Data Governance Platform for Precision Agriculture: Enhancing Traceability and Sustainability

Eduardo Antonio Speranza[1], Ricardo Yassushi Inamasu[2], Ricardo Sobkaj[3], Isaque Vacari[1], Luciana Alvim Santos Romani[1], João de Mendonça Naime[2], Cláudio Leones Bazzi[3], Sakae Shibusawa[4]

[1] Brazilian Agricultural Research Corporation (Embrapa), Campinas, SP, Brazil.

[2] Brazilian Agricultural Research Corporation (Embrapa), São Carlos, SP, Brazil.

[3] Parana Federal University of Technology – Paraná, Medianeira, PR, Brazil.

[4] Tokyo University of Agriculture and Technology, Tokyo, Japan.

A paper from the Proceedings of the
17th International Conference on Precision Agriculture and 11th Brazilian Congress on Precision and Digital Agriculture
13-15 July 2026
Porto Alegre, Brazil

Abstract.

Precision Agriculture (PA) is one of the enablers of data-driven agriculture. Digital Agriculture (DA) tools are increasingly vital in driving the adoption of PA techniques across small, medium, and large-scale farming operations. These technologies, including the Internet of Things (IoT), sensors, drones, satellite imagery, Artificial Intelligence (AI), and Big Data, work synergistically to capture detailed information on soil conditions, plant health, climate, and machinery performance. This digitization allows farmers to gradually replace uniform, average-based practices with data-driven, geo-referenced decision-making. Advanced algorithms process this data, providing the insights for PA to optimize input application only where and when needed, maximizing efficiency, reducing costs, and ultimately boosting agricultural productivity and sustainability. The use of PA in Brazil has evolved, and there are reports of success on large farms. However, small and medium-sized landholders face significant barriers to the effective adoption of these technologies. Although contemporary machinery is frequently equipped with advanced sensor arrays for data acquisition, two primary bottlenecks limit progress: the deficit in rural connectivity and the lack of interoperability between proprietary data systems. These constraints prevent the seamless integration of heterogeneous data streams into unified, user-friendly platforms. As a result, valuable information remains confined in technical silos, often relegated to stagnant historical records on local hardware rather than being leveraged for real-time, data-driven decision-making. This work explores the hypothesis that while PA generates vast amounts of data, it remains underutilized due to the absence of a framework that harmonizes technological integration with data governance—specifically regarding security, control, and transparency. Platforms such as Wagri – Japan, which employs open APIs (Application Programming Interfaces), point toward a solution that addresses these critical gaps. Furthermore, it represents the missing link for PA to reach a new technological level, enabling systemic access to data while adding value, management, and transparent control over information, thereby empowering farmers. With the aim of creating this solution for PA and DA, a pilot for an Agricultural Data Governance Platform

The authors are solely responsible for the content of this paper, which is not a refereed publication. Citation of this work should state that it is from the Proceedings of the 17th International Conference on Precision Agriculture and 11th Brazilian Congress on Precision and Digital Agriculture. EXAMPLE: Last Name, A. B. & Coauthor, C. D. (2026). Title of paper. In Proceedings of the 17th International Conference on Precision Agriculture and 11th Brazilian Congress on Precision and Digital Agriculture (unpaginated, online). Monticello, IL: International Society of Precision Agriculture and Brazilian Congress on Precision and Digital Agriculture.

was developed to test the potential that such a platform would offer for farmers to interact with, manage, analyze, and share their agricultural data in a secure and traceable manner. The architecture focuses on leveraging APIs to ingest data generated both by agricultural machinery during field operations (e.g.planting, cultivation, harvesting) and by laboratory analyses of soil and plants. Data can be acquired automatically by the pilot APIs when accessing vendor data platforms or manually via farmer file uploads. To ensure these features, certain precautions were taken during development, such as providing functions related to access permissions and observability. A responsive, open-source front-end, with simplified functions for data access and processing by the farmer, completes the platform architecture. The first version was successfully integrated with three other platforms. It is currently being validated with farmers in the state of Parana. Following successful validation, the goal is to propose the establishment of a consortium of interested companies to scale the platform and ensure its continued operation, transforming how agricultural data is used in Brazil.

Keywords.
Decision Support Systems, Cloud Platforms, and Open Data Solutions

Introduction

Humanity is experiencing the consolidation of a hyperconnected society, driven by an unprecedented digital transformation that is reconfiguring industries, economic flows, and social relations. The agricultural sector is not immune to this global metamorphosis. On the contrary, agricultural activity is at a historical inflection point, where designing the future of food, fiber, and bioenergy production obligatorily requires the digitalization of workflows and the dematerialization of data management. In this transition scenario, Precision Agriculture (PA) is consolidating itself as one of the main enablers of Data-Driven Agriculture, acting as a bridge between traditional biophysical management and advanced digital ecosystems (Shamshiri et al., 2024).

Through the synergy of Digital Agriculture (DA) tools—such as the Internet of Things (IoT), embedded sensors, unmanned aerial vehicles (UAVs), satellite imagery, artificial intelligence (AI), and big data infrastructures—PA allows for the capture of spatial and temporal crop variability with extremely high resolution. This continuous flow of raw data regarding soil conditions, plant health, micrometeorology, and mechanized fleet performance holds the theoretical potential to replace uniform, regional-average-based management with surgical, georeferenced, and real-time optimized interventions. The direct consequence sought is the maximization of input efficiency, the reduction of operational costs, and the elevation of productivity and environmental sustainability indices (Khwidzhilli et al., 2026).

However, the realization of this digital future faces a critical paradox in the agricultural ecosystem, especially in technologically avant-garde countries like Brazil. Although contemporary machinery and field sensors generate a massive and unprecedented volume of data, most of this informational wealth is underutilized or simply lost. This stagnation stems from severe structural barriers that limit the full adoption and utilization of PA by small, medium, and even large producers. Among the traditionally cited bottlenecks, such as high capital costs and the scarcity of qualified labor, two technical factors stand out as amplifying forces of these difficulties: the chronic deficit of rural connectivity and, fundamentally, the lack of interoperability between proprietary data systems (Bolfe et al., 2020; Dibbern et al., 2025).

The absence of standardization prevents the continuous and fluid integration of heterogeneous data streams. Valuable geospatial and agronomic information remains confined in vertical technological silos, stored in proprietary systems lacking portability. Even when these data are physically extracted from machines and transferred to farm office computers, the farmer faces codified formats and closed ecosystems that create a strong dependency on manufacturers. This fragmentation precludes a systemic, holistic, and weighted analysis of the field data collected, transforming what should be a strategic decision-making asset into an inert historical record (Wiseman et al., 2019).

Therefore, challenges surrounding data interoperability, portability, reliability, and transparency are positioned at the epicenter of the scientific and commercial debate on PA. Without the producer holding control and the ability to freely connect data from different sources (machines, laboratories, sensors, and weather), the transition to hyperconnected agriculture remains incomplete. Overcoming this scenario requires new architectural arrangements that enable open data-sharing ecosystems—a concept already explored globally by data governance initiatives and agricultural Data Spaces. Grounded in these initiatives, this work proposes a decentralized framework designed to grant farmers sovereign control over their data.

Theoretical Framework and Hypothesis

Solving the problem of data fragmentation in the field requires a paradigm shift: the transition from isolated data collection to the consolidation of Agricultural Data Science, or simply Agrodata. In the context of modern Precision Agriculture, Agrodata represents not just the raw volume of bytes generated by operations, but the structured, contextualized, and integrated flow of information originating from actual agronomic practice (Mendes, 2024). Unlike data obtained in controlled experimental plots at research institutes, commercial practice data carries the complexity, scale, and noise of the real world, making it immensely valuable for predictive modeling—provided it is subjected to robust governance.

The central hypothesis of this work is that Precision Agriculture generates an immense and valuable amount of data that remains underutilized not only due to hardware technology limitations but due to the lack of a digital governance structure that ensures interoperability, security, portability, and transparency in the storage and use of this information. From the farmer's perspective, there is legitimate concern regarding data sovereignty, the loss of competitive privacy, and the lack of clarity on how third-party suppliers manipulate their harvest information.

Adding to this, accessing and sharing these information flows face complex legal and operational challenges, as they require strict governance control to ensure full compliance with data protection regulations such as the LGPD (General Data Protection Law in Brazil) and GDPR (General Data Protection Regulation in the European Union). Data identifying the property, the producer, financial performance, or cultivation patterns fall under legal protection, demanding explicit consent mechanisms, usage traceability, and access revocability. Therefore, to unlock the potential of agrodata safely and legally, it is imperative to develop solutions that decentralize technical control and empower the farmer as the definitive owner and legal manager of their digital assets.

Internationally, this gap in governance, regulatory compliance, and integration has begun to be filled through ecosystems based on open Application Programming Interfaces (APIs) and Data Spaces, which provide the exact technical tools to operationalize this strict control:

- WAGRI Platform (Japan): Created under the leadership of the Japanese government and academic-industry consortiums, WAGRI acts as a public agricultural data infrastructure. Through open APIs, it connects weather data, soil maps, machinery data from different brands, and cultivation records, allowing software developers to create modular tools for farmers, ensuring portability and eliminating technological silos via controlled and authorized access keys (Kawamura et al., 2022).
- CEADS / Agricultural Data Spaces (Europe): Aligned with the European Union's data strategy guidelines, the concept championed by initiatives like CEADS focuses on creating a reliable and secure agricultural data ecosystem. The central premise is data sovereignty, ensuring that the farmer decides exactly who, when, and for what purpose their operational and agronomic data will be accessed, utilizing federated architectures and standardized APIs to avoid technological monopolies (Gil et al., 2025).

Inspired by these successful global models, this work explores the technical feasibility and architecture of a pilot agricultural data governance platform adapted to Brazilian reality. It is believed that employing open APIs and rigorous control, privacy, and transparency mechanisms is the missing link to elevate national Precision Agriculture to a new technological level, enabling systemic access to data, adding value to the production chain, and ensuring sovereign and legally secure control in the hands of producers. To demonstrate this, the subsequent section outlines the microservices architecture and API endpoints developed for our pilot implementation.

Materials and Methods

To materialize the concepts of sovereignty, portability, and data governance discussed previously, a pilot of an Agricultural Data Governance Platform was developed. The system's architecture was designed specifically to handle the heterogeneous and fragmented nature of current Precision Agriculture (PA) and Digital Agriculture (DA) ecosystems, acting as an agnostic middleware layer between data-generating sources and end-users (Figure 1).

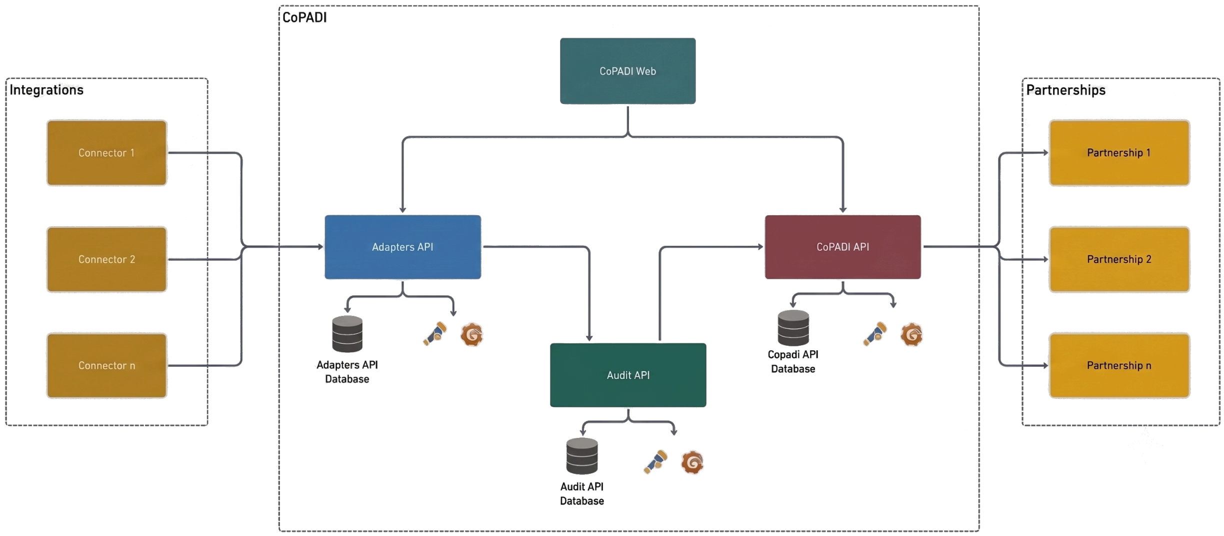

Figure 1. General architecture of the platform under development, highlighting the possibilities for integration with external data sources (Integrations) and with solutions developed by partners (Partnerships).

The backbone of the platform relies on the strategic utilization of open and modular Application Programming Interfaces (APIs), structured to perform the ingestion, standardization, and secure storage of two major information flows crucial for precision management:

- **Operational Data from Agricultural Machinery:** Data streams generated in real-time or asynchronously during essential field operations (planting, spraying, fertilizing, and harvesting). These data include yield maps, applied variable rates, travel speed, and fuel consumption.
- **Agronomic Laboratory Data:** Results from chemical and physical soil analyses, as well as foliar tissue and plant health reports, which are fundamental for calibrating recommendation models and defining management zones.

Considering the connectivity abyss and the varying levels of digital maturity among Brazilian producers, the ingestion architecture was designed with a dual data acquisition modality, granting resilience to the system.

Automated Ingestion via API Connectors

For producers utilizing modern fleets and cloud-based telemetry platforms, specific connectors integrated into the pilot APIs were developed. These connectors perform scheduled searches (polling) directly on the servers of specific machinery and sensor providers. This process occurs entirely automatedly but depends strictly on a prior authentication and authorization flow by the farmer (using advanced security protocols), ensuring that no data is extracted without explicit consent.

Manual Ingestion via File Upload

Recognizing the technical bottleneck where machine data or laboratory reports are isolated on local computers without network communication, the platform incorporates a manual ingestion channel. The farmer or technical consultant can directly upload proprietary data files to the interface. The API's reception subsystem processes these heterogeneous files, extracts georeferenced coordinates and agronomic attributes, and converts them into the platform's standardized structure.

2.3. User Interface (Front-End)

The farmer's interaction with the governance platform is mediated by a responsive, open-source front-end. The interface design prioritized simplified accessibility functions, allowing users without advanced information technology knowledge to view their data inventory, grant or revoke access permissions for consultants or partner platforms, and monitor the processing of their information. By opting for an open-source architecture in the interface and APIs, the solution mitigates the risk of vendor lock-in, ensuring that the academic and developer community can continually audit, extend, and adapt the system.

Results and Discussion

For Agrodata to transcend the function of mere operational records and become reliable strategic assets, the API designed for data reception and processing incorporates a set of critical software engineering and information security features. These attributes ensure that agricultural data generated in field practices become fully auditable, immutable, and consequently capable of substantiating scientific metrics, legal audits, and Environmental, Social, and Governance (ESG) sustainability reports.

The pillars supporting the security and governance infrastructure of the pilot API are structured around eight essential dimensions:

Tab. 1. API governance essential dimensions

API Governance Pillars			
Interoperability	Traceability	Integrity	Authenticity
Security	Privacy	Governance	Availability

During the pilot's development cycle, a series of architectural precautions were taken to ensure the robustness and compliance of these dimensions.

Role-Based Access Control (RBAC) and Encryption

To ensure privacy, security, and governance, the platform implements granular access control. Strict roles were parameterized within the API to guarantee that only users explicitly authorized by the farmer (the original data owner) possess credentials to read or write each collected dataset. The ecosystem protects traffic and storage through end-to-end encryption layers. Once the data is ingested and validated, database control mechanisms prevent its arbitrary modification by third parties, safeguarding the integrity and authenticity of the harvest's historical information.

System Observability Applied to Agrodata

A major differentiator of the pilot is the incorporation of the system observability concept, transposed to the monitoring of agronomic data. Instead of simply recording whether a transaction occurred or failed, the API was designed to expose three fundamental software telemetry vectors:

- **Detailed Logs:** An exact chronological record of all system events, identifying which actions were executed within the data ecosystem.

- **Ingestion Metrics:** Performance indicators and quantitative behavior of real-time data flows (e.g., volume of telemetry records ingested per second, connector latency).
- **Operation Tracing:** The ability to follow the complete journey of a piece of data, from its origin (a specific machine or laboratory report), through the API's transformations and standardizations, to its final consumption by an application.

This observability infrastructure generates a continuous audit trail, allowing for deep analysis of who accessed, when they accessed, and what was done with the producer's data.

Secure Connectors and Availability

Automated acquisition from external providers is governed by specific connectors that utilize modern delegated authorization protocols (such as OAuth 2.0). This allows the pilot API to fetch machine data from manufacturer servers without the farmer needing to share their master passwords, thereby preserving security. Finally, the modular architecture based on microservices ensures high system availability, allowing the ingestion of large data volumes (characteristic of harvest and planting periods) to occur uninterruptedly while maintaining query stability.

The convergence of these technical features grants the platform the status of a highly reliable data environment. By ensuring that the Agrodata lifecycle is transparent and auditable, the API resolves the mistrust that has historically hindered data sharing in Precision Agriculture, paving the way for the ecological and economic validation of production.

Discussion and Application in Sustainability Reports (ESG)

The implementation of the pilot Agricultural Data Governance Platform and its open API-based architecture brings to light profound discussions about the future of Precision Agriculture in Brazil. By mitigating technological silos and solving the challenge of proprietary data portability, the solution not only optimizes conventional agronomic management but also creates the digital infrastructure necessary to validate agricultural production sustainability on a global scale.

Currently, agribusiness faces increasing pressure for transparency and traceability, driven by demands from importing markets, investment funds, and socio-environmental certifications. In this context, the validation of sustainable practices—such as reducing the carbon footprint, increasing efficiency in nitrogen fertilizer use, and promoting soil conservation—intrinsically depends on the reliability of field data.

The significant advantage of an API governed under principles of integrity, authenticity, and observability is the transformation of operational data into auditable evidence:

- **Carbon and Input Metrics:** When a farmer uses Variable Rate Application (VRA) to apply inputs surgically, the data generated by the machine and validated by the API proves the effective reduction of waste.
- **Line of Defense Against Greenwashing:** Because the platform's logs, metrics, and tracing prevent retrospective modification of operational data and lab reports, the information becomes immune to fraud.

In this way, Agrodata ceases to be merely static reports and begins to automatically feed environmental accounting systems and ESG sustainability reports. The producer gains the ability to scientifically and legally prove the ecological efficiency of their crops, adding value to their commodities and accessing green credit lines.

Conclusion

The development of this pilot demonstrates that the next major leap in Precision Agriculture lies not only in creating new isolated sensors or more powerful machines, but in the governance and orchestration capacity of existing data. Inspired by internationally successful ecosystems like

Wagri (Japan) and European Data Space concepts (like CEADS), the proposed architecture proves that it is technically feasible and operationally secure to integrate heterogeneous machine and laboratory data streams within the Brazilian scenario.

The platform fulfills the strategic role of decentralizing technological control. By providing an open-source front-end and APIs that strictly respect producer sovereignty and LGPD guidelines, the system returns definitive ownership of digital assets to the farmer.

For future work, it is recommended to validate the pilot on a commercial scale with a larger number of agricultural machinery brands and to integrate Artificial Intelligence models directly into the middleware layer. Ultimately, the democratization of systemic data access paves the way for a truly connected, transparent, sustainable, and empowered Precision Agriculture.

Acknowledgments

We thank JICA (Japan International Cooperation Agency) for the technical cooperation and funding of the Collaborative Development Project for Precision and Digital Agriculture to Strengthen the Innovation Ecosystem and the Sustainability of Brazilian Agrifood Chains – CoPADi, process 21000.060279/2020-11 (DOU).

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