



GLOMALIN AND ITS FUNCTIONAL SIGNIFICANCE IN SOIL ECOSYSTEMS

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Complex interactions among soil minerals, organic matter, microbial communities, and plant roots are key factors for maintaining the optimum soil health. Arbuscular mycorrhizal fungi (AMF) are very important among the microbial contributors due to their widespread symbiotic association with nearly 80% of terrestrial plant species. AMF enhance the nutrient availability to plants such as phosphorus (P), nitrogen (N), potassium (K), and water, in exchange for carbon derived from plant photosynthates.

During the growth, turnover, and decay of AMF hyphae, a persistent glycoprotein known as glomalin is released into the soil. This material, now operationally defined as glomalin-related soil protein (GRSP), has been recognized as a significant fraction of stable soil organic matter and an important structural binding agent

contributing to soil aggregation, carbon sequestration, and nutrient cycling.

ORIGIN, BIOCHEMICAL CHARACTERISTICS & CLASSIFICATION OF GLOMALIN

Glomalin was first recognized in the early 1990s by Sara F. Wright (USDA-ARS) as a distinct glycoprotein linked with the hyphal surfaces of AMF. The compound is rich in carbon (36–59%) and nitrogen (3–5%), contributing substantially to the soil organic matter pool. Its primary ecological purpose appears to be protection of fungal hyphae, reducing desiccation risk and shielding hyphal membranes from microbial attack. When hyphae senesce, glomalin is released, accumulates in the soil, and interacts with mineral particles to form stable aggregates. Table 1 explains classification of glomalin

Table 1. Operational Classification of Glomalin

Classification	Extraction Method and Functional Significance
Easily extractable glomalin-related soil protein (EE-GRSP)	Soil glomalin fraction extracted by autoclaving soil once at 121°C in 20 mM sodium citrate, pH 7.0 (Wright & Upadhyaya, 1998; Rillig, 2004). Represents recently produced glomalin and ongoing AMF activity.
Total glomalin-related soil protein (T-GRSP)	Soil glomalin fraction extracted by autoclaving soil repeatedly at 121°C in 50 mM sodium citrate, pH 8.0, until the extract appears straw-coloured (Wright &



Upadhyaya, 1998; Rillig, 2004). Also described as a combination of the DE—GRSP* and EE-GRSP** fractions (Wu et al., 2015).

Difficulty extractable glomalin-related soil protein (DE-GRSP)	Soil glomalin extract when the total glomalin extraction protocol is applied after first extracting the easily extractable glomalin from the soil (Wu et al., 2015). Represents older, more stable glomalin.
Immunoreactive soil protein (IRSP)	Glomalin-related soil proteins quantified with monoclonal antibody MAb32B11 using an indirect ELISA (Wright & Upadhyaya, 1998; Rillig, 2004)

*EE-GRSP-Difficultly Extractable Glomalin-Related Soil Protein, **EE-GRSP Easily Extractable Glomalin-Related Soil Protein

ECOLOGICAL ROLES OF GLOMALIN

Soil Aggregation and Structural Stability: Glomalin promotes the formation of stable macroaggregates through disulfide bonds and N-glycosylation that can help bind soil organic matter, micro aggregates, and soil particles, producing a water stable aggregate which in turn improve the soil structure, porosity, aeration, and resistance to erosion (Figure 1).

Carbon Sequestration: Glomalin contributes directly to soil carbon storage and enhances aggregate stability

that reduces the decomposition of encapsulated carbon (Figure 2).

Nitrogen Dynamics and Microbial Activity: Glomalin contains organic nitrogen that is gradually released through microbial decomposition, contributing to soil nitrogen mineralization.

Plant Growth and Stress Tolerance: AMF hyphae effectively function as an extension of the plant root system, supporting nutrient uptake, drought tolerance, and disease resistance.

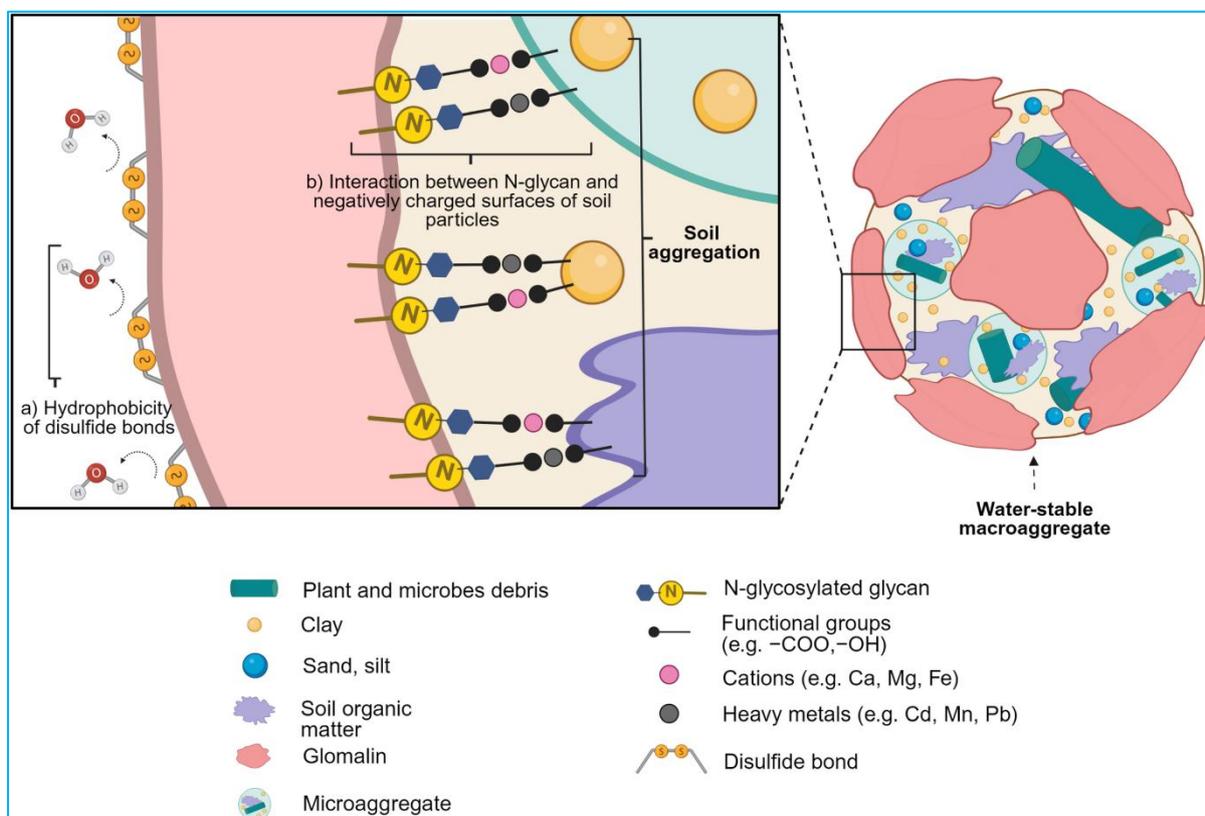


Figure 1. Outline of the formation of a water-stable macro aggregate facilitated by GRSP (Source: Son et al., 2024).

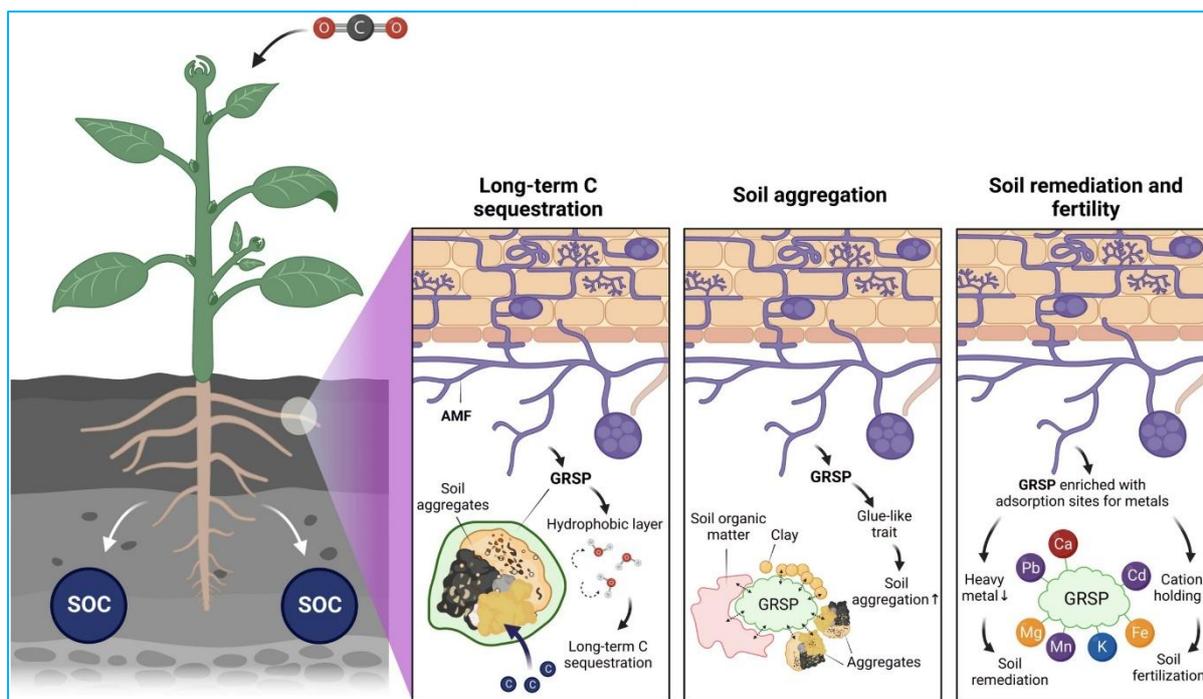


Figure 2. The positive impacts of GRSP on soil ecosystem: long-term carbon (C) sequestration, improved soil aggregation, and improved soil fertility (Source: Son et al., 2024)

IMPACT OF AGRICULTURAL MANAGEMENT PRACTICES ON GLOMALIN

Conservation Agriculture

Conservation agriculture (CA) steadily increases the activity of arbuscular mycorrhizal fungi (AMF) and glomalin-related soil protein (GRSP), enhancing soil aggregation and the C/N cycling. This is especially true in the case of zero/minimum tillage with residue retention and diversified crop rotations.

Long-term CA in rice-wheat systems in India showed more glomalin in both macro- and micro-aggregates under zero tillage with residue retention, compared to conventional tillage with residue burning, along with increased aggregate-associated C and β -glucosidase/ β -galactosidase activity (Dutta et al., 2023). In contrast to farmer practice, CA treatments considerably enhanced AMF colonisation, EE-GRSP, total GRSP, and water-stable aggregates, with strong positive relationships to SOC and microbial biomass, according to field research from southern India.

Long-term studies conducted worldwide show that maintaining stubble and minimising disturbance raise

EE-GRSP which in turn increased N mineralisation, supporting GRSP's function as a soil health indicator under CA (Jha et al., 2022). Concurrent improvements in soil aggregation, glomalin, and enzyme activity compared to conventional tillage are also reported in complementary results from conservation/zero-tillage studies (Singh et al., 2022).

Organic and Regenerative Farming Systems

Organic and natural farming systems typically increase GRSP levels by promoting AMF activity and providing consistent organic inputs. Evidence from India, including an integrated organic farming system trial, has shown significantly higher readily extractable and total glomalin under organic farming than conventional practices, along with broader improvements in soil health (Kumar et al., 2025). Similar findings have been reported from global studies where manures, compost, and straw additions-characteristics of organic/natural systems-consistently raise GRSP fractions in comparison to mineral-only fertilisation, and glomalin tracks gains in soil organic matter and structure.

Results from the Indo-Gangetic Plain support GRSP as a helpful indicator of soil development under organic



management by connecting changes towards increased glomalin fractions and SOC stabilisation with long-term land use and organic inputs. Emerging syntheses also demonstrate that GRSP responds positively to low-input, biologically intense systems, which helps explain observed increases in aggregation and carbon retention under organic/natural farming (Ling et al., 2025).

Integrated Nutrient Management

Integrated nutrient management (INM), which combines organic inputs with mineral fertilisers, reliably increases GRSP, increasing macro-aggregation and improving soil C and N cycles. Long-term fertilisation trials show that compared to the use of mineral fertiliser alone, combining manure with NPK increases GRSP level and chemical stability and is strongly associated with larger mean weight diameter and SOC (Yang et al., 2024).

Higher glomalin levels and better soil biological characteristics under integrated/organic models than under conventional management are also reported in Indian farm systems, suggesting that combining organic inputs with balanced nutrients promotes AMF activity and GRSP development.

Complementary research comparing mineral and organic fertilisation reveals good GRSP connections with nutrient status and humic substances, bolstering INM as a viable option for maintaining soil structure and fertility across contexts.

CONCLUSION

Glomalin is a fundamental biological component of soil organic matter with significant implications for soil structure, carbon stabilization, and nutrient cycling. Agricultural practices that support continuous fungal network development favour greater glomalin accumulation and contribute to enhanced soil health.

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