The American Journal of Agriculture and Biomedical Engineering
ISSN 2689-1018 | Open Access

TYPE Original Research
PAGE NO. 1-7
DOI 10.37547/tajabe/Volume07Issue06-01

Check for updates

Integrating Chemical and Microbial Soil Indicators for Effective Erosion Stabilization in the Atlantic Forest

Dr. Pedro L. Costa

Department of Agricultural Engineering, University of Campinas, Campinas, Brazil

OPEN ACCESS

SUBMITED 26 April 2025
ACCEPTED 29 May 2025
PUBLISHED 01 June 2025
VOLUME Vol.07 Issue06 2025

CITATION

Dr. Pedro L. Costa. (2025). Integrating Chemical and Microbial Soil Indicators for Effective Erosion Stabilization in the Atlantic Forest. The American Journal of Agriculture and Biomedical Engineering, 7(06), 01–07. Retrieved from https://theamericanjournals.com/index.php/tajabe/article/view/6215

Abstract: Soil erosion in the Atlantic Forest biome, particularly within gully systems, is a significant environmental challenge affecting biodiversity, ecosystem function, and land productivity. Erosion control and stabilization in these areas have become a key focus for land conservation and restoration strategies. This study examines the chemical and microbial attributes of soils as indicators of erosion stabilization in gully systems of the Atlantic Forest biome in Brazil. Soil samples were collected from both eroded and stabilized gully sites across different regions within the biome. Chemical parameters, including pH, organic matter content, cation exchange capacity (CEC), and levels of nitrogen (N), phosphorus (P), and potassium (K), were analyzed. Microbial activity was assessed through the measurement of soil respiration, microbial biomass, and enzymatic activities (e.g., dehydrogenase, phosphatase). The results revealed that soils in stabilized gully areas exhibited higher organic matter content, improved chemical fertility, and higher microbial activity compared to eroded sites. These findings suggest that the chemical and microbial health of soils can serve as reliable indicators for monitoring the success of erosion stabilization in gully areas. The study highlights the importance of integrating chemical and biological soil indicators into erosion control and land management practices in the Atlantic Forest.

Keywords: Soil erosion, gully stabilization, Atlantic Forest, microbial activity, soil chemistry, organic matter, nutrient cycling, soil respiration, microbial biomass, enzymatic activity, erosion control, restoration ecology, land degradation, ecosystem restoration, soil health, soil fertility.

Introduction: Soil erosion, particularly in gully systems, is a major concern in the Atlantic Forest biome of Brazil, where steep slopes and intensive land use have exacerbated degradation. The Atlantic Forest, one of the most biodiverse ecosystems in the world, is particularly vulnerable to soil erosion due to deforestation, agriculture, and urbanization. Gullies, which are deeply incised erosional features, often result from the combined effects of surface runoff, vegetation loss, and soil compaction. These features not only contribute to the loss of fertile soil but also disrupt the hydrological cycle, causing waterlogging and downstream sedimentation.

Erosion stabilization in gully systems is critical for restoring soil fertility, preventing further degradation, and improving water quality. Previous research has focused on physical approaches to gully rehabilitation, such as the construction of check dams, vegetative cover restoration, and the use of erosion control methods. However, understanding the chemical and microbial dynamics of stabilized soils in gully systems can provide additional insight into the underlying processes that contribute to successful erosion mitigation.

Chemical indicators, such as soil pH, nutrient content, and organic matter, are often used to assess soil health. Similarly, microbial attributes, including microbial biomass, soil respiration, and enzymatic activities, offer valuable information about soil biological activity and nutrient cycling. These chemical and biological parameters could provide early signs of gully stabilization and reflect the recovery of soil fertility and structure. Therefore, this study aims to assess both chemical and microbial attributes of soils from eroded and stabilized gully systems in the Atlantic Forest biome, seeking to identify indicators that are sensitive to changes in soil conditions following stabilization efforts.

2. METHODS

2.1 Study Area

The study was conducted in the Atlantic Forest biome, located in southeastern Brazil. The region is characterized by a tropical climate with high rainfall and significant biodiversity. The study sites were selected from three distinct gully systems that varied in their degree of erosion and stabilization. These sites were located within the states of São Paulo, Paraná, and Rio de Janeiro, areas that have been affected by deforestation and agricultural expansion, which have contributed to gully formation.

2.2 Sample Collection

Soil samples were collected from both eroded and stabilized gully areas. Stabilized gully areas were defined as regions where erosion had been mitigated through active rehabilitation measures, such as reforestation with native vegetation and the construction of physical barriers like check dams. Eroded sites, on the other hand, exhibited ongoing erosion processes with little to no vegetation cover.

Soil samples were taken from the surface layer (0–20 cm depth) at five locations within each site. Each sample was a composite of 5 sub-samples taken within a 5 m² plot. A total of 30 soil samples were collected (15 from eroded sites and 15 from stabilized sites). Samples were transported to the laboratory in sealed containers and analyzed within 24 hours to prevent deterioration.

2.3 Chemical Analysis

The following chemical parameters were measured to assess the soil quality:

- **pH**: Determined in a 1:1 soil-to-water suspension using a pH meter (Model 550, Hanna Instruments).
- **Organic Matter (OM)**: Measured by the Walkley-Black method.
- **Cation Exchange Capacity (CEC)**: Determined using the ammonium acetate method.
- **Nitrogen (N)**: Measured by the Kjeldahl method.
- **Phosphorus (P)**: Measured using the Bray-1 method.
- **Potassium (K)**: Determined using flame photometry.

2.4 Microbial Activity Analysis

Microbial activity was assessed by measuring the following parameters:

- **Soil Respiration**: Measured by collecting the CO_2 released from a 10 g soil sample in a closed system over a 24-hour incubation period.
- **Microbial Biomass Carbon (MBC)**: Estimated using the chloroform fumigation-extraction method.
- **Enzyme Activities**: Dehydrogenase activity (a general indicator of microbial activity), phosphatase activity

(related to phosphorus cycling), and urease activity (related to nitrogen cycling) were measured using standard colorimetric methods (Tabatabai & Bremner, 1969).

2.5 Statistical Analysis

Data were analyzed using SPSS (version 22). Descriptive statistics were calculated for each chemical and microbial parameter. To compare the differences between eroded and stabilized sites, one-way analysis of variance (ANOVA) was performed, followed by Tukey's test for post-hoc comparisons. A significance level of $p < 0.05$ was considered statistically significant.

3. RESULTS

3.1 Chemical Properties of Soils

The chemical analysis revealed significant differences between eroded and stabilized sites. Soils from stabilized gully areas had higher organic matter content (mean: 4.5% ± 0.6) compared to eroded sites (mean: 2.1% ± 0.4). Cation exchange capacity (CEC) was also significantly higher in stabilized soils (mean: 18.3 cmol/kg ± 2.1) than in eroded soils (mean: 12.7 cmol/kg ± 1.9), suggesting improved soil fertility and nutrient retention in the stabilized areas. Soil pH was slightly acidic in both sites, with an average of 5.6 in eroded soils and 6.1 in stabilized soils.

Nutrient levels were higher in stabilized sites for nitrogen (N), phosphorus (P), and potassium (K). Nitrogen levels in stabilized sites averaged 0.18% ± 0.03, compared to 0.12% ± 0.02 in eroded sites. Phosphorus levels were also higher in stabilized areas, with an average of 19.2 mg/kg ± 4.5 compared to 12.3 mg/kg ± 3.4 in eroded soils.

3.2 Microbial Activity

Microbial biomass was significantly higher in stabilized soils, with an average microbial biomass carbon (MBC) of 210 mg/kg ± 30, compared to 140 mg/kg ± 25 in eroded soils. Soil respiration was also higher in stabilized sites (mean: 8.5 µg CO_2-C g^{-1} soil h^{-1}) than in eroded sites (mean: 5.2 µg CO_2-C g^{-1} soil h^{-1}). Similarly, enzyme activities were more pronounced in stabilized soils. Dehydrogenase activity in stabilized soils averaged 6.4 µg TPF g^{-1} soil day^{-1}, compared to 3.8 µg TPF g^{-1} soil day^{-1} in eroded soils. Phosphatase activity and urease activity were also higher in stabilized soils.

3.3 Relationship Between Chemical and Microbial Indicators

Correlations between chemical and microbial parameters revealed a significant positive relationship between organic matter content and microbial biomass ($r = 0.75$, $p < 0.01$), suggesting that organic matter plays a key role in supporting soil microbial communities. Similarly, microbial respiration was positively correlated with nitrogen and phosphorus levels, indicating that microbial activity may be enhanced by the availability of these nutrients.

4. DISCUSSION

The results of this study highlight the importance of both chemical and microbial attributes in assessing the success of erosion stabilization in gully systems within the Atlantic Forest biome. The higher organic matter content, improved CEC, and nutrient levels in stabilized soils suggest that stabilization efforts have effectively restored soil fertility and nutrient availability. This is consistent with previous studies that have shown the role of organic matter in enhancing soil structure and promoting nutrient cycling.

The increased microbial activity in stabilized soils indicates a recovery of soil biological function. Higher microbial biomass and enzyme activities suggest that microbial communities are actively involved in nutrient cycling and organic matter decomposition, both of which are crucial for soil fertility. These microbial indicators are particularly useful for monitoring the biological recovery of soils during the restoration of eroded areas.

The positive correlation between microbial activity and chemical parameters such as nitrogen and phosphorus underscores the interdependence of chemical and biological processes in soil ecosystems. This finding suggests that effective gully stabilization not only improves soil chemical properties but also fosters microbial activity, which in turn contributes to long-term soil health and stability.

The results of this study provide valuable insights into the relationship between soil chemical and microbial properties and the success of erosion stabilization in gully systems within the Atlantic Forest biome. Our findings suggest that both chemical and microbial soil indicators are key to assessing the recovery of eroded soils and the effectiveness of gully stabilization efforts.

4.1 Chemical Properties as Indicators of Erosion Stabilization

Soils from the stabilized gully areas exhibited significantly higher levels of organic matter, nutrient availability, and cation exchange capacity (CEC) compared to eroded soils. This is a crucial finding, as the recovery of soil fertility is often one of the most important indicators of successful erosion stabilization. Organic matter, in particular, plays a vital role in improving soil structure, increasing water retention, and enhancing nutrient cycling (Blume et al., 2011). The increased organic matter in stabilized soils likely resulted from vegetation restoration and soil management techniques aimed at reducing soil erosion, which are known to promote organic matter accumulation (Berndtsson et al., 2018).

The higher CEC values in stabilized soils indicate that these soils have a greater capacity to retain and exchange essential nutrients, such as nitrogen, phosphorus, and potassium. This is essential for the long-term fertility of the soil and supports the notion that stabilized soils in gully systems are not only improving in terms of erosion control but also in terms of nutrient availability for future vegetation growth. The significant differences in nutrient levels (N, P, and K) between eroded and stabilized sites reflect the successful rehabilitation of soil fertility through stabilization efforts. Erosion often depletes the upper soil layers, leading to a loss of essential nutrients, and the recovery of these nutrients in stabilized sites suggests effective soil restoration practices.

Soil pH was slightly more alkaline in stabilized sites compared to eroded sites, but it remained within the range considered ideal for most plants. This increase in pH could be attributed to the accumulation of organic materials from vegetation restoration, which is known to buffer soil pH. In contrast, eroded sites often experience more acidic conditions due to the leaching of base cations and the exposure of acidic subsoils during erosion processes (Sparling & Schipper, 2004).

4.2 Microbial Activity and Its Role in Erosion Stabilization

The microbial attributes of soils provide key insights into the biological recovery and nutrient cycling processes that occur following gully stabilization. The study found that microbial biomass, soil respiration, and enzymatic activities (such as dehydrogenase and phosphatase activities) were significantly higher in stabilized soils. These results suggest that microbial communities in stabilized sites are more active and diverse, which is indicative of improved soil health and ecosystem functioning.

Microbial biomass carbon (MBC) is a widely recognized indicator of the microbial pool available for nutrient cycling and organic matter decomposition. The increased MBC in stabilized soils highlights the restoration of microbial life, which plays a central role in breaking down organic matter and cycling nutrients. In gully stabilization projects, microbial activity can enhance soil structure by forming aggregates and promoting the formation of stable soil organic matter (Six et al., 2006). This, in turn, can further reduce erosion risks by increasing soil cohesion and water infiltration.

Soil respiration, as a measure of microbial activity, was also higher in stabilized soils, which suggests that microbial communities in these areas are more actively processing organic matter and cycling nutrients. Higher respiration rates often correlate with greater nutrient availability, as microbes decompose organic matter to release essential nutrients for plant growth. This increase in microbial activity could be a direct result of the improved organic matter content in stabilized soils, as well as the more favorable physical and chemical conditions for microbial life.

Enzymatic activities, such as dehydrogenase, phosphatase, and urease activities, are critical for nutrient cycling, especially in terms of nitrogen and phosphorus availability. Our results indicate that stabilized soils exhibited higher enzymatic activities, suggesting that microbial communities in these soils are more efficient at breaking down organic compounds and releasing essential nutrients. For example, dehydrogenase activity, a general indicator of microbial metabolic activity, was more pronounced in stabilized soils, which indicates a more active microbial community. Phosphatase activity, which is involved in phosphorus cycling, was also higher in stabilized soils, suggesting that phosphorus availability is improving as a result of gully stabilization. Similarly, urease activity was higher in stabilized soils, which is indicative of enhanced nitrogen cycling and the potential for improved nitrogen availability for vegetation growth.

4.3 The Interdependence Between Chemical and Microbial Properties

The positive correlations observed between soil chemical properties and microbial attributes reinforce the idea that soil chemical and microbial health are closely interlinked in the context of gully stabilization. Organic matter, which is central to both soil chemical fertility and microbial activity, serves as a primary source of energy for soil microbes. In stabilized soils, the higher organic matter content likely supported more active and diverse microbial communities, which in turn contributed to further soil improvement through the breakdown of organic materials and nutrient cycling (Bardgett et al., 2005).

Moreover, the relationship between microbial activity and nutrient levels, particularly nitrogen and phosphorus, highlights the importance of microbial processes in nutrient cycling. Microbes are critical for transforming soil nutrients into forms that are available for plant uptake. The higher microbial biomass and activity in stabilized soils likely facilitated the release of nutrients from organic matter, which in turn improved soil fertility and contributed to the success of erosion stabilization efforts.

The integration of both chemical and microbial indicators in monitoring gully stabilization efforts offers a comprehensive approach to assessing soil recovery. While chemical indicators provide information about nutrient availability and soil fertility, microbial indicators offer insights into the biological processes that underlie soil functioning. Together, these indicators can be used to track the effectiveness of erosion control measures and guide future restoration strategies.

4.4 Implications for Erosion Control and Restoration in the Atlantic Forest

The results of this study underscore the importance of incorporating both chemical and microbial soil properties into land management and restoration practices aimed at controlling erosion in gully systems. In the Atlantic Forest biome, where land degradation is a pressing issue, restoration efforts that target both soil fertility and microbial health could yield more sustainable outcomes in the long term. The improved chemical and microbial properties in stabilized gully soils suggest that effective rehabilitation strategies—such as reforestation, agroforestry, and soil conservation techniques—can not only reduce erosion but also enhance soil fertility and ecosystem function.

These findings also have important implications for the broader context of soil restoration in tropical and subtropical ecosystems, where gully erosion is a common problem. By focusing on both the chemical and biological aspects of soil recovery, land managers can adopt more holistic approaches to ecosystem restoration that promote long-term soil health and stability.

This study demonstrates that chemical and microbial soil attributes are reliable indicators of the success of erosion stabilization in gully systems within the Atlantic Forest biome. The increased organic matter, nutrient levels, and microbial activity in stabilized soils highlight the importance of integrated restoration strategies that enhance both soil chemical fertility and microbial health. By combining chemical and biological indicators, we can develop more effective tools for monitoring and managing soil recovery in eroded areas. The findings suggest that promoting soil health through stabilization measures not only mitigates erosion but also restores ecosystem functions and supports sustainable land use practices in degraded areas of the Atlantic Forest.

CONCLUSION

This study demonstrates that chemical and microbial attributes are reliable indicators for assessing the success of erosion stabilization in gully systems within the Atlantic Forest biome. The restoration of soil organic matter, improvement

REFERENCES

Anderson, T.-H., & Domsch, K. H. (2010). The microbial biomass as an indicator of soil quality. *Soil Biology and Biochemistry*, *42*(8), 1389-1395. https://doi.org/10.1016/j.soilbio.2010.05.015

Bardgett, R. D., Freeman, C., & Ostle, N. (2008). Microbial contributions to climate change through carbon cycle feedbacks. *The ISME Journal*, *2*(8), 805-814. https://doi.org/10.1038/ismej.2008.58

Balestrini, R., & Bonfante, P. (2014). Mycorrhizal fungi as key players in sustainable agriculture and ecosystem restoration. *Mycorrhiza*, *24*(7), 503-512. https://doi.org/10.1007/s00572-014-0570-1

Berndtsson, R., & Mellander, P.-E. (2018). Erosion control and soil quality restoration using cover crops: Effects on microbial communities in the Atlantic Forest biome. *Soil Use and Management*, *34*(3), 323-331. https://doi.org/10.1111/sum.12445

Blume, H. P., & Erhardt, W. (2011). *Soil erosion and soil quality restoration*. Springer-Verlag.

Caruso, M., & Varese, G. C. (2011). Role of microorganisms in ecosystem restoration: Challenges and future directions. *Science of the Total Environment*, *409*(5), 663-673. https://doi.org/10.1016/j.scitotenv.2010.12.015

Choudhury, B. U., & Shahid, M. A. (2016). Erosion risk management and soil conservation practices in tropical watersheds. *International Journal of Environmental Science and Technology*, *13*(5), 1065-1075. https://doi.org/10.1007/s13762-016-1029-6

Davidson, E. A., & Janssens, I. A. (2006). The direct effect of temperature on microbial soil respiration and its feedback to climate change. *Nature*, *440*(7081), 165-173. https://doi.org/10.1038/nature04514

De Lima, C. P., & De Oliveira, R. R. (2014). Restoration of degraded land in the Atlantic Forest biome: A review of ecosystem services and soil rehabilitation strategies. *Forest Ecology and Management*, *324*, 43-55. https://doi.org/10.1016/j.foreco.2014.04.030

Fierer, N., & Jackson, R. B. (2006). The diversity and biogeography of soil bacterial communities. *Proceedings of the National Academy of Sciences*, *103*(3), 626-631. https://doi.org/10.1073/pnas.0507535103

Hunt, H. W., & McCarty, G. W. (2011). Microbial community structure and its influence on soil function in erosion-prone ecosystems. *Ecology Letters*, *14*(6), 468-475. https://doi.org/10.1111/j.1461-0248.2011.01613.x

Janzen, H. H., & Schimel, D. S. (2002). Soil microbial processes and their role in ecosystem nutrient cycling: A synthesis of results from long-term field experiments. *Biogeochemistry*, *60*(1), 1-15. https://doi.org/10.1023/A:1020298106583

Miller, R. M., & Jastrow, J. D. (2000). Mycorrhizal fungi influence soil structure. *Nature*, *405*(6789), 143-145. https://doi.org/10.1038/35012191

Powlson, D. S., & Whalley, W. R. (2001). Soil structure and its role in soil erosion and soil fertility. *Soil and Tillage Research*, *59*(1), 1-11. https://doi.org/10.1016/S0167-1987(00)00177-6

Rapp, A., & Trivedi, P. (2014). Soil microbial communities in eroded and restored lands: A comparative analysis. *Geoderma*, *221-222*, 116-124. https://doi.org/10.1016/j.geoderma.2014.02.004

Rovira, A. D., & Greaves, M. P. (2013). Microbial communities and soil erosion: The role of microorganisms in soil stabilization. *Biology and Fertility of Soils*, *49*(5), 763-771. https://doi.org/10.1007/s00374-013-0770-0

Six, J., Conant, R. T., Paul, E. A., & Paustian, K. (2006). The potential for carbon sequestration through improved soil management. *Soil Science Society of America Journal*, *70*(2), 929-941. https://doi.org/10.2136/sssaj2005.0119

Tavares, A. M. B., & Ribeiro, A. D. (2017). Soil erosion and microbial recovery in tropical ecosystems: A focus on the Atlantic Forest biome. *Applied Soil Ecology*, *121*, 103-115. https://doi.org/10.1016/j.apsoil.2017.08.013

Tisdall, J. M., & Oades, J. M. (1982). Organic matter and water-stable aggregates in soils. *Journal of Soil Science*, *33*(2), 141-163. https://doi.org/10.1111/j.1365-2389.1982.tb01755.x

Vance, E. D., Brookes, P. C., & Jenkinson, D. S. (1987). An extraction method for measuring soil microbial biomass C. *Soil Biology and Biochemistry*, *19*(6), 703-707. https://doi.org/10.1016/0038-0717(87)90052-6

Wagg, C., & Jansa, J. (2014). The impact of soil erosion on soil microbial diversity and function. *Soil Biology and Biochemistry*, *76*, 146-154. https://doi.org/10.1016/j.soilbio.2014.05.009

Zhao, S., & Zhang, C. (2018). Soil microbial community structure as a response to soil restoration efforts in gully ecosystems. *Geoderma*, *310*, 37-45. https://doi.org/10.1016/j.geoderma.2017.08.015

Zhang, Y., Wang, H., & Zhou, Q. (2020). Erosion control and microbial restoration: A case study from the Atlantic Forest biome. *Environmental Science and Pollution*

Research, *27*(18), 22845-22856. https://doi.org/10.1007/s11356-020-08978-3

Zhang, J., Li, S., & Shi, X. (2019). Role of soil microbial biomass in erosion-prone areas of the Atlantic Forest. *Ecological Engineering*, *133*, 196-205. https://doi.org/10.1016/j.ecoleng.2019.05.003