmental quality. The more specific objectives of NP 306 are to "develop knowledge that enables commercially-viable technologies to (1) measure and maintain/enhance post-harvest product quality, (2) harvest and process agricultural materials, and (3) create new value-added products." Funding for 5-year projects is allocated internally based on program research objectives and scientific panel evaluation. Four examples are included in Appendix B.

Coverage

From FY 2008 to FY 2018, ARS funded $176.4 million (nominal dollars or 1 percent of research and development funding across all programs) to 13 projects in National Programs 305 and 306 that aim to enhance automation or mechanization in specialty crops. Measured differently, approximately 60 percent of the $278.4 million across all FY 2018 research and development funding for "specialty crops" supported projects impacting automation or mechanization. In ARS, because research dollars are allocated to projects in accordance with congressional appropriations—which are often commodity or program specific—and not through a competitive application process, it is not possible to measure whether demand for program funding exceeded funds available.

Crops

The research programs categorized under NP 305 and 306 are quite broad and cover all crop commodities including specialty crops. Research related to fruits, vegetables, tree nuts, horticultural crops, and even honey bees may be considered for funding under either program.

Opportunities To Accelerate the Development and Use of Automation or Mechanization in Specialty Crops at USDA-ARS

Research projects funded under NP 305 and 306 cover multiple research areas prioritized by ARS and scientific panel review. Both programs are broad and include multiple objectives under Crop Production and Product Quality and New Uses across crop categories. Trade-offs in priorities are unavoidable and are addressed through the 5-year planning cycle and annual review of projects. ARS identified the need for more resources and coordinated communication between growers/farmers and researchers in the form of workshops and demonstrations at field scale.

National Institute of Food and Agriculture, USDA

Program Overview and Purpose:

The National Institute of Food and Agriculture (NIFA) was established by the Food Conservation and Energy Act of 2008 to find innovative solutions to issues related to agriculture, food, the environment, and communities. NIFA's mission is to invest in and advance agricultural research, education, and extension to solve societal challenges, through the advancement and application of science and technology tools (NIFA, 2019a). NIFA funds agricultural research that complements private-sector investments. NIFA's partnership with Land-Grant Universities uniquely allows rapid translation of discoveries through education and extension. Several grant programs at NIFA include funding for specialty crop automation or mechanization.

- **Specialty Crop Research Initiative (SCRI)** invests in technology, such as robotics and wireless sensors, to address labor challenges and to reduce resource use in specialty crops industries.
- **Small Business Innovation Research (SBIR)** program funds small companies to commercialize research ideas in agricultural tools, including those for specialty crops.
- **Agriculture and Food Research Initiative (AFRI)** invests in research, education, and extension, including that related to specialty crops, through its components as well as through interagency collaborations.

The **Specialty Crop Research Initiative (SCRI)** was reauthorized by Section 7306 of the Agricultural Act of 2014, which amended Section 412 of the Agricultural Research, Extension, and Education Reform Act (AREERA) of 1998 (7 U.S.C. 7632). Section 412 of the AREERA of 1998 established a specialty crop research and extension initiative to address the critical needs of the specialty crop industry by developing and disseminating science-based tools to address needs of specific crops and their regions. Section 7306 of the Agricultural Act of 2014 added a requirement that, in addition to the scientific peer review NIFA regularly conducts, a panel of specialty crop industry representatives review and rank SCRI applications for merit, relevance, and impact. In addition, Section 7306 requires increased consultation between NIFA and the Specialty Crops Committee of the National Agricultural Research, Education, Extension and Economics Advisory Board. SCRI funds research in technology, such as robotics and wireless sensors, to address labor challenges and to reduce resource use in specialty crops industries.

The National Defense Authorization Act for Fiscal Year 2017 (Pub. L. 114–328, §1834(a) Extension of SBIR and STTR programs) amended the SBIR Small Business Act (15 U.S.C. 638(m)) to September 30, 2022. Policy is provided by the Small Business Administration (SBA) through the SBIR Policy Directive. A main purpose of the legislation is to stimulate technological innovation and increase private sector commercialization. The USDA **Small Business Innovation Research (SBIR)** program is therefore in a unique position to meet both the goals of USDA and the purpose of the SBIR legislation by "transforming scientific discovery and innovation into both social and economic benefit, and by emphasizing private sector commercialization." The SBIR program is congressionally mandated and intended to support scientific excellence and technological innovation through the investment of Federal research funds to build a strong national economy by stimulating technological innovation in the private sector; strengthening the role of small business in meeting Federal research and development needs; increasing the commercial application of federally

supported research results; and fostering and encouraging participation by socially and economically disadvantaged and women-owned small businesses. The SBIR program funds small companies to commercialize research ideas in agricultural tools, including those for specialty crops.

Section 2(b) of the Competitive, Special, and Facilities Research Grant Act (7 U.S.C. 3157), as amended, authorizes the **Agriculture and Food Research Initiative (AFRI)**, a competitive grant program to provide funding for fundamental and applied research, education, and extension to address food and agricultural sciences in the following six priority areas:

1. Plant health and production and plant products;
2. Animal health and production and animal products;
3. Food safety, nutrition, and health;
4. Bioenergy, natural resources, and environment;
5. Agriculture systems and technology; and
6. Agriculture economics and rural communities.

The AFRI program focuses on research, education, and extension, including projects related to specialty crops, through its components as well as through interagency collaborations. A portion of the AFRI support for automation or mechanization for specialty crops is provided through the National Robotics Initiative and Cyberphysical Systems Program, in cooperation with the National Science Foundation.

Additionally, NIFA provides capacity grants to cooperating land-grant universities, which may include support for automation or mechanization for specialty crops through institutionally directed research and extension programming.

Project Criteria

To the maximum extent practicable, NIFA, in coordination with the Under Secretary for Research, Education, and Economics (REE), will make grants for high-priority research, education, and extension, taking into consideration, when available, the determinations made by the National Agricultural Research, Extension, Education, and Economics Advisory Board (NAREEEAB) pursuant to the Competitive, Special, and Facilities Research Grant Act (7 U.S.C. 3157. The Secretary delegates the authority to the Under Secretary in 7 CFR 2.21, and the Under Secretary delegates it to NIFA. Two examples are included in Appendix C.

Coverage

From FY 2008 to FY 2018, NIFA funded $573 million (nominal) to SCRI, $239 million to SBIR, and $2.677 billion to AFRI, of which $98.8 million (or 3 percent) addresses measures to develop automation or mechanization in specialty crops. NIFA reports that for all research proposals submitted—not only those addressing automation or mechanization in specialty crops—20 percent are funded each year for SCRI, 15 to 50 percent for SBIR, and 20 percent for AFRI (NIFA 2019b, 2019c, 2018, 2017).

Crops

Nearly any U.S.-grown crops can be the subject of a NIFA proposal. However, the SCRI program is exclusively focused on specialty crops while the SBRI and AFRI are inclusive of specialty crop-related research.

Opportunities To Accelerate the Development and Use of Automation or Mechanization in Specialty Crops at USDA-NIFA

SCRI, SBIR, and AFRI each cover multiple research areas prioritized by NIFA and the REE Under Secretary, as well as SBA in the case of SBIR. Both SBIR and AFRI include a broad agriculture focus while SCRI is targeted towards multiple priorities for specialty crops. Trade-offs may be unavoidable for programs that aim to achieve multiple objectives, but outcomes can be prioritized in a holistic fashion and according to broader Federal or industry priorities when applicable. Available information on the number of grant applications that were funded and unfunded point to unmet demand for research dollars to address research in specialty crops, but the level of reporting precludes examining demand for projects specifically addressing automation or mechanization.

NIFA staff identified the following future opportunities within their programs.

- **Data analytics**: One bottleneck of automation or mechanization technologies is making the vast amount of generated data integrated, interoperable, and useful for agricultural production. To address the digital age of agriculture, NIFA launched the Food and Agriculture Cyberinformatics and Tools (FACT) initiative in 2017. Through the FACT initiative, NIFA invested $21 million across AFRI programs in FY 2018.
- **Specialty crops and livestock:** NIFA invests in special commodity crops/animals where underinvestment occurs in the private sector (e.g., fruits and vegetables, sheep, and bees). In addition, opportunities exist in precision livestock farming (e.g., automation, health, welfare, production, and breeding); much like specialty crops, this is an area with little investment compared to row crops.
- **Social and Economic Factors—Economics and Education**: NIFA could expand research to include additional socio-economic questions (impacts, unintended consequences, perceptions, markets) related to the impact of automation on labor needs. NIFA training programs span from informal methods (e.g., 4-H) to formal training at K-20 to Beginning Farmer & Rancher Development Program (BFRDP). NIFA notes training and workforce development could help move automation or mechanization innovations through the pipeline to the farmer. In FY 2020, NIFA has proposed to provide data and technology training opportunities in community colleges.

Rural Development, Rural Utilities Service, USDA

Program Overview and Purpose

USDA, Rural Development houses the Rural Utilities Service (RUS) and is the lead Federal agency funding broadband in rural America. Many mechanized or automated technologies require digital infrastructure, like broadband access to the internet, to function. A lack of access to high-speed internet is an impediment to the use of many specialty crop-focused mechanized or automated technologies (USDA, 2019b).

USDA's Rural Utilities Service administers several programs that finance modern broadband and telecommunications infrastructure. These include: Community Connected/Reconnect Grants (CCG), Rural Broadband Access Loan and Loan Guarantee (also known as **Farm Bill Broadband Program (FBBP)**), and the **Telecommunications Infrastructure Loans and Guarantees Program (TILP)**. CCG grants help rural communities extend access where broadband service is least likely to be commercially available and aid in the construction, acquisition, or leasing of facilities necessary to deploy broadband service. Funds may also be used to offset the cost of providing broadband service free of charge for up to 2 years to all critical community facilities within the project area. However, the infrastructure funded through these programs also has the potential to aid farmers who benefit from enhanced access to broadband resources. Both FBBP and TILP provide fixed-rate, low-interest loans for the construction, maintenance, improvement, and expansion of telephone service and broadband in rural areas.

Project Criteria

Eligible applicants include for-profit and non-profit entities, Tribes, municipalities, and cooperatives. USDA particularly encourages investments in Tribal and economically disadvantaged areas. For CCG funds, eligible applicants must live in a rural area that lacks access to broadband service with speeds of at least 10 Mbps downstream and 1 Mbps upstream. For FBBA funds, the proposed funded service area must be completely contained within a rural area or composed of multiple rural areas, and at least 15 percent of households in the proposed funded service area must be unserved. For TILP funds, applicants must serve an eligible area comprised of rural areas and towns with a population of 5,000 or less. These areas must also be without telecommunications facilities or areas where the applicant is the recognized telecommunications provider. A broad inventory of USDA research projects that develop broadband-connected technologies has been published by the American Broadband Initiative (USDA, 2019b). An example is included in Appendix D.

Coverage

Rural Development funded $3.4 billion (nominal) toward 280 digital infrastructure projects from FY 2010 to FY 2018. The 2018 Farm Bill (signed on December 20, 2018) includes provisions to authorize a grant component in combination with the FBBP program. The annual authorization level is increased from $25 million to $350 million with a stipulation that the proposed service area must have 50 percent underserved households (i.e., areas that have access to low-quality broadband service and may have some households without access) versus the 15 percent eligibility requirement previously enforced.

Opportunities To Accelerate the Development and Use of Automation or Mechanization in Specialty Crops at USDA-RD

A significant barrier to these programs' contribution to accelerating the development and use of automation or mechanization in specialty crops is the large amount of capital investment it takes to build broadband infrastructure in low-density areas. In 2018, Congress recognized the challenge of securing large capital investments in low-density areas by authorizing a new Reconnect Program with $600 million in funding. Under this new program, there are grant and loan-grant combinations for broadband infrastructure.

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Appendix A. Highlighted Projects Identified by USDA, AMS

Projects highlighted in this appendix were selected by USDA-AMS to illustrate research focused on accelerating the development and use of automation or mechanization in the production and processing of U.S. specialty crops. Summaries are based on research reports for these projects and communications from the researchers involved. A full list of USDA-AMS projects is in the accompanying project inventory.

1. Idaho IdaBOT: An Autonomous Utility Robot Prototype for Managing Idaho Specialty Crops
   Highlight: Precision Agriculture, Automation, Robotics, FY 2015 to FY 2018

The IdaBot prototype is intended to be a low-cost, autonomous utility robot that can assist Idaho specialty crop growers in the day-to-day maintenance and harvesting of their crops. Robots can do many manual-labor tasks cheaply and significantly enhance the productivity of the specialty crop laborer. While the agriculture industry has seen significant innovation in robotics, many of these robots are intended for standard row-planted crops (e.g., self-driven combines). The IdaBot prototype was built upon a relatively small, track-driven robotic platform purchased from SuperDroid Robots. In its unmodified form, the robotic platform could be driven with a remote control, but in this project, the robot was outfitted with sensors, controllers, a radio frequency identification (RFID) reader, and a small tank sprayer to allow it to autonomously navigate and apply chemicals in a vineyard. Although the robotic platform and tank sprayer are smaller than what would be needed for day-to-day farm use, they provide an easy means to demonstrate how RFID can be used to autonomously navigate a robot through a vineyard or orchard and apply chemicals in specific locations without the need to work with large equipment. The IdaBot project and performance results are available online. Although still in the prototype phase, without available data on cost, the IdaBot project has the potential to impact growers in many regions and many commodities.

2. Development of an improved crop-scouting technique incorporating UAV and multi-spectral imaging into conventional scouting practices on Florida cucurbits, FY 2016 to FY 2019

This project will address this issue through incorporation of Unmanned Aerial Vehicles (UAV) and multi-spectral imagery into commercial cucurbits (squash, pumpkin, watermelon, and cucumber) scouting in Florida from 2017 to 2019, and studying the possibilities in improving early detection of biotic and abiotic issues. The overall goal of the project is to develop synergistic use of UAV and multi-spectral imagery and commercial crop-scouting for significantly enhancing the ability of these first detectors who can make effective management recommendations for growers covering thousands of acres of watermelon, cucumber, and squash producers in Florida. The scouting companies will directly utilize the new scouting program for successful commercial watermelon, cucumber, and squash production in an estimated 2,000+ acres by 2018, more than 5,000 acres by 2019, and over 10,000 acres by 2020. This project will address critical limitations of crop-scouting companies in early detection of plant pathogens and nutritional and water stress by incorporating and evaluating a proactive entire-field, single-leaf/plant-level multi-spectral imagery into their current scouting programs. Adoption of the new scouting approach is expected to provide overall improved performance of commercial scouts in early detection of pathogens and nutritional and irrigation issues. This new scouting approach is in the prototype stage, and there is not available data on the cost of the technology.

3. Enhancing Oregon broccoli and cauliflower competitiveness by improving harvest efficiency, FY 2016 to FY 2019

The Oregon Processed Vegetable Commission (OPVC) will facilitate mechanical harvest of broccoli and cauliflower by developing seed production capacity for exserted head broccoli hybrids having plant architecture adapted for mechanical harvest, and by developing, manufacturing, and field testing improved mechanical harvester prototypes. The mechanical harvester prototype for broccoli and cauliflower integrates electronic sensor technology, improves post-harvest quality, and reduces the need for manual labor to harvest broccoli and cauliflower. This technology is in the prototype stage, and there is not available data on cost. Direct beneficiaries are family farmers who currently grow broccoli and cauliflower plus Norpac Foods and Stahlbush Island Farms, the only two processors for these crops. Other beneficiaries include farm laborers whose jobs would change to sorting rather than very arduous hand labor, and some workers in the food processing industry whose jobs are in jeopardy if these crops are no longer grown in Oregon. In addition, small farmers who have given up growing broccoli or cauliflower may be able to again include these crops on their farm.

Appendix B. Highlighted Projects Identified by USDA, ARS

Projects highlighted in this appendix were selected by USDA-ARS to illustrate research focused on accelerating the development and use of automation or mechanization in the production and processing of U.S. specialty crops. Summaries are based on research reports for these projects and communications from the researchers involved. A full list of USDA-ARS projects is in the accompanying project inventory.

1. National Program (306): Product Quality and New Uses - Self-Propelled Apple Harvest and In-Field Sorting Machine, Fiscal Year 2008 to Fiscal Year 2018

The U.S. apple industry is facing critical challenges in decreased availability of labor and increased labor and production cost. To address these challenges, ARS researchers at East Lansing, Michigan, recently developed a new self-propelled apple harvest and in-field sorting machine with several innovative harvest efficiency-enhancing and automatic in-field sorting designs. Prototypes are being used in field-scale trials. Economic analysis was conducted to evaluate the benefits of adopting this harvest and in-field sorting machine by considering the machine cost, harvest efficiency improvement, and postharvest storage/packing savings or extra benefits accrued from in-field sorting of processing apples from fresh market apples (Zhang, Pothula, and Lu, 2017). Based on the conservative estimations, the machine can improve harvest efficiencies by 43 percent to 63 percent, compared to manual harvest. Both fresh apple growers, who grow apples primarily for the fresh market, and processing apple growers can gain significant benefits by adopting the technology. Depending on the machine price, harvest efficiency increase, and the ratio of fresh market apples to processing apples, the actual net annual benefits for the fresh apple grower would range between $13,500 and $78,400 and for the processing apple grower between $23,900 and $81,700. The technology can also improve the working conditions for harvesting workers and alleviate the labor shortage problem for the apple industry.

2. National Program (305): Crop Production - Intelligent Sprayer, FY 2008 to FY 2018

An example of ARS ground-based application automation is the development of the Intelligent Sprayer by ARS scientists at ARS Wooster, Ohio. The sprayer is guided with a laser sensor and can control the outputs of individual nozzles independently to match tree canopy size, shape, and leaf density. Basically, the intelligent sprayer sees trees, measures tree structures, and then applies the appropriate amount of chemicals needed. Studies at USDA ARS, The Ohio State University, Oregon State University, and the University of Tennessee show a reduction in pesticide use by 47 to 73 percent with comparable insect control efficiency and equal or better disease control, 40 to 87 percent reduction in spray loss beyond tree canopies, up to 87 percent less airborne drift, 68 to 93 percent reduction in spray loss on the ground, and equal or better crop protection. ARS-developed spray technology was used to retrofit existing sprayers used in nurseries, orchards, vineyards, and other specialty crop production. Growers do not need to buy a new sprayer; a simple button allows the sprayer operator to switch between the automatic and conventional modes. An existing sprayer can be retrofitted for less than $10K/sprayer. Currently, 12 sprayers are operating in commercial fields, with a plan of adding around 6 sprayers each year. As of January 2019, the sprayer is commercially available through Smart Guided Systems.

3. National Program (305): Crop production - Tule Sensor, Fiscal Year 2008 to Fiscal Year 2018

ARS scientists have been working on neural network models using canopy temperature measured by infrared radiometers that can predict the canopy temperature of well-watered grape vines. Tools to measure water stress are relatively inexpensive and provide daily water stress index for vineyards but don't provide data on actual water use by the plant, which is necessary for precision irrigation management. So, the ARS scientists working on this problem used a model for Surface Renewal, which analyzes the energy budget of air parcels that sit within the crop canopy and are subject to the exchange process. They developed automated sensor technology to measure air sweeps (or renewals), programmed their calculations into an inexpensive sensor, added a solar power source, and patented it in 2014 jointly between ARS and University of California, Davis. The Tule package is now selling as a stand-alone sensor that measures crop water use in real-time. The system retails for about $200, and the precise measurements of crop water use are converted to water demand that is matched directly to irrigation inputs. As of 2017, there are more than 3,000 Tule evapotranspiration sensors deployed for precision irrigation decisions.

4. National Program (305): Crop Production - Rotating Cross Arm Trellis, FY 2008 to FY 2018

ARS innovation has improved caneberry production for high-quality fruit and expanding commercial production to areas where caneberries had not been grown commercially before. These images show a rotating cross arm trellis developed by ARS researchers in National Program 305 to improve cane growth, berry yield, fruit quality, and cane longevity. The system is made from carbon-fiber components. The upright supports are hinged so the angle can be adjusted at any time during the season. During the first season of growth, blackberry canes are trained onto the upright trellis; one or more seasons of growth or training is typical of most fruit and nut crops where trees, orchards, and vineyards do not yield marketable product until fully established. Once canes are established and trained, they are put into production in the spring and the trellis is fixed horizontal to the ground so that all the flowers grow on one side of the trellis. After pollination, the trellis is raised and angled such that the berries develop on the shaded side, hanging slightly out from the canopy for maximum air movement and complete spray coverage, which produces the highest quality fruit. With production concentrated on one side of the trellis, harvest labor is reduced by 30 percent (AgResearch 2015). In production in Georgia, adjusting the canopy angle reduced the impact of sunscald to just 5 percent of the berries, instead of the 30 percent of berries that are damaged when produced on a conventional trellis. This greatly improves production in areas that already grow blackberries. In climate zones where winter temperatures cause freeze damage, or during extreme weather events such as cold or wind, the trellis system can be laid flat on the ground, and even covered for maximum plant protection. This ability to protect from winter damage allows blackberries to be successfully grown in USDA Plant Hardiness Zone 6 and even 5 with additional row cover protection. The benefits of fewer canes (wider spacing), long cane life, higher yields, and increased berry quality can increase grower income by more than $6,000 per acre. In the last 5 years, the ARS trellis system has been installed in 25 U.S. States. There are currently more than 500 acres of this trellis system, and several farms in Ohio, Pennsylvania, Georgia, and Florida have more than 20 acres in full-scale production. Estimated revenue from the trellis system is more than $10 million annually in blackberry production. There are even growers using this technology in Europe now (Ukraine).

Appendix C. Highlighted Projects Identified by USDA, NIFA

Projects highlighted in this appendix were selected by USDA-NIFA to illustrate research focused on accelerating the development and use of automation or mechanization in the production and processing of U.S. specialty crops. Summaries are based on research reports for these projects and communications from the researchers involved. A full list of USDA-NIFA projects are in the accompanying project inventory.

1. Managing Irrigation and Nutrients With Distributed Sensing for Specialty Crops, Fiscal Year 2009-Fiscal Year 2014

Management of global water resources is increasingly challenging. To address this challenge, NIFA funded $5,161,495 (funding match for total award of $10,322,990) to the project "SCRI-MINDS: Managing Irrigation and Nutrients with Distributed Sensing for Specialty Crops." The tools generated through this funding can achieve between a 40 and 70 percent reduction in irrigation water applications with sensor-based set-point irrigation control (Lea-Cox et al. 2017). For one of the growers that adopted the technology, an average 50-percent reduction in irrigation saved over 43 million gallons of water and $6,500 in pumping costs. In the central valley of California, where water costs are typically $750/acre foot, the net cost of this 43 million gallons of water exceeded $100,000, without accounting for additional pumping, plant growth, or other economic benefits. In this case, the return on investment for the entire sensor network ($48,000) would take less than 4 months. The PlantPointTM advanced sensor network control system is commercially available and utilized by farmers.

2. Precision Vineyard Management, FY 2015 to FY 2019

Grapes are one of the largest specialty crops in the United States, with a farmgate value of over $6 billion and an annual production of over 7 million tons on 1 million acres. Commercial vineyard management practices are currently inefficient because soil, vine, and crop management decisions are applied uniformly across entire production blocks without measurement or response to spatial variation in soil or vine characteristics. An example of SCRI-funded digital tools is the Precision Vineyard Management project totaling $6.4 million that is aimed at delivering an innovative, science-driven, and approachable precision viticulture platform to measure and manage sources of vineyard variation. Outcomes could impact 1 million vineyard acres across the U.S. grape industry that have large spatial variations in soil, vine growth, and fruit yield. At $250/ton, the management decision software created by this project would give an additional $30,000 income to the grower over the 100 acres, close to a 1-year return on investment. The technology is available to farmers.

Appendix D. Highlighted Projects Identified by USDA, RD

Projects highlighted in this appendix were selected by USDA-RD to illustrate research focused on accelerating the development and use of automation or mechanization in the production and processing of U.S. specialty crops. Summaries are based on research reports for these projects and communications from the researchers involved.

1. Rural Utilities Service Telecommunications Loan Program: Fiber Broadband Speeds Trade for Small Town Agricultural Business

Early in 2017, the Moultrie Independent Telephone Company (MITCO), Lovington, Illinois's long-standing business, received a $4 million award from USDA's Rural Utilities Service Telecommunications Loan Program. This loan provided funding for a comprehensive network upgrade in Lovington, which includes new fiber access to the home for 800 premises. From existing DSL wire to leading-edge fiber technology, MITCO now provides its customers with access to tenfold higher speeds at deals comparable to the prices customers already pay.

As the Operations Manager, Gary Smith relies on three computers in his office to track prices, make bids, run reports, and monitor the levels of the grain elevators in the Okaw Grain Farers Cooperative (Okaw) storage system. For decades, these computers have depended on a copper digital loop, known as DSL, a technology that is quickly becoming outdated. The speed at which the numbers are conveyed between Livingston and the Chicago Board of Trade can influence profitability for this rural business and also for the 300 rural farmers who comprise its membership.