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Extending GeoNode as a Foundation for Research Data Management Infrastructures in Agricultural Research

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Abstract

Research data management infrastructures for agricultural sciences must handle heterogeneous datasets spanning geospatial layers, tabular records, and model outputs while satisfying the FAIR principles and supporting interactive spatial exploration. Existing research repositories provide robust curation and persistent identifier workflows but lack geospatial visualisation capabilities to address direct interaction of researches and research data on first met. This work presents the extension of GeoNode, an open-source geospatial content management system, into a FAIR-compliant research data repository deployed at the Leibniz Centre for Agricultural Landscape Research (ZALF) to operate the BonaRes Repository. The platform introduces a multi-step publication workflow with DataCite DOI registration, an extended metadata model, non-spatial dataset support. To limit long-term maintenance costs, ingestion, automation, and bibliographic presentation are implemented as independent API-driven components. The full stack is deployed on Kubernetes providing reproducible and horizontally scalable operation. The platform currently hosts about one thousand DOI-registered datasets and is integrated into FairAgro, the German national research data infrastructure for agricultural sciences. All components are released as free and open-source software, providing a transferable reference architecture for institutions seeking to build domain-specific research data infrastructures on open geospatial technology.

1. Introduction

The increasing volume and heterogeneity of digital research data have intensified the need for integrated research data management (RDM) infrastructures that support the full lifecycle of data stewardship across scientific domains. In agricultural and environmental sciences, datasets commonly combine geospatial information, experimental measurements, tabular records, and model outputs, demanding systems that align with the FAIR principles—ensuring data are findable, accessible, interoperable, and reusable. While many research repositories provide strong metadata and archival capabilities, they often lack interactive exploration tools, whereas geospatial platforms, though rich in visualisation features, are typically not designed for comprehensive RDM workflows. This disconnect hinders data reuse, as users cannot assess dataset content, structure, or spatial context without downloading data or using specialised software. To bridge this gap, this work presents the adaptation of GeoNode as a unified RDM infrastructure that integrates robust repository functionalities—such as persistent identifiers, extended metadata models, and structured publication workflows—with advanced web-based visualisation and interactive exploration capabilities. By enabling users to inspect both geospatial and non-geospatial datasets directly in the browser, the platform facilitates early understanding of data context and quality, significantly improving discoverability and reusability. This approach demonstrates how GeoNode can be extended beyond its traditional role to serve as a scalable, FAIR-compliant foundation for managing diverse research data in agricultural and environmental sciences.

The presented platform has been developed at the Leibniz Centre for Agricultural Landscape Research (ZALF) to operate the BonaRes Repository, a research data repository supporting the German agricultural research community. The repository was originally established within the BonaRes research initiative (meaning soil as a sustainable resource) and has since become part of the national research data management initiative FairAgro (FairAgro Consortium, 2024), which aims to build a FAIR-compliant data infrastructure for agricultural research in Germany. The system currently hosts approximately 2,000 datasets and is accessible to researchers across the German agricultural research community.

The objective of this work is to investigate how an open-source geospatial data platform can be adapted and extended to support the requirements of a domain-specific research data management infrastructure. Particular attention is given to the architectural integration of repository workflows, metadata interoperability, data validation mechanisms, and scalable deployment infrastructure. It is hoped that this work provides a practical reference for other institutions seeking to adopt open-source geospatial platforms for domain-specific RDM.

2. Background

Research data management (RDM) has grown in recent years into an important component of the scientific workflow. RDM helps researchers, on the one hand, to structure, find, and reuse data in their day-to-day work, and on the other hand provides services to publish data alongside research publications, which is understood as good scientific practice as it increases reproducibility and transparency in research. RDM is oriented around the FAIR principles, introduced by Wilkinson et al. (2016), which define four properties every dataset and its metadata should satisfy: Findable (unique identifiers, standardised metadata), Accessible (open standardised protocols), Interoperable (formal shared vocabularies enabling machine integration), and Reusable (clear licences and domain-relevant provenance). Uniquely, FAIR targets machine-actionability, not just human readability (Wilkinson et al., 2016). In practice, published

datasets are assigned Digital Object Identifiers (DOIs) via DataCite (DataCite Metadata Working Group, 2021), which registers structured metadata enabling citation and tracking. One key aspect of research data management is data stewardship, which involves the active curation and quality assurance of datasets by dedicated data stewards who review metadata, ensure compliance with standards, and facilitate data reuse while supporting researchers' day-to-day workflows, including data pipelines and data publication.

These kinds of data publications, especially those assigned a DOI, are bound to a publication platform, which is usually a research data repository. Examples include Zenodo (CERN, 2021), Dryad (Dryad, 2021), and institutional repositories. These repositories are designed to support the FAIR principles and are mostly built for specific research communities or domains. As this work describes a repository for agricultural research, the challenges in this domain are pronounced: datasets are unusually heterogeneous, combining remote-sensing rasters, field survey shapefiles, soil sample tables, meteorological time series, and genomic records within a single project. A large-scale survey of German agricultural scientists by Senft et al. (2022) found that roughly 75% were unaware of relevant metadata schemas, fewer than 26% published their data at all, and existing repositories were too fragmented to reliably reach end users. Beyond heterogeneity, most agricultural datasets have an inherent spatial dimension.

Therefore, repository software that supports the FAIR principles, interactive geospatial exploration, and features to handle other arbitrary data types is needed to meet the requirements of agricultural research data management. GeoNode is an open-source geospatial content management system built on Django, GeoServer, PostGIS, and OpenLayers, first developed in 2009 and now an OSGeo project (Corti et al., 2019). It provides a complete, self-hosted platform for publishing, discovering, and visualising geospatial data: users can upload vector and raster datasets, share them as OGC-standard WMS/WFS/WCS services, compose interactive web maps, and manage access through a built-in user and group permission system—all without requiring desktop GIS software. GeoNode is actively maintained, extensively documented, and already deployed in over 25 countries for humanitarian and governmental data sharing (World Bank / GFDRR, 2019). However, standard GeoNode is not a research repository: it lacks DOI minting, multi-stage curation workflows, embargo support, and data steward review processes. Conversely, general-purpose repositories such as Zenodo lack interactive spatial exploration and OGC service publishing. The present work closes this gap by extending GeoNode with the repository features required for FAIR-compliant RDM while preserving its spatial exploration strengths.

3. Related Work

Several domain-specific research data repositories address parts of the RDM challenge in environmental and agricultural sciences, but none fully combines spatial exploration with repository workflows. PANGAEA (Diepenbroek et al., 2002), operated jointly by AWI and MARUM, is one of the largest earth and environmental science repositories with over 430,000 curated datasets, CoreTrustSeal certification, and a map-based bounding-box discovery interface—yet deposit is curated-only and no persistent OGC layer endpoints for direct GIS consumption are provided. OpenAgrar (Haase and Tschöpe, 2019) serves the German federal agricultural research institutes (Thünen, JKI, MRI, BfR) as an open-access publication and dataset archive with DOI support, but offers no spatial search or map viewer. The CGIAR Data Portal (Brandão de Oliveira and Ruben, 2021) aggregates metadata from the 15 CGIAR international agricultural research centres globally, with an open data mandate and DOI assignment, but spatial functionality is fragmented across centre-specific deployments and lacks a unified geospatial layer management layer. In all three cases, spatial data are either absent or reduced to bounding-box metadata—researchers cannot visually explore dataset content before downloading.

GeoNode, by contrast, is already established as a platform for geospatial data sharing across a wide range of institutional contexts. Notable deployments include the UN World Food Programme's humanitarian geospatial platform (World Food Programme, 2024), the World Bank's Open Data for Resilience Initiative active in over 25 countries (World Bank / GFDRR, 2019), the Thünen Atlas for German national agricultural land use data (Johann Heinrich von Thünen Institute, 2024), and the ICRAF Landscape Portal for agroforestry research (World Agroforestry Centre (ICRAF), 2014). These deployments demonstrate GeoNode's maturity as a spatial data infrastructure but were not designed to meet research repository requirements such as DOI minting, structured curation workflows, or domain-specific metadata schemas. To the authors' knowledge, the present work is the first to deploy a DOI-minting, multi-step curation workflow, and domain-schema-compliant research repository on GeoNode at production scale for a specific scientific domain.

4. GeoNode as a Research Data Management Platform

The BonaRes Repository (Lachmuth et al., 2025; Leibniz Centre for Agricultural Landscape Research (ZALF), 2024), hosted and operated by ZALF, is a domain-specific research data repository serving the German agricultural research and international community. Originally established within the BonaRes funding programme—a BMBF initiative focused on soil as a sustainable resource for the bioeconomy—the repository has since grown to host approximately 2,000 datasets, contributed by research groups from across Germany and Europe. All datasets originate from agricultural and soil science projects covering long-term field experiments, soil monitoring networks, and land use studies. The repository is now part of FairAgro (FairAgro Consortium, 2024), the national research data management initiative for agricultural sciences within the NFDI (National Research Data Infrastructure) programme, which aims to build a FAIR-compliant and interoperable data infrastructure for agricultural research in Germany. The current system is in an active transition phase to GeoNode as its primary platform technology, replacing the previous custom-built infrastructure with an extensible, open-source foundation.

The central motivation for adopting GeoNode is its capacity for spatial data exploration—a feature class absent from conventional research repositories. Where standard RDM platforms restrict interaction with geospatial data to metadata display and file download, GeoNode enables researchers to visually inspect layers directly in the browser, compose interactive maps, apply styling and filtering, and publish datasets as OGC-standard web services consumable by GIS clients. Building on this, the ZALF implementation introduces GeoStories—narrative map-based presentations that combine spatial layers with contex-

tual text and media, allowing data providers to communicate the scientific context of their datasets without requiring users to download or process data locally. This exploratory dimension constitutes the platform's primary differentiator from existing agricultural RDM solutions. Producing comparable exploration experiences through custom development would require substantial engineering effort for each individual dataset or collection. GeoNode lowers this barrier significantly: the browser-based map composer, styling tools, and GeoStory editor require no prior GIS or programming knowledge, allowing researchers and data stewards to enrich datasets with spatial context directly in the web interface with minimal time investment. Equally important, the entire platform stack—GeoNode, GeoServer, PostGIS, and all ZALF-developed extensions—is free and open-source software. This not only eliminates vendor lock-in but directly supports European digital sovereignty: research institutions retain full control over their infrastructure, data, and workflows without dependence on proprietary cloud services or commercial licensing. For publicly-funded research infrastructures operating under EU and national open science mandates, this alignment between open-source tooling and institutional autonomy is a decisive advantage.

Conventional research repositories and geospatial data portals have historically developed along separate tracks: repositories prioritise curation workflows, persistent identifiers, and metadata completeness, while geospatial portals prioritise layer publishing, visualisation, and OGC interoperability. Agricultural research data sits at the intersection of both domains—it requires rigorous RDM support and spatial exploration in equal measure. The ZALF GeoNode platform bridges this gap by unifying publication and exploration within a single infrastructure: datasets are submitted through a structured curation workflow, assigned DOIs, described with domain-specific metadata, and simultaneously made available for interactive spatial exploration and OGC service consumption. The following subsections describe the key architectural components and introduced GeoNode features through which this integration is realised.

4.1 GeoNode Extensions for Research Data Workflows

Standard GeoNode provides a solid foundation for geospatial data sharing but does not meet all the requirements of a research repository out of the box. It lacks DOI minting, embargo support, partially multi-step curation states, and domain-specific metadata fields; its user interface is oriented towards GIS professionals rather than domain scientists; and it has no mechanism for managing non-geospatial tabular datasets alongside spatial layers. To address these gaps, the ZALF implementation introduces a substantial set of extensions and modifications to the core platform. Table 1 summarises the primary changes, which span the metadata model, publication workflow, data ingestion, user interface, and infrastructure.

The following subsections describe the most important extensions in detail; a comprehensive changelog and full commit history are available in the ZALF fork repository (ZALF Research Data Management Team, 2024b).

4.1.1 Metadata Models and Interoperability: A central requirement for research data infrastructures is broad metadata interoperability. Standard GeoNode covers basic ISO 19115 spatial metadata fields, but the ZALF fork extends this substantially. The metadata model and editor were enhanced to capture funding bodies and organisational affiliations using Research Organization Registry (RoR) identifiers, related identifiers in multiple schemes (DOI, URL, ARK), data and metadata lineage, per-attribute measurement units and methods, and ordered contact roles compliant with citation standards. Full ISO 19115 and GDI-DE compliance is maintained for interoperability with national spatial data infrastructure catalogues. Additionally, the platform implements the BonaRes Metadata Schema—an extended INSPIRE-oriented schema for soil and agricultural research—and exports metadata in the DataCite format via a pycsw3 integration, enabling automatic indexing in research data discovery portals.

A recurring challenge in multi-layer dataset collections is keeping metadata consistent between a collection-level map record and its constituent layer resources. The ZALF fork addresses this through a dedicated metadata synchronization view: from a GeoNode map's detail page, a data steward can select which metadata fields to propagate to all linked layer resources and preview the diff before committing the changes. The operation is executed through the GeoNode REST API, meaning it requires no direct database access and respects the platform's permission model. This eliminates the manual duplication effort that would otherwise be required to keep provenance, licensing, and attribution fields coherent across dozens of related layers within a single published dataset.

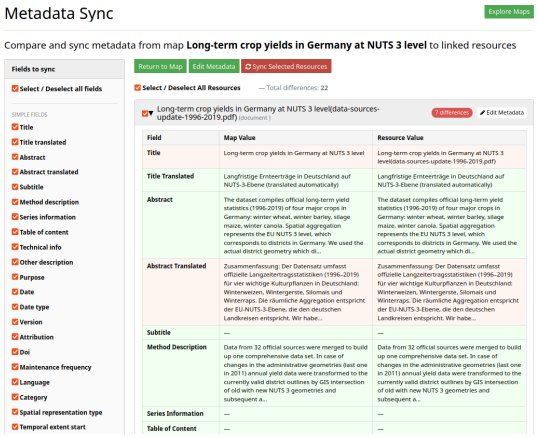

Figure 1. Metadata synchronisation view comparing map-level and linked-layer field values, with selectable field propagation before committing changes.

Research data citations are a prerequisite for academic credit and compliance with institutional open science policies. To make correct citation straightforward for users, a citation panel is integrated directly into the resource detail view of the GeoNode MapStore-based frontend. The panel generates formatted citations on-the-fly from the resource's existing metadata—drawing on the ordered author list, DOI, publication date, and publisher fields already stored in the platform—and presents them in eight widely-used citation styles: APA, Harvard, MLA, Vancouver, Chicago, IEEE, BibTeX, and RIS. A dropdown selector switches between formats, and a copy-to-clipboard button with visual confirmation allows users to embed the citation in manuscripts, data management plans, or reference managers with a single click. Because the citation is derived directly from the repository metadata rather than a separately maintained text field, it remains accurate as metadata is updated, and the inclusion of the DOI ensures the citation resolves persistently even if the URL structure changes.

Category	Description
Metadata	fully extension to iso19115; gdi-de compliant metadata model; implemented bonares metadata schema
Metadata	extended attribute model to capture domain-specific fields (measurement units and methods)
Metadata	view to find differences in metadata and action to synchronize metadata between maps and linked resources
Data Download	capability to download a map, including all layers and resources; download statistics for management reporting
Data Management	extended to support programmatic dataset management; metadata handling; DOI assignment
Data Management	Support for tabular datasets (CSV) with interactive browser-based viewer
Publication Workflow	copyable citation for published datasets in several formats (APA, MLA, Chicago, Bibtex ...)
Publication Workflow	DOI registration and management
User Management	ORCID integration for user profiles and single sign-on

Table 1. Overview of GeoNode extensions and modifications in the ZALF fork (690 commits ahead of upstream 4.4.3)

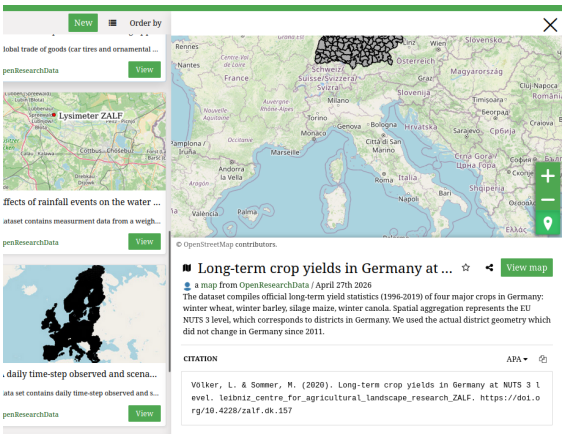

Figure 2. Citation panel in the GeoNode resource detail view, generating formatted citations on-the-fly from stored metadata in eight widely-used bibliographic styles.

4.1.2 Non-Spatial Data Support: Agricultural research datasets frequently include non-geospatial tabular data—crop trial records, soil chemistry measurements, sensor time series—that must be managed alongside spatial layers within a single repository record. Developed in collaboration with the Thünen Institute and the GeoNodeUserGroup-DE (Wallschläger et al., 2025), this extension introduces a Tabular Collection resource type for CSV and structured tabular datasets. Uploaded tables are displayed as interactive, searchable viewers directly in the browser, and multiple related tables can be grouped in a Tabular Collection with a tabbed navigation interface, allowing users to explore related data within a single dataset record without downloading files.

4.1.3 Data Publication Workflow: Datasets enter the repository through the upload tool (ZALF Research Data Management Team, 2024a), which handles local validation and initial metadata entry before submitting to GeoNode via its REST API. Once ingested, data stewards can use GeoNode's built-in GIS tools to enrich automatically uploaded spatial datasets—adjusting layer styles, composing overview maps, and adding contextual annotations.

For final publication, the repository implements an extended workflow: the data steward assembles a GeoNode Map collecting all layers and resources belonging to the dataset, then triggers DOI registration through the DataCite API. The DOI is assigned to the map, propagated to all constituent resources, and the entire collection is set to public simultaneously. This ensures that the persistent identifier resolves to a spatially explorable, browser-accessible representation of the published dataset—not merely a landing page with a file download.

4.2 Component Architecture and Externalization

A practical lesson from extending GeoNode is that deep modifications to the core application increase the long-term maintenance burden: every upstream release must be merged against a growing number of local changes, and the risk of divergence compounds over time. Where possible, it is therefore preferable to keep changes to the core GeoNode codebase minimal and to implement additional functionality as external components that communicate with GeoNode through its public REST API.

The upload tool (ZALF Research Data Management Team, 2024a) and the geonodectl command-line client (GeoNodeUserGroup-DE, 2024b) embody this approach for the data submission side: both operate entirely through the GeoNode REST API, are independently versioned and deployable, and require no modifications to GeoNode internals. An equally important external component is the BonaRes repository portal (Leibniz Centre for Agricultural Landscape Research (ZALF), 2024), a public-facing web application that serves as the primary entry point for researchers. While GeoNode's interface is optimised for spatial exploration, the portal presents repository content in a bibliographic style—full-text search, faceted filters, structured dataset detail pages—more familiar to researchers without a GIS background. It queries the GeoNode REST API for dataset metadata and links directly to the GeoNode instance for map-based exploration and file download. The portal is also open source and available on GitHub. This separation of concerns—a capable GeoNode backend with lightweight, API-driven frontends—keeps each component easier to maintain, test, and evolve independently of the others.

4.2.1 Data Ingestion and Quality Assurance: Supporting efficient data ingestion while ensuring high data quality remains a critical challenge for research data repositories. Researchers submit datasets via the upload tool (ZALF Research Data Management Team, 2024a), which validates data structure and metadata locally before pushing to GeoNode through its REST API. A key enhancement in this workflow is the data steward review process: after upload, a data steward inspects the dataset, may request revisions to metadata or data structure, and only then approves it for public release. This collaborative feedback loop strengthens data governance and ensures adherence to domain-specific standards before a DOI is assigned.

Implementing this workflow required significant extensions to the GeoNode 4.x REST API to support programmatic dataset

management, extended metadata handling, and multi-step publication states (draft, review, public). To further support automation, we developed geonodectl (GeoNodeUserGroup-DE, 2024b), a dedicated Python command-line client for the GeoNode API that provides a structured interface for managing datasets and publication workflows, enabling seamless integration with external tools and automated ingestion pipelines.

4.2.2 Deployment Architecture: Reliable and scalable operation of the research data repository is essential for sustained use in research environments. The entire platform—GeoNode catalogue, GeoServer, the BonaRes portal, and the upload tool—is deployed as a unified Kubernetes application using the geonode-k8s Helm chart (GeoNodeUserGroup-DE, 2024a), a production-ready, open-source deployment solution developed and maintained by the GeoNodeUserGroup-DE. Because the portal and upload tool were designed as API-driven external components (Section 4.2), they translate directly into independently deployable Kubernetes services: each runs in its own pod with its own resource allocation, health checks, and update lifecycle, yet all share the same cluster network and communicate with GeoNode through internal service endpoints. A single Helm *values* file—version-controlled alongside the application code—fully describes the desired state of the entire stack, enabling reproducible deployments across development, staging, and production environments without manual configuration drift.

Scalability is addressed at two levels. At the service level, Kubernetes Horizontal Pod Autoscalers scale GeoNode application workers and Celery task queues independently in response to observed CPU and memory pressure, so ingestion-heavy periods (bulk dataset uploads) and query-heavy periods (public search traffic) can be handled without over-provisioning either workload permanently. At the infrastructure level, the cluster itself can be expanded across additional nodes without any application-level changes—new nodes are automatically incorporated into existing autoscaling groups. This elasticity was benchmarked under concurrent user loads representative of repository traffic peaks, demonstrating stable response times without manual intervention (Wallschläger et al., 2024). The separation of concerns between the catalogue (GeoNode), the public portal, and the submission tool also means that a spike in public read traffic does not affect the ingestion pipeline, and vice versa—each component degrades or scales independently, improving overall resilience.

5. Conclusion

The presented work demonstrates that GeoNode can serve as a foundation for domain-specific research data management infrastructures when complemented by targeted architectural extensions. By combining repository workflows with interactive geospatial exploration capabilities, the platform enables researchers to both publish and explore datasets within a unified environment. This approach supports improved dataset discoverability and practical data reuse, while the architectural patterns and open-source components developed in this project provide a reference for other institutions seeking to implement interoperable research data infrastructures based on free and open-source geospatial technologies.

Several key contributions distinguish this work from prior GeoNode deployments. First, the extension of GeoNode's metadata model to align with the DataCite Metadata Schema and the BonaRes Metadata Profile enables machine-actionable, FAIR-compliant dataset descriptions at the level required by domain-specific research infrastructures. Second, the introduction of the Tabular Collection resource type addresses a structural gap in geospatial platforms: non-spatial tabular research data can now be managed, published, and explored within the same system as spatial layers, removing the need for separate archival tools. Third, the integration of DOI registration, multi-step publication workflows, and GeoStory-based scientific context narration into a single platform removes the friction that typically forces research data to be split across multiple services. Fourth, the deliberate minimisation of upstream GeoNode modifications—achieved by externalising ingestion, automation, and bibliographic presentation into independent API-driven components—reduces long-term maintenance costs and makes the resulting architecture more transferable to other institutions.

Looking ahead, planned work includes a richer DOI versioning model to support dataset updates without invalidating existing persistent identifiers, deeper integration with the FairAgro (FairAgro Consortium, 2024) cross-institutional search infrastructure, and formalisation of the upload tool's validation framework to support community-defined discipline profiles. All components described in this paper are released as free and open-source software, and the community is invited to contribute through the GeoNodeUserGroup-DE and the ZALF fork repository (ZALF Research Data Management Team, 2024b).

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