

DOI:10.1145/3760437

Five federally funded AI institutes provide a backbone for agriculture-focused AI research.

BY VIKRAM ADVE, STEVE BROWN, ALAN FERN, BASKAR GANAPATHYSUBRAMANIAN, ANANTH KALYANARAMAN, SHASHI SHEKHAR, ILIAS TAGKOPOULOS, AND JESSICA WEDOW

Advancing AI in Agriculture through Large-Scale Collaborative Research

THE GRAND CHALLENGE facing global agriculture today is the need to increase food production to feed a rapidly growing population, amid diminishing natural and human resources and climate pressures. With the global population expected to exceed 9.5 billion by 2050, and with several key resources

being depleted (see sidebar), the agricultural community is turning to a digital revolution to secure the future of our food production. Touted Agriculture 4.0, this new movement is deploying digital technologies at scale, including field and aerial sensing, automation, and other smart devices to monitor and track resources and to improve operational efficiency. Artificial intelligence (AI) technologies are playing a central role in driving this revolution: enabling real-time decision support using spatiotemporal data collected on farms, augmenting human labor with automated decision making and robotics, estimating and forecasting risks due to extreme weather, and aiding in longer-term planning under climate-imposed uncertainties.

To propel the development and deployment of AI tools and technologies for U.S. agriculture, since 2020 the U.S. Department of Agriculture's National Institute of Food and Agriculture (USDA NIFA) has made a strategic investment in five AI institutes. These institutes are part of the broader National AI Research Institutes ecosystem supported by a partnership between NIFA and the U.S. National Science Foundation (NSF). The five NIFA-funded "AG-AI" institutes cover a breadth of research areas in which AI and machine learning (ML) principles and methodologies are effecting change in agricultural decision making, while advancing the state of both use-inspired and foundational AI techniques. These institutes have also emerged as a nexus point for fostering regional and international collaborations at the intersection of AI and agriculture, for developing an AI-ready workforce, and for envisioning new partnerships between the public and private sectors.

Federal funding of the AI Institutes program has been *the* key enabler for its broad range of impacts. The National AI Research Institutes program made an important strategic choice in investing in societal





applications of AI advances, combining foundational and use-inspired AI research to address important challenges in a wide range of sectors, including agriculture, education, trustworthy AI, chemical manufacturing, cybersecurity, law, physics, optimization, decision making, cyberinfrastructure, edge computing and networking, and astronomy. This has brought a large number of core AI researchers into close collaboration with researchers in numerous other disciplines, addressing important societal problems and advancing the frontiers of AI itself, but motivated by specific application areas. The five AG-AI institutes exemplify all these benefits. Numerous AI experts *who had never worked on agriculture or food problems before* are now collaborating closely with ag and food researchers to address problems in these domains. Moreover, by coordinating projects toward specific areas, each of the institutes has organized their research into broad themes that go beyond what small-scale funded projects would be able to accomplish. The institutes have also individually and collectively taken numerous steps to address the profound shortage of AI skills in the workforce,

which is especially problematic in many application areas (such as agriculture), further underscoring the importance of federal investment in research and education.

Selected Technical Contributions

In what follows, we briefly describe each of the five AG-AI institutes along with a selected listing of technical outcomes from each institute.

AgAID: AI Institute for Transforming Agricultural Workforce and Decision Support. The AgAID Institute⁹ was established in 2021 with the goal of advancing AI for specialty crop agriculture. The U.S. specialty crop industry is a multibillion-dollar industry, with the West Coast contributing to well over 300 of these crops. Most of them are high-value perennial crops (for example, tree fruits, grapes, berries, nuts) that are grown on irrigated lands and are labor-intensive (employing more than 80% of the agricultural workforce). Consequently, AgAID develops AI tools for farm-scale decision support, water-allocation and management decisions, and labor automation.

Farm operations intelligence. Crop managers often face uncertainty about crop biological state, localized weather, and how crops will respond to interventions. Applying standard AI techniques presents challenges, as the datasets for specialty crops are typically small and sparse, and field sensors can be noisy, broken, or unevenly distributed. To address these issues, AgAID is developing AI prediction tools integrated with AgWeatherNet, a Web-based platform used by more than 350 growers for accessing local weather and crop-specific predictions.

As an example, AgAID has developed state-of-the-art AI models to predict grape cold-hardiness,¹⁹ which is critical for frost-mitigation decisions. Using a historical dataset of laboratory measurements across more than 30 cultivars, the team trained a deep multi-task learning model, exploiting shared structure among cultivars to overcome the limited data challenge. The resulting model is now deployed on AgWeatherNet. To handle noisy and incomplete weather data, AgAID researchers have also designed gen-

erative AI models for imputation and forecasting.⁸

Specialty crops such as grapes and cherries require season-long planning, but the delayed effects of actions and sparse, noisy feedback make reinforcement learning (RL) difficult to apply effectively. To address these issues, the AgAID team developed WOFOSTGym,²³ an open source simulation environment based on a well-established crop growth model. WOFOSTGym provides an easy-to-use API for training RL and imitation learning agents across a wide range of annual and perennial crops, including multi-year dynamics and dormant seasons. The simulator can also be tailored to specific farms using calibrated model parameters on crop phenological data.

Labor intelligence. Agricultural labor shortages and their associated costs are often cited as the top concern for labor-intensive U.S. specialty crop farmers, and with uncertainties around labor market coupled with the impacts of frequent extreme weather events, the risks of losing crops are growing significantly.

As a result, the AgAID team is developing various robotics-enabled human-AI workflows to perform a variety of complex crop manipulation tasks (for example, pruning, thinning, harvesting) in tree fruits (for example, apples, cherries) and grapes. As a concrete example, consider the case of dormant season pruning. Despite its importance, no commercially available autonomous pruning systems exist today. The AgAID Institute is addressing this gap by developing AI-driven robotic solutions for enabling more scalable and cost-effective autonomous pruning.³² Some of the salient features include simulated orchard environments to train robotic pruning and enhanced human-AI collaboration through expert interviews for rule extraction. With robotic pruners and blossom thinners, every cut is logged, implying the possibility of a longer-term feedback loop that could be highly valuable for growers in planning their harvest and labor operations down the season.

Water intelligence. Agriculture accounts for approximately 90% of

The Grand Challenges Facing Agricultural Food Production

Land: The fraction of land used in agriculture increased by just over 8% in the past 60 years. This increase is lopsided, with the Global South (Africa, Latin America, and Asia) contributing significantly to the increase, while in the Global North (North America, Europe, Australia, and New Zealand) available land for agricultural use decreased by 16%.⁴

Water: Agriculture accounts for more than 70% of global freshwater use. But in the past 20 years, groundwater wells have been depleted anywhere between 10% and 40% across the globe, and terrestrial water storage has been depleted to below normal levels.^{11,29}

Labor: The world's agricultural labor has reduced by over 20% in the past 20 years, with projections indicating a significantly shrinking supply from rural communities.^{3,26}



consumptive water use in the U.S., and with the continuous depletion of reserves alongside long-term climatic shifts,²⁹ water has become one of the most important agricultural resources to optimize. As an example of the AgAID Institute's work on regional and seasonal scale hydrological modeling, consider a reservoir manager in the U.S. West Coast, making water release and storage decisions for consumptive use in agriculture. To make effective decisions, the manager needs to continuously estimate two variables: 1) the measure of water available in the streams (that is, streamflow forecasting), and 2) the measure of water that will result from snow melt (snow-water equivalent (SWE)). The AgAID team has developed two types of spatiotemporal ML models. The streamflow model⁶ uses a recurrent convolutional graph neural network to model spatial and temporal dependencies, along with a constrained reasoning and learning approach to integrate physical laws as logical constraints. The model has been successfully validated for more than six watersheds in the Western U.S. The SWE model²⁷ uses spatiotemporal attention to extract and exploit spatial and/or temporal correlations, and uses spatial and temporal embedding to incorporate an array of static and dynamic features. This model has been successfully validated for more than 300 locations with snow telemetry (SNOTEL) stations in the Western U.S. for 18 years, and has been extended to provide uncertainty estimates as well as daily and weekly forecasting.

AIFARMS: AI Institute for Future Agricultural Resilience, Management, and Sustainability. AIFARMS was established in 2020 with a broad mission to develop foundational advances in AI and use them to ensure that future agriculture is environmentally friendly, sustainable, affordable, and accessible to diverse farming communities. Agricultural challenges are organized into four research-focused thrusts: autonomous farming, livestock management, environmental resilience, and soil health. The institute has led to significant foundational AI advances in computer vision, autonomous robot navigation,

soft-object manipulation, generative AI reasoning, domain knowledge, learning from heterogeneous data, open world learning, and the efficiency of edge machine learning. To illustrate the potential benefits of AI for row-crop systems, we describe three major outcomes.

Robotics for efficient and effective cover crop planting. Each year across most of the U.S. Midwest, following the harvest of cash crops, soil lies bare from late fall to early spring. Planting cover crops has shown to have many advantages, including preventing topsoil erosion,²⁴ improving nutrient retention,¹⁵ and sequestering atmospheric CO₂.¹⁷

Researchers within AIFARMS and external collaborators, including the startup company EarthSense Inc., are developing new technologies for autonomous cover-crop planting robots and drones. These technologies have vastly improved the robustness of the autonomous vision-based navigation system for small field robots with the CropFollow++ algorithm,²² currently being commercialized by EarthSense. The company has also adapted autonomous under-canopy robots to use multi-camera, machine-vision-based autonomy to inter-seed cover crops in fields. The robots are now being marketed by EarthSense together with drones for commercial-scale cover-crop planting.

Novel and trustworthy generative AI systems for agriculture. The CropWizard project in AIFARMS is investigating and developing ways in which large language models (LLMs) can be used in agriculture to achieve a wide range of novel and impactful outcomes. The CropWizard system^a is an interactive Web-based question-answering system that uses retrieval augmented generation (RAG) to consult more than 650,000 documents in answering agronomic questions. CropWizard supports questions with both images and text, automatically invokes computational functions via LLM-based "tool calling" for data-driven decisions, and can automatically extract data values for tool inputs to simplify usage.

A key research outcome in Crop-

^a <https://uiuc.chat/cropwizard/>

Wizard is the benchmarking of AI-enabled advisory services in agriculture, one of the most promising and fastest-growing use cases for LLMs. The AIFARMS team has developed a rigorous methodology and two different datasets for evaluating multimodal question-answering: AgMMU⁵ for short-form question answering to test factual knowledge, and MIRAGE² for long-form question answering to test interactive decision-support services.

Ensuring the reliability and accuracy of the advice provided to farmers is paramount because errors can have serious consequences for farm incomes, soil health, and the sustainability of family farming operations. To this end, AIFARMS is also leading a new, public benchmarking consortium called AI AgriBench, along with several companies and other groups, including Bayer CropScience, John Deere, Microsoft, and the Extension Foundation. The consortium aims to provide a rigorous and unbiased evaluation service that can strengthen the adoption and trust of the farming community in AI-based advisory and decision services for agriculture.

Autonomous weeding solutions for specialty crops. Specialty crops face serious challenges with weed management and herbicide resistance. Many such crops, such as horseradish and pumpkin, lack the advanced solutions being developed for high-volume commodity crops like corn, wheat, and soybeans. Consequently, specialty crop farmers often rely on labor-intensive manual weeding.

An AIFARMS team is working closely with the farmers to develop a computer-vision-guided robotic weeding solution for horseradish and other specialty crops. The project is using a Farm.ng robot outfitted with cameras to collect extensive images of weeds and horseradish plants in various stages of development and has trained a "you only look once" (YOLO) computer vision model to recognize individual weeds. The team has also experimented with multiple physical mechanisms to destroy the weeds using attachments on the back of the Farm.ng robot, including rakes and hoes.

All components of these solutions—cameras, computer vision



models, and the destruction mechanisms—are modular enough to be mounted on a variety of equipment, including smart implements on the backs of tractors. This innovative project is creating technology solutions that can be licensed by companies for commercialization or spun off as startup ventures to address a wide range of specialty crops.

AIFS: AI Institute for Next Generation Food Systems. AIFS was established in 2020 to address one of the most urgent and complex global challenges: ensuring a sustainable, nutritious, efficient, and safe food supply for a growing population in the face of mounting environmental pressures.²⁵ AIFS leverages advances in AI—both foundational and use-inspired—to drive breakthroughs in research and pave the way for transforming the food system from farm to fork, essentially improving how we plant, grow, process, and consume food products. What sets AIFS apart is its systemic approach that aims to connect the dots across the value chain, with AI being the connective tissue that brings them all together. The AIFS Institute’s academia-led industrial collaborations have created opportunities for students to apply AI to domain-specific challenges such as precision irrigation, nutrient optimization, food safety, and waste valorization.

AI-driven molecular, sensory, and bioactive atlas of food and food by-products. A compelling issue that AIFS tackles is elucidating what is in our food and how that affects our health. In collaboration with USDA Food Data Central, the Periodic Food Table Initiative (PTFI), the Rockefeller Foundation, the American Heart Association, and companies like Mars Inc., AIFS has created resources to predict the flavor, texture, and chemical composition of food. One such project is FoodAtlas, an AI-powered knowledge graph that uses the latest natural language processing techniques to mine 155,000 scientific papers and extract 230,000 food-chemical relationships, nearly half of which were previously undocumented in any database.³³ This massive evidence-backed repository bridges a critical knowledge gap: Whereas

conventional resources cover only a fraction of foods and often lack links to scientific sources, FoodAtlas aggregates all known food composition data with citations to the original literature. The result is a quality-controlled knowledge base that can assist in the design of novel foods, personalized diets, and dietary treatments. Similarly, the by-products database uses an agentic AI framework that maps the mass balance of byproducts and valorization potential of various California crops, such as almonds, pistachios, pomegranates, and tomatoes. Early applications of these resources in applied research include identifying biomarkers for dietary efficacy in irritable bowel syndrome and predicting antibiotic-resistant genes in food-borne pathogens.³⁴

Standardizing agricultural machine learning datasets and benchmarks. In an effort to help the development and evaluation of agricultural ML models, AIFS researchers have developed AgML, a public framework to standardize datasets and benchmarks.^b These have been used in various studies that have combined drone imaging, ML, and biophysical modeling to optimize fertilizer use. For example, a 2025 AIFS study demonstrated how hyperspectral drone imagery and AI models can accurately map nitrogen levels in individual almond trees, avoiding uniform fertilizer application and thus improving sustainability, cost savings, and yields.¹⁶

Accelerating innovation and entrepreneurship. In addition to publications and prototypes, AIFS has catalyzed more than \$60 million in funded projects across its partner institutions, reflecting the institute’s role as a hub for collaborative, high-impact research. AIFS investigators have also shared their expertise in prominent venues, including presentations at the National Academies and testimony before U.S. Senate subcommittees on AI’s role in the food system. These foundational research efforts have led to tangible real-world outcomes in the form of startup companies translating AIFS-affiliated innovations into scalable solutions. Notable affiliated startups include

Scout, an AI-driven vineyard management platform;^c PIPA, an AI in food, nutrition, and health company;^d VinZymes, a UC Davis enzyme-discovery startup addressing smoke taint in wine; and Rivalz Snacks, applying AI-drive extrusion technology to create protein- and nutrient-dense plant-based snacks.^e

AIIRA: AI Institute for Resilient Agriculture. The AIIRA Institute was established in 2021 with the goal of delivering theory, algorithms, and tools (software and hardware) for the principled creation of AI-driven predictive digital twins at the individual plant scale, as well as the plot and field scale. The advances directly apply to climate resiliency, sustainability, and producer profitability,¹⁸ coupled with a social science thrust to maximize stakeholder understanding, trust, and acceptance.

Multimodal AI-ready datasets. A critical challenge in agricultural AI is the scarcity of comprehensive multimodal datasets capable of capturing the complex dynamics of agricultural systems. AIIRA addresses this by creating and validating extensive datasets that integrate multiple data modalities, such as satellite imagery, drone-based sensing, ground sensor measurements, 3D imaging, and structured ecological annotations. AIIRA demonstrated that high-resolution satellite imagery can effectively substitute or augment drone-based and ground-level data collection for large-scale agricultural phenotyping, and consequently for agricultural breeding and production decision support.²¹ By systematically comparing phenotypic trait predictions derived from satellite imagery against drone and ground sensor measurements, AIIRA established the feasibility of scalable and cost-effective AI-enabled phenotyping methods suitable for diverse environments.

In addition to satellite and drone datasets, AIIRA developed AgriField3D,¹³ a dataset comprising high-resolution 3D point clouds of maize plants across diverse genetic backgrounds, captured using ter-

c <https://agscout.ai/>

d <https://pipacorp.com/>

e <https://rivalzsnacks.com/>

b <https://github.com/Project-AgML/AgML>



restrial laser scanning (TLS). This resource supports detailed plant structural analysis, critical for training and validating advanced AI-driven phenotyping and functional-structural plant models (FSPMs). Further enhancing multimodal capabilities, AIIRA curated the BioTrove biodiversity dataset, consisting of more than 160 million images annotated with ecological and phenological metadata.³⁰ These datasets bolster AI model generalizability and facilitate learning paradigms, including zero-shot and few-shot learning.

Democratizing agricultural AI through large foundation models. To democratize advanced AI capabilities in agriculture, AIIRA has trained and deployed large-scale models in vision-language and reasoning domains, notably through initiatives like InsectNet, WeedNet, AgEval, and AGREASON. InsectNet¹ and WeedNet²⁰ exemplify AIIRA's vision of deploying globally scalable AI solutions with high accuracy in real-world agricultural scenarios. InsectNet achieves over 96% accuracy in identifying more than 2,500 insect species by leveraging citizen science data and self-supervised learning, enabling targeted pest-management strategies. WeedNet employs a similar global-to-local model strategy, achieving 97% accuracy in regional weed identification, crucial for timely management and ecological conservation. Both are currently in beta test status, and have found enthusiastic adoption in the U.S. Midwest. Additionally, several global partners are fine-tuning and deploying these global models for region-specific and context-specific applications.

AIIRA further developed AgEval, a comprehensive benchmarking framework for evaluating vision-language models (VLMs) in agricultural contexts, showing that state-of-the-art VLMs could rapidly adapt to specialized agricultural tasks with minimal training data. Complementing this, the AGREASON initiative advances large reasoning models (LRMs) tailored for agriculture, tackling complex decision-making scenarios involving geospatial, climatic, and economic variables.³⁵

Computational design and decision

support tools for resilient crops. A focused moonshot in crop ideotype optimization has been the development of a computational framework combining field-based 3D reconstruction with detailed AI-enabled functional-structural plant modeling (FSPM) for (maize) ideotype design. This framework systematically explores canopy traits to optimize the plant architecture under various planting conditions, weather scenarios, and input availability. An early win has been in identifying non-intuitive, high-performance trait combinations such as vertically stratified leaf angles and radially tiled leaf arrangements. This ability, as well as the ability to explore various what-if scenarios that help mitigate risk, validate the potential of AI-driven breeding strategies for resilient crop production. Additionally, AIIRA's AgGym platform integrates RL with realistic agricultural simulations to predict biotic stress spread and crop yield outcomes under varying management strategies.¹²

AI-LEAF: AI Institute for Land, Economy, Agriculture and Forestry. AI-LEAF, the youngest in the cohort of five AG-AI Institutes, started in June 2023. It focuses on AI for accelerating the adoption of regenerative agriculture, sustainable forestry, and other conservation practices. These practices have been of interest to land stewards (for example, farmers, foresters, companies, policymakers) for a long time. For example, during the 1930s Dust Bowl years, severe dust storms damaged the agriculture and ecology of North American prairies, possibly due to topsoil loss from a multi-year drought and intensive agriculture. This, along with better understanding of ecosystem services, led to greater emphasis on land management and soil conservation, including the development of several conservation practices, some of which have been adopted widely. Land stewards therefore face a key decision: *Which conservation practices should be used where, when, and for how long?* This is difficult due to the trade-offs between short-term and long-term economic and environmental considerations, as well as confounding factors such as cropping, soil condition, climatic zones, and weather. To support these



Federal funding of the AI Institutes program has been the key enabler for its broad range of impacts.





AI for agriculture is in its infancy; the next decade and beyond are likely to be important for driving forward both basic knowledge and practical deployment of AI techniques.

decisions, AI-LEAF is developing novel AI methods and AI-driven models to improve prediction accuracy, providing AI-informed higher-resolution maps to improve data quality, and sharing AI-guided surrogate models and multi-objective Pareto optimization⁷ algorithms to speed up computational response time. However, these novel use cases violate several crucial assumptions underlying traditional AI and computing,³¹ requiring the strengthening of AI for challenges such as out-of-sample prediction while honoring hard constraints (for example, conservation of mass). AI-LEAF is thus advancing AI by incorporating laws of nature to improve prediction out of sample, and by combining learning and reasoning.

AI-driven KGML-Ag models to improve prediction accuracy of carbon cycle. Accurate methods to estimate carbon cycle are needed for developing credible measurement, monitoring, reporting, and verification (MMRV) of agricultural emissions to incentivize the adoption of conservation practices and boost rural economies. However, current decision-support tools²⁸ have limited accuracy in quantifying carbon cycle due to their reliance on process-based models. Purely data-driven ML models also have limited success due to the lack of data about key explanatory state and flux variables, including soil microbes and land-management practices.

To address limitations of the state of the art, AI-LEAF team members developed a knowledge-guided ML framework for agriculture (KGML-Ag) by leveraging process-based models, machine learning, and high-resolution remote-sensing observations.¹⁴ In experiments with a U.S. Corn Belt testbed, KGML-Ag outperformed both conventional, process-based and black-box ML models in quantifying carbon cycle dynamics.¹⁴ Also, KGML-Ag reveals richer spatial detail of soil organic carbon changes than traditional coarse-resolution alternatives. AI-LEAF has outlined a protocol for improving KGML-Ag via various paths, which can be generalized to better predict complex agroforestry and earth-system dynamics.

AI-informed higher-resolution soil moisture maps to improve data qual-

ity. Soil moisture data is critical for many decisions, including scheduling irrigation and fertilization, forecasting drought and forest fires, and conserving water. However, traditional in-situ sensors are sparse, and satellite-derived products have coarse resolution. For example, NASA's soil moisture active passive (SMAP) mission provides a spatial resolution in kilometers, even though soil moisture can vary greatly within a kilometer due to variations in soil-type, terrain, crops, and other factors.

To overcome the limitations of the state of the art, AI-LEAF team members developed DeepSoil,¹⁰ a novel, science-guided framework leveraging the AI framework of knowledge-guided machine learning along with diverse data sources (for example, topography, environmental conditions, in-situ sensors, remote sensing) and soil science models (for example, HydroBlocks and van Genuchten). It also clusters the U.S. into hydrologically similar zones to address the challenge of regional variations. DeepSoil generates high-precision soil moisture content maps at 30-meter resolution, which outperform existing satellite- and physics-based products, reducing soil-moisture errors and improving robustness across years and regions. Within DeepSoil, the regional-clustering-based design significantly outperforms a global-model-based design.

Preparing an AI-Ready Workforce for Agriculture

With a shared vision to transform the agricultural workforce into an AI-ready state, the AG-AI institutes have used a multi-pronged approach by collectively developing and offering numerous training programs and curricula targeted at current- and next-generation agriculture and the agtech workforce. There are some unique traits that distinguish workforce development in the agricultural sector from that in most other sectors. First, the user base for AI tools and technology in agriculture is largely rural, placing emphasis on training programs that need to reach out to both the current workforce and school districts in rural communities. Second, agricultural extension

is an integral component of these institutes, connecting university researchers to industry practitioners and facilitating adoption.

Consequently, the AG-AI Institutes have developed numerous training programs, curricula, and industry outreach programs that target students in K–12, undergraduate, graduate, and postdoctoral levels, as well as farmers, farm workers, crop consultants, district and regional planners, and policymakers. Over the past five years, these programs have reached thousands of K–12 students in rural and urban school districts across at least 20 U.S. states, trained hundreds of undergraduate and graduate students in research and mentored scores of postdoctoral scholars, and run field days and technology-centric events for thousands of industry participants. A few example programs are listed below; full descriptions are available on the individual institute websites:

► *K–12 examples.* At the 2025 Washington State Future Farmers of America (FFA) convention, AgAID piloted the first-of-its-kind “Ag Innovation” FFA Career Development Event for agricultural uses of robotics, drones, computer science, and other technologies, and are now bringing this to a national level. AIFARMS introduced a Digital-Ag-in-a-Box kit and curriculum for K–12 afterschool activities and are developing in-class curricula around it. AIIRA developed gamified educational modules in collaboration with 4-H, and has created specialized minors and stackable certifications in applied AI and cyber-physical systems. AI-LEAF has organized multiple short summer workshops for high school students.

► *Examples in undergraduate training.* AgAID hosted three hackathons at which hundreds of students from four U.S. states competed in computer vision, robotics, and water and soil challenges, all using real-world datasets and questions motivated by industry needs. AIFS has developed a Career Exploration Fellowship program, collectively training 1,500 undergraduates at the food-agtech interface, while AI-LEAF offers minors in digital agriculture.

► *Examples in AI for domain sci-*

tists. AIFS has developed AIBridge, a machine learning boot camp designed to bridge AI with domain sciences—introducing non-computer scientists to AI and data science through Python coding, foundational ML techniques, and emerging topics such as LLMs and diffusion models. AI-LEAF has published code and datasets for KGML-Ag.¹⁴

► *Training the current ag workforce.* AIIRA’s technologies, including InsectNet and WeedNet, were showcased to more than 10,000 farmers and decision makers at the 2024 Farm Progress Show. AgAID, in partnership with extension scientists, has hosted more than six smart orchard field days in Washington state, reaching hundreds of tree fruit and grape growers and farm workers with modules in crop-load management and robotic and sensing technologies. It has also partnered with Semilleros de Ideas, a nonprofit organization, to host technology innovation challenges for farm workers. AI-LEAF’s partner Agronomy e-Learning Academy offers three online courses related to precision agriculture along with a crop professional certificate.

AG-AI Institutes as a Nexus for AI in Agriculture

The institute funding model supported by USDA NIFA for the AG-AI institutes has been a transformative strategic investment, enabling the establishment of a new nationwide coalition of AI experts, agricultural scientists, industry practitioners, and extension experts to join hands in solving some of the most pressing challenges facing food security. Each of these institutes has fostered a new academia-led public-private partnership to ensure the research innovation ecosystem is grounded in practice and ensures translational outcomes. They have also organized new conferences at the intersection of AI and agriculture for expanding this interdisciplinary community, including the 4th Annual Conference on AI in Agriculture and Natural Resources and the Workshop on Agricultural Robotics for a Sustainable Future, now an annual event at the IEEE/RSJ International Conference on Intelli-

gent Robots and Systems (IROS).

All of the AG-AI institutes are part of the AI Institutes Virtual Organization (AIVO)—the national convener, connector, and collaboration enabler for all 29 AI institutes under the NSF-led National AI Research Institutes Program. The key activities by the AG-AI institutes within the framework of AIVO have included (among others): attending the annual Summit for AI Institutes Leadership conferences for all AI institutes, sponsoring travel grants and collaboration-building opportunities, and supporting participation at the annual Ag Outlook Forum and other shared AG-AI institute events.

AI-for-agriculture visioning conference and 10-year roadmap. AI for agriculture is in its infancy; the next decade and beyond are likely to be important for driving forward both basic knowledge and practical deployment of AI techniques. As these institutes have brought together a large number of the leading researchers, both within the U.S. and globally, in this multidisciplinary space, a key potential role for them is to *help identify the priorities* for these future directions.

To meet this goal, in July 2024, the AG-AI institutes jointly organized a community-wide “visioning conference” at the National Academies building in Washington, D.C., aimed at identifying these priorities. Federal funding made this event possible, including funds from both NSF (through AIVO) and USDA NIFA, as well as travel support for institute participants. The conference brought together leading researchers and practitioners across academia, industry, nonprofit groups, farmers, the major public funding agencies, and private foundations. The two-day conference addressed both research directions (day 1) and the implementation priorities (day 2) required to maximize the research and practical outcomes. The research directions were organized into four broad themes: AI for sensing and perception, AI for autonomous farm management, AI for decision making, and AI for crop improvement. These themes encompass (more or less) all the aspects of agriculture in



which AI capabilities are expected to have a significant impact. The day included technical talks to frame the themes and breakout discussions to obtain inputs from conference attendees. The second day included talks and panel discussions on the most important implementation challenges, including AI policy concerns (including labor impacts, data ownership, and AI trustworthiness), environmental and climate policy, expanding the community of participants, and public and private funding priorities.

A writing team from the five AG-AI institutes has drafted a white paper (currently undergoing review) using the information gathered at the conference. The white paper describes a 10-year vision for the important research challenges that must be addressed to maximize the benefits of AI techniques for agriculture, and the policy and funding priorities that will be critical to delivering those benefits to farmers and the agriculture community worldwide. The recommendations in these documents can help shape the investments and research goals of the community in the next few years. Such a visioning process will need to be repeated every few years to update the goals and priorities for the community, especially to keep pace with rapid advances in AI. We invite the computing and agricultural communities to actively participate in charting this roadmap. We also call on the funding agencies to consider a longer-term strategic investment into the AG-AI institutes to ensure that the foundations already established provide a sustainable and scalable path forward for responsible adoption of AI in agriculture.

Acknowledgments

This work is supported by USDA NIFA and the NSF National AI Research Institutes program. The article reports on the work of members of five NIFA supported AI institutes, namely, AgAID (2021-67021-35344), AIFARMS (2020-67021-32799), AIFS (2020-67021-32855), AIIRA (2021-67021-35329), and AI-LEAF (2023-67021-39829). Special thanks to Joe Davidson, Jessica Bell, Jordan Jobe, David Mulla, Kirti Rajagopalan, Ranga Raju Vatsavai,

Joe Davidson, and several others for providing input on this article. The institutes also appreciate the support of the AI Institutes Virtual Organization (AIVO), a national hub connecting all current 29 NSF and USDA AI Institutes. 

References

- Chiranjeevi, S. et al. InsectNet: Real-time identification of insects using an end-to-end machine learning pipeline. *PNAS Nexus* 4, 1 (2025), 575.
- Dongre, V. et al. MIRAGE: A benchmark for multimodal information-seeking and reasoning in agricultural expert-guided conversations. *arXiv:2506.20100 [cs.LG]* (2025).
- Fuglie, K. et al. World agricultural output and productivity growth have slowed. U.S. Department of Agriculture, Economic Research Service (2023); <https://www.ers.usda.gov/amber-waves/2023/december/world-agricultural-output-and-productivity-growth-have-slowed>.
- Gardezi, M. et al. Artificial intelligence in farming: Challenges and opportunities for building trust. *Agronomy* 11, 6, 3 (2024), 1217–1228.
- Gaub, A. et al. AgMMU: A comprehensive agricultural multimodal understanding and reasoning benchmark. *arXiv:2504.10568 [cs.CV]* (2025).
- Gharsallaoui, M.A. et al. Streamflow prediction with uncertainty quantification for water management: A constrained reasoning and learning approach. In *Proceedings of the Intern. Joint Conf. on Artificial Intelligence* (2024), 7269–7277.
- Grimson, M. et al. Scaling up pareto optimization for tree structures with affine transformations: Evaluating hybrid floating solar-hydropower systems in the Amazon. In *Proceedings of the 38th AAAI Conf. on Artificial Intelligence and 36th Conf. on Innovative Applications of Artificial Intelligence and 14th Symp. on Educational Advances in Artificial Intelligence*. AAAI Press (2024), Article 2462; 10.1609/aaai.v38i20.30210.
- Islam, M.R.U. et al. Self-attention-based diffusion model for time-series imputation in partial blackout scenarios. In *Proceedings of the 39th AAAI Conf. on Artificial Intelligence* (2025), 17564–17572.
- Kalyanaraman, A. et al. Special report: The AgAID AI institute for transforming workforce and decision support in agriculture. *Computers and Electronics in Agriculture* 197 (2022), 106944.
- Khandelwal, P. et al. DeepSoil: A science-guided framework for generating high precision soil moisture maps by reconciling measurement profiles across in-situ and remote sensing data. In *Proceedings of the ACM Intern. Conf. on Advances in Geographic Information Systems*. ACM (2024), 233–246.
- Khokhar, T. Chart: Globally, 70% of freshwater is used for agriculture World Bank Blogs (2017); <https://blogs.worldbank.org/en/opendata/chart-globally-70-freshwater-used-agriculture>.
- Khosravi, M. et al. AgGym: An agricultural biotic stress simulation environment for ultra-precision management planning. *arXiv:2409.00735* (2024).
- Kimara, E. et al. AgriField3D: A curated 3D point cloud and procedural model dataset of field-grown maize from a diversity panel. *arXiv:2503.07813* (2025).
- Liu, L. et al. Knowledge-guided machine learning can improve carbon cycle quantification in agroecosystems. *Nature Communications* 15 (2024), 357.
- Nouri, A. et al. When do cover crops reduce nitrate leaching? A global meta-analysis. *Global Change Biology* 28, 15 (Aug. 2022), 4736–4749.
- Oswald, D. et al. 3D radiative transfer modeling of almond canopy for nitrogen estimation by hyperspectral imaging. *Precision Agriculture* 26, 1 (2025), 12.
- Qin, Z. et al. Assessing long-term impacts of cover crops on soil organic carbon in the central U.S. Midwestern agroecosystems. *Global Change Biology* 29 (2023), 2572–2590.
- Sarkar, S. et al. Cyber-agricultural systems for crop breeding and sustainable production. *Trends in Plant Science* 29, 2 (2024), 130–149.
- Saxena, A. et al. Grape cold hardiness prediction via multi-task learning. In *Proceedings of the 37th AAAI Conf. on Artificial Intelligence and 35th Conf. on Innovative Applications of Artificial Intelligence and 13th Symp. on Educational Advances in Artificial Intelligence*. AAAI Press (2023), Article 1796.
- Shen, Y. et al. WeedNet: A foundation model-based global-to-local AI approach for real-time weed species identification and classification. *arXiv:2505.18930* (2025).
- Shrestha, N. et al. Plot-level satellite imagery can substitute for UAVs in assessing maize phenotypes across multistate field trials. *Plants, People, Planet* 7, 4 (2025), 1011–1026.
- Sivakumar, A.N. et al. Demonstrating CropFollow++: Robust under canopy navigation with keypoints. In *Proceedings of Robotics: Science and Systems* (2024); <https://www.roboticsproceedings.org/rss20/p023.pdf>.
- Solow, W. et al. WOFOSTGym: A crop simulator for learning annual and perennial crop management strategies. In *Proceedings of the Reinforcement Learning Conf.* (2025).
- Suomi-Lecker, L. Cover crop and no-till management case study: Hewett Farm. University of Maine Cooperative Extension (2018); <https://extension.umaine.edu/agriculture/soil-health/no-till-and-reduced-tillage/cover-crop-and-no-till-management-case-study-hewett-farm/>.
- Tagkopoulos, I. et al. The AIFS Institute: Building a better food system through AI. *AI Magazine* 45, 1 (2024), 89–93.
- Taylor, J.E. and Charlton, D. *The Farm Labor Problem: A Global Perspective 1st Ed.* Academic Press (2018).
- Thapa, K.K. et al. Attention-based models for snow-water equivalent prediction. In *Proceedings of the 38th AAAI Conf. on Artificial Intelligence* (2024), 22969–22975.
- USDA NRCS and Colorado State University. Estimate your whole farm and ranch carbon sequestration and greenhouse gas emissions using COMET-Farm (2025); <https://comet-farm.com/home>.
- World Meteorological Organization. WMO report highlights growing shortfalls and stress in global water resources (2024); <https://wmo.int/media/news/wmo-report-highlights-growing-shortfalls-and-stress-global-water-resources>.
- Yang, C.H. et al. Biotrove: A large curated image dataset enabling AI for biodiversity. *Advances in Neural Information Processing Systems* 37 (2024), 102101–102120.
- Yang, M. et al. Climate smart computing: A perspective. *Pervasive and Mobile Computing* 108 (2025), 102019.
- You, A. et al. Optical flow-based branch segmentation for complex orchard environments. In *Proceedings of the IEEE/RISJ Intern. Conf. on Intelligent Robots and Systems*. IEEE (2022), 9180–9186.
- Youn, J. et al. FoodAtlas: Automated knowledge extraction of food and chemicals from literature. *Computers in Biology and Medicine* 181 (2024), 109072.
- Youn, J. et al. Knowledge integration and decision support for accelerated discovery of antibiotic resistance genes. *Nature Communications* 13, 1 (2022), 2360.
- Zaremeherjerdi, H. et al. Towards large reasoning models for agriculture. *arXiv preprint arXiv:2505.19259* (2025).

Vikram Adve (vadve@illinois.edu), University of Illinois Urbana-Champaign, AIFARMS Institute, USA.

Steve Brown, University of California, Davis, AIFS Institute, USA.

Alan Fern, Oregon State University, AgAID Institute, USA.

Baskar Ganapathysubramanian, Iowa State University, AIIRA Institute, USA.

Ananth Kalyanaraman, Washington State University, AgAID Institute, USA.

Shashi Shekhar, University of Minnesota, AI-LEAF Institute, USA.

Ilias Tagkopoulos, University of California Davis, AIFS Institute, USA.

Jessica Wedow, University of Illinois Urbana-Champaign, AIFARMSInstitute, USA.

 This work is licensed under a Creative Commons Attribution International 4.0 License.

© 2025 Copyright held by the owner/author(s).