The NAPDC: Stakeholder Input and Strategic Directions

Major Takeaways

- Trust and transparency are essential and achievable. One way these can be cultivated and sustained is by using current and future best practices for security, privacy, and provenance while pursuing a robust communication and engagement strategy.
- Data literacy and technology education play a major role in adoption on two fronts: data literacy for producers helps them understand the impact of their choices regarding data management and access, and technology education will be vital for precision agriculture adoption and for new entrants into the producer space.
- Enabling analytics or predictive analyses of any kind will involve the interoperability of data, which means defining metadata standards of various kinds depending on sector, and developing tools that help identify and apply metadata uniformly.
- User-driven development and interoperability of hardware, software, and data will encourage additional producers and agricultural service providers to engage in framework development and adoption.
- Participation can be incentivized by developing a robust neutral platform that provides a clear value proposition for producers. This involves data tools and cyberinfrastructure that are easy to use, supported, and dovetail with producer needs.
- Future incentives for participation will require additional funding opportunities related to accessibility, productivity, carbon capture, precision management, and sustainability.
- Coalescence of funding opportunities and research activities around common data sharing platforms and tools is essential to avoid unnecessary duplication of effort.

Introduction

In 2021 the United States Department of Agriculture launched a national program called the Open Data Framework (ODF). The ODF program is designed to ‘build a framework needed to create a neutral and secure data repository and cooperative where producers, universities and nonprofit entities can store and share data in ways that will foster agricultural innovation and will support technological progress, production efficiencies, and environmental stewardship’ [1]. A multidisciplinary team of faculty based at the University of Nebraska-Lincoln is leading the ODF through an effort named the National Agricultural Producers Data Cooperative (NAPDC) [2]. The NAPDC has assembled a cross-disciplinary group of participants representing multiple agroecosystems and organizations to explore producer data needs including physical and cyberinfrastructure, education and training, and policy. These needs are being addressed through funding opportunities made available through the NAPDC for pilot projects conducted by partner institutions including land grant institutions and non-profit organizations.

In May 2023 the NAPDC held an inaugural All-Hands Conference at the Nebraska Innovation Campus. The conference featured presentations by national leaders in agricultural data, panel
discussions of stakeholders across agricultural sectors, and reports from ongoing pilot projects. Over 70 individuals from the US and Canada participated in person. Participants engaged in directed visioning exercises designed to elicit strategic directions for neutral framework development. Further information about the conference, including access to recorded presentations, can be found at the NAPDC website [2].

This report provides a summary of the strategic priorities identified at the conference, listed by topic (with brief introductions), and recommendations for the future of the framework.

Critical Use Cases

If a neutral framework existed for sharing of agricultural data such that the strategic priorities addressed herein have been resolved, there are numerous practical problems that could be addressed to enhance producer decision making leading to improved sustainability. As examples, we describe five use cases for sharing on-farm data. Each use case tackles the improvement of one or two significant performance metrics of the agriculture industry.

**UC 1: Can we increase crop yield by investigating outliers?**
The yield reports per acre per year show outliers of significantly over-performing locations while on average the theoretical yield potential is far out of reach for producers. Such locations could give the needed insight into agronomic management of varieties to move average yield closer to the theoretical potential. To obtain such an understanding we need to obtain on-farm data of management practices (e.g. pesticide and fertilizer applications), environmental conditions during the growing season, and the genetic information of the used varieties. Competition metric: Yield per acre

**UC 2: Do models of soil degradation (or soil health improvement) increase efficiency of resource input planning on the farm?**
Increasing yield relies on the timely response to limited resource conditions in the field. Better models are needed to address degrading soils, forecast the next season’s fertilizer needs, and optimize input resources. Such models demand on-farm data input from soil sample analyses and their locations to generate a time series of soil degradation that allows the farmer to economically plan fertilizer and soil amendment needs for the growing season. Competition metric: Fertilizer and pesticide unit of input per unit of production.

**UC 3: Is it possible to use large-scale monocultures as means to understand gene-environment interactions to develop stress resilient crops?**
Agriculture at scales capable of providing global food security with the potential to lower atmospheric CO2 concentrations will rely on established farm logistics for monocultures (e.g., corn, soy, wheat) and monoculture rotations. Foundational to developing novel cultivars is an improved understanding of the gene-environment interaction of crop plants. Production scale plantings of hybrids give us the chance to observe the same genetics across many environments and measure both plant responses and soil carbon. Competition metric: Plant health and vigor indices per field, and soil carbon content per acre

**UC 4: How close can we get to a net-zero beef production?**
Beef production has long been targeted as a main source of greenhouse gas emissions from agriculture globally (primarily methane from enteric fermentation and nitrous oxide from manure deposition on pastures). Beef production as a system includes the grassland where cattle feed
on grass, inputs for cattle finishing, and the transportation of cattle and meat (plus the use of manure in crop production). Each of these elements is associated with its unique opportunities to reduce emissions. Competition metric: Reduced system level carbon emissions per country

**UC 5: Can monitoring of plant & animal health enable more effective intervention strategies for threats to public health?**

On-farm data of the occurrence of plant and animal diseases could protect consumers from sickness and re-establish trust in producers after an outbreak. Such data have the potential to prevent endemic spread and stimulate the development of disease tests and treatments at early stages of occurrence. Competition metric: Minimized production loss per disease occurrence per production sector

The five proposed use-cases are feasible within a 5-year horizon given the technological capabilities available today. While economic benefits for the consumer and producer are obvious, additional research investments are required to incentivize leading academic teams. Many of the proposed use cases are technology intensive and would not fit into the funding ranges of a typical NIFA AFRI proposal. Therefore, a clear road to foster public-private partnerships and increased federal funding is needed.

**Strategic Priorities**

**Advanced cyberinfrastructure**

The promise of advanced cyberinfrastructure (CI) in agriculture is yet to be realized despite the existential need for digital ag solutions to ensure healthy food and fiber to a burgeoning world population [3]. Advances in cyberinfrastructure in the cloud and at the edge and integrated internet of things (IoT) proceed very rapidly, driven by research and development in the larger economy, while much of agricultural research moves at the pace of multi-year decision making in agricultural production (see figure). Typically, agriculture is an adopter of these developments and rarely has the opportunity to influence architectures in software or hardware. In general, the training of professionals in these two areas is very different, with a focus on mathematics, computer science, and engineering on the cyberinfrastructure side and biology, environmental science, agronomy, and farm management on the agricultural sciences (AS) side. To enable agriculture to more quickly adopt and ultimately influence developments in advanced cyberinfrastructure, a re-imagining of the role of ag extension
specialist will be essential. The human in the loop in the figure is, in our view, the key to improvement.

Artificial intelligence (AI) has been looked at as a tool for agricultural improvement and the progress in the field has taken an exponential leap with the advent of ChatGPT by OpenAI, Bard from Google, and many other large language models [3]. Other research has been done on automatic classification of objects in video and images, as well as prediction and planning based on many different data sources. AI model training may require large quantities of both data and compute services (e.g., hardware, software, edge compute, networking) to train the models and run the actual model on the data. In traditional settings, collected and curated data are often sitting next to the computation source and is easily available with little to no restrictions on access to this data when training the model. Once the model has been trained and/or a new algorithm has been developed, the results are published in many of the conference papers associated with this (such as ACM and IEEE) and the researcher will move on to the next project. What will be needed is a way for these models to be trained on decentralized data (not co-located), and then collected in a central location and clearly labeled and classified, with a description of the training data and how data were accessed, allowing the results to be evaluated and, if appropriate, easily shared and used by farmers. This begs the question of how to educate, encourage, and enable producers to share data, i.e., recognize the value in making this investment.

Design, implementation, deployment, and evaluation of advanced CI solutions tailored to ag applications require a more holistic consideration of the involvement of stakeholders, including industry partners, and their interplays. It is challenging for CI engineers to develop and maintain the technological infrastructure without a deep understanding of farmers’ requirements which could involve gathering and analyzing data about their crops, livestock, soil, weather patterns, and other relevant factors that could impact their practices. It is also challenging for farmers to understand and leverage the advanced CI platforms to effectively monitor their fields and make data-driven decisions about crop or livestock management. We propose to enhance existing extension resources to bridge the gaps among the technological innovation enabled by CI engineers, available tools from the public and private sectors, and the agriculture practices posed by producers. Extension services would provide training on how to use the platform and advice on best practices while collecting and providing the feedback of farmers back to the CI development, thereby closing the loop. In addition, the new form of extension could enable a more sustainable pipeline to develop the next generation of workforce in both the CI and agriculture sectors.

Data analytics and tools

The advent and acceleration of the digital age have dramatically reshaped the landscape of public and private sector operations, prompting an urgent need for tools that can navigate this new frontier. Traditional decision support tools, while useful, are often developed with technology as the primary driver, leaving users to adjust their needs and processes to fit the technology. Herein we propose a user-centric development approach that begins with the needs and values of the user, tailoring the technology to serve them effectively and efficiently.
The framework encourages the development of tailored solutions for each enterprise and promotes the following four characteristics. First, there must be a focus on *co-design and co-development*. By involving end users in the design and development process, a richer understanding of their needs and pain points can be obtained, leading to the creation of tools that are more accurately tailored to their requirements. This not only fosters a more knowledgeable user interaction but also enhances the quality and relevance of the tools developed. Second, an *understanding of user values* is essential. User values can range from the need for efficiency and speed to a desire for transparency and control. By clearly defining these values, developers can align the features and capabilities of the tools with what users truly value, leading to greater user satisfaction and tool adoption. Third, producers require *intuitive and dynamic user interfaces*. Technological tools should not be a burden for users to navigate. The tools developed need to be intuitive, simple, and quick to use, requiring minimal training and learning curves for end users. Moreover, the analytics provided by these tools should be dynamic and adaptable, capable of catering to individual and multiple users in a variety of changing conditions. Finally, tools should be built on a *modular architecture* so individual components or modules can be modified, replaced, or upgraded without affecting other parts of the system. This not only ensures the longevity of the tools but also enables them to adapt to new uses of data as they emerge, keeping them relevant and effective in the face of changing circumstances and requirements.

As a longer-term goal, the framework can be applied to the development of a wide range of decision support tools, each serving specific needs and use-cases. These include tools capable of *monitoring and analyzing real-time data*. For instance, tools can track real-time human behavior data intersecting with commodities, enabling immediate understanding of market trends. Moreover, tools that provide geographically referenced product accessibility information and crowd-sourced real-time pricing data on differentiated products can support strategic decision-making processes. There is a need for *free-form data collection tools* as not all valuable data comes in structured forms. Much of the information shared by users, whether through feedback forms, emails, or social media, is in free-form text. Tools capable of collecting, indexing, and analyzing free-form data can unlock a wealth of insights that would otherwise remain hidden. *Random capture of information* can be a powerful tool for quality monitoring, determining standards and identifying trends. By periodically capturing random samples of data, these tools can assist quality control while providing a clearer picture of processes and emerging trends. Finally, production data are scattered across various stages, locations, and processes. For instance, in the beef industry, relevant data spans from birth to the retail market. Similarly, in the agricultural sector, data related to weather, soil conditions, and production history are typically stored in separate systems. Tools capable of *integrating this disparate data* can facilitate risk management and strategic planning.

By embracing this user-centric, use-case oriented, and adaptable approach to technology development, the framework can ensure that the tools developed harness the power of modern technology while genuinely serving the needs and values of the users, leading to greater tool adoption, improved user satisfaction, and ultimately, more effective and efficient operations.
Cybersecurity and access control

Cybersecurity and access control are unfortunate, but inevitable, requirements of the ever connected, digital world we live in. Cybersecurity is a wide-reaching topic that spans many different types of problems and solutions. In the digital age, more and more things are managed and controlled by computers, and every computer is a potential target for malicious actors. In the world of digital agriculture, this includes devices like sensors in the field and GPS enabled tractors, as well as large scale public databases and analytical services. The types of attacks can also vary, ranging from the theft of intellectual property, to attempts to compromise or ransom the functionality of the system, to attacks on human safety involving robotics or personal identifying information. The most common vulnerability in a cybersecurity framework is the people using it [4], pointing to a need for education and training.

Digital security is often a struggle for balance between convenience, cost, and protection. Data sitting on a backup hard drive in a steel safe is inexpensive and well protected, but difficult to access. A corporate email server is convenient to use for those with access and well protected, but too expensive for many institutions to achieve on their own. These illustrate that the level of cybersecurity needed for any use case will be drastically different depending on the priorities of these three factors.

When looking at general cybersecurity in the digital agriculture space, these factors need to be considered. The protection must match the threat, the costs should not be biased against smaller operations, and the systems must be convenient enough to use so that they are actually used, promoting good data sharing practices.

Access control is a major subset of the cybersecurity umbrella. As the term suggests, it covers everything to do with the control of access to data, hardware, and software. Access control covers several sub-topics: layers of access, granting access to specific actors (people or software), usage auditing, and access policy. A layered system allows for more flexible accessibility options. One dimension of access control is the types of data different users are allowed to see, generally characterized by “roles” or “permissions”, while another dimension deals with data ownership, generally characterized by “user groups”. Although data access is the prime example, these concepts can be applied to software tools and hardware as well. A system of layered access control gives a lot of flexibility on who is allowed to access which types of data or tools. In the context of digital agriculture, it is often stated that farmers own their data and have a right to decide who has access to it and who doesn’t. Yet ownership can be a complex issue. Who owns the data on a field rented by a farmer generated during an operation by a custom operator? Absent any agreement up-front, each party has a reasonable claim on at least part of the data. However, the custom operator gets final say in this situation since they control access to the data.

When allowing access to data, it is critical that the farmer trusts the community and tools they are sharing with. Allowing access is relatively easy but revoking that access once it is given can be hard or impossible. The cake batter analogy is relevant when dealing with some of the common computational models: once you add an ingredient to the batter, you can’t take it back.
out. Data used to build a computational model can’t be easily removed without throwing out the whole model.

User tracking and system auditing are important for keeping track of who did what to the system and when they did it. Generally, no one is monitoring these things live, but if a noteworthy event occurs, it is important to have some record of it. The “noteworthy event” could be a good thing; for example, if a particular data set is being accessed a lot more than others, that could be an indicator of high quality, useful data. However, user tracking often allows for the documentation of system error and misuse. Policy defines the rules of accessibility (who and how) and what happens if you break those rules. An important point is to make sure the security policies are as fair and unbiased as possible. This includes unobtrusive user tracking to make sure policies can be enforced.

Structure for framework governance

Data governance is a framework of policies, procedures, and controls to ensure the availability, usability, integrity, and security of data throughout its lifecycle. In the context of grower/producer generated data, the challenge is to identify which organization should spearhead data governance, owing to the highly diffuse nature of the grower/producer landscape; limited incentives for participation in data sharing; and low trust across the agri-food sector and agricultural data ecosystem. Postponement of the development of a data governance framework incurs substantial risks as there is likely to be confusion and inconsistency in how data are managed. Moreover, the absence of clear roles and responsibilities may impede effective collaboration among stakeholders. And without a transparent approach to data governance, trust may erode, hindering data utilization.

Farmers and ranchers need a competitive environment for data services, meaning choices. Some level of the mistrust and concern expressed by producers is their sense of getting cornered to how and where the data being collected is archived and only available for use by corporations. The pool of options is shrinking.

Both trust and encouraging grower participation in USDA federal programs through data use were identified as common themes to building a framework of data governance. Other aspects identified were tiered data access; transparency regarding data usage; protecting the agricultural producer; and utilizing data to improve programs and facilitate research. Further exploration and stakeholder input is needed to define the structure of any governing body and the role of government/USDA. It is recommended that the NAPDC assemble a Data Governance Team to develop a data governance system that will support the development of the NAPDC ecosystem and ensure comprehensive and well-informed decision-making processes.

Trust was identified as a foundational value and a primary driver for the development and implementation of a successful data governance framework. Components of trust included: building relationships, establishing clear roles, benchmarking, ensuring equitable sharing of benefits, implementing a code of conduct, defining data users and uses, and building trust.
through face-to-face interactions. The development of a data governance framework should carefully consider existing pain points and incentives for ag producers to encourage their participation. Another important consideration is how to measure trust and how to determine whether trust has been achieved. Embracing openness and agility through continuous engagement with stakeholders, including industry, and a willingness to adapt the data governance approach in response to technological advancements is critical.

Incentivizing adoption of the framework means empowering growers. This raises the question of how to engage stakeholders from across the community in an oversight function. To achieve broad adoption, the following ideas were generated: generating sufficient USDA buy-in, investments in the data system, educating growers, universal accessibility, a digital interface for program enrollment, and the need for a flexible system that can adapt to changes in technology. Any system designed by or on behalf of USDA needs to be efficient and simple to use, in order to attract and retain farmers and growers. By proactively incorporating mechanisms to address common concerns like privacy, cybersecurity, data rights, etc., the cooperative can build trust and promote a secure and ethical approach to data governance.

Data stewardship

Introduction

Data stewardship is a critical aspect of data management that involves ensuring the integrity, quality, and usability of data over its entire lifecycle. It encompasses several interrelated activities including but not limited to data curation, metadata management, data integration, and preservation. An emerging set of principles for data stewardship activities are the FAIR (Findable, Accessible, Interoperable, Reusable) and CARE (Collective Benefit, Authority to Control, Responsibility, and Ethics) principles [5]. These principles are crucial for fairness and equity and to ensure ethical long-term data availability and access while considering data provenance and intellectual property rights. Below we mention three specific subtopics related to data stewardship: (1) metadata, (2) interfaces and tools/wizards for visualization, and (3) integration of data, and sunsetting and deaccessioning.

Metadata

Metadata is an essential aspect of data stewardship that involves creating, managing, and maintaining descriptive information about data. Metadata provides a comprehensive understanding of the data, including its origin, structure, content, and context. Versioning enables tracking of changes made to metadata over time, while provenance provides information about the origin and history of the metadata. Reliability measures for data and metadata help to establish trustworthiness by providing quality metrics and performance indicators.

Harmonization across metadata is another essential component of metadata management, which ensures that metadata conforms to established standards and guidelines. This requires programmatic access to controlled vocabularies and ontologies. The NAPDC may involve the manufacturers of machines that automatically produce data and metadata to be involved and willing to accept some shared standards for metadata, or alternatively may involve connectors/
middle layers (e.g., APIs) and personnel that specialize in automated data annotation. Standards for documentation and metadata already exist (e.g., Data Documentation Initiative) and should be adopted wherever appropriate for interoperability and consensus.

While responsible stewardship of data would prevent the ingest of data without a minimum set of metadata, it is possible that irreplaceable and potentially valuable legacy data might be remediated as needed or requested, rather than in advance. We anticipate the development of machine learning tools that could automate the enhancement of metadata and make re-curation of potentially valuable legacy data possible in a less labor-intensive way.

**Interfaces and tools/wizards for integration and visualization of data**
Interfaces and tools/wizards for visualization and integration of data are critical to enable easy access and visualization of data. Simple visualization tools enable users to interact with data and gain insights quickly. Automatic summarization of data provides a summary of the key insights and trends in data, enabling users to gain a quick overview of the dataset.

One of the main challenges for integrating a wide array of data ranging from experimental field studies to farmer enterprise data is the diversity of the data with respect to spatial and temporal attributes, data collection methods, units, accuracy etc. To encourage data collectors to contribute their data, tools and wizards are required that make it relatively easy for seamless integration of the data sets. These tools can also provide added value to data contributors as a form of encouragement. It is envisioned that an AI-based wizard will scan the data upon submission and recommend appropriate data attributes using data vocabulary and ontologies. The data can then be summarized and compared with similar data from prior years or other experiments or fields, while further analysis can link to the application tools to study correlations with weather conditions, inputs, genetics, etc.

**Sunsetting and deaccessioning**
Sunsetting and deaccessioning are crucial aspects of data stewardship that ensure that data remains relevant and useful over time. Processes for sunsetting are essential to ensure that resources are not retained unnecessarily, and plans for where and how data types and their persistent identifiers remain interrelated help to ensure the continued usability and accessibility of data over time even if the repository itself dissolves.

Regardless of the volume of data under stewardship, an important concept is retention. A professional system should have clear markings (annotations, metadata), based on consistent criteria/policy, indicating how long the dataset is to be quickly accessible, and after that, how long the data should be kept in cold storage (less easily accessible, but still archived, e.g. tape) and when it can be finally removed. Ideally, the implementation of these decisions is automatic with a human in the loop (e.g. a platform notifies a curator and/or depositor that a dataset is due for deletion, and an opportunity is provided to override based on justification.) Similarly, should a repository be shut down (for whatever reason) the data in it almost certainly remain valuable. Therefore, a repository should have a clear succession plan for the data after the platform ceases operations.
Education and Training

As the density of data grows and advanced analytical tools become increasingly available to a wide array of domains and users, the notion of education, both formally and informally, rises in importance. Such educational efforts must focus on current and future users of data including students, faculty, extension personnel, agricultural producers, and members of allied industries. Consequently, educational efforts must be multi-pronged including train-the-trainer approaches, internships, and co-learning opportunities. An immediate temptation might be to develop a curriculum with corresponding courses specifically designed to address data curation and utilization in the classroom for students and via extension for producers. However, such efforts would inherently ignore the need to integrate such learning into existing curricula such that skills related to data collection, curation, and utilization become a routine component of learning across all agricultural domains. Training in this space must be directly tied to existing domain-specific training such that trainees see application to their own needs. Certainly, advanced courses that specialize in such topics are needed, but if the goal is to increase knowledge across a large mass of stakeholders, then integration of these concepts into existing education and training material is required.

Using hands-on practicums or laboratory sessions to provide experience with real agricultural data would aid in student learning. Examples of this in university classrooms exist now but could become more extensive across a broader representation of courses. The same hands-on experiences could be translated to extension settings where data collection, management, and use could be illustrated using producer data. Co-learning opportunities exist in this space given agricultural producers have an opportunity to learn from each other. The power of learning by doing cannot be overlooked—internships whereby students learn from producers of the practicality of data collection and real-time use, and producers learn from a more technology-savvy generation about the use of newer tools, is an exciting opportunity.

Education on cybersecurity practices is essential. Generally speaking, the most common vulnerability to every cybersecurity framework is the people using it. The best place to start is an education program on the security systems in place around a US digital ag system. Why is cybersecurity important? Why are things done a certain way? What bad things can happen if there is an error (or carelessness) in the security? These are things that should be communicated clearly to the farmers, researchers, and other experts using these digital ag tools. This is not a trivial task as it will take experts on security, experts on teaching, and experts in agriculture to come together to build training materials. The training materials need to be relatable, focused on reducing the frustration at the inconvenience security can cause instead of the technical details of how digital encryption works. This education will provide greater understanding to the users about their role in keeping things secure, leading to an overall higher level of security and more trust in the system.

Sustainability

The concept of sustainability must be an initial discussion point, not a concern to raise after a framework has been built. Key to a sustainable effort is creating a framework that has utility to
several end-users such that the perceived (and eventually observed) return on investment merits their support of the data framework. If the framework, and analytical tools it enables, provide enhanced decision-making abilities that impact the day-to-day activities of agricultural producers and allied industries, and fosters innovation by the academic community, then the effort has a chance to become sustainable.

The likelihood of sustainability for the framework can be increased by user ownership and self-governance. Engaging with agricultural producers and pairing participation with governance contributes to perceived value. Intuitively, another key element to sustainability is maintaining trust. This trust relates to how the framework is governed, establishment and enforcement of reasonable data use policies, cybersecurity and access control, and meeting stakeholder expectations.

Conclusion

The reaction of the agricultural producer community to the anticipated arrival of artificial intelligence, automation, and precision management tools is a mixture of excitement, confusion, and mistrust. The excitement is driven by expectations for increased profitability and sustainability of production systems and operations. This is tempered by the mistrust of federal authorities and large corporations based on fear of data misuse, privacy concerns, and lack of benefits from data and cyber-related services. The combination of excitement and mistrust is exacerbated by confusion around what is artificial intelligence; what is the economic argument for adoption of precision tools and services; and how can data and cyber security protect and benefit their operations.

The NAPDC can provide tangible benefits – data-driven insights, ownership, access control - to agricultural producers while contributing to a food secure domestic population by providing a safe and secure neutral platform for data tools and services. Today most growers are not actively engaged in collecting or managing data on their farms. For the framework to be sustainable, growers must be interested in collecting and managing (quality) data or providers of data services must see value in the framework. These require ongoing cooperation with existing organizations (land-grant universities; stakeholder groups; industry partners; federal agencies) and increased investment to support development of the necessary hardware, software, human resources, and user trust.

References

Appendices

Appendix 1. of participants

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<tr>
<td>Tianjing Zhao</td>
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Appendix 2. of current pilot projects/subawards [https://www.agdatacoop.org/convening-awards](https://www.agdatacoop.org/convening-awards)
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