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# Artificial Soil Formation and it's Impact on Soil Health

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**Abstract**

Soil health is vital for ecosystem services like nutrient cycling, water regulation, plant growth and microbial diversity. Urbanization, agriculture and mining have degraded soils globally, driving interest in artificial soil formation (technosol construction) to restore function. This review highlights materials used natural minerals, industrial by-products, organics and synthetic additives and design strategies such as horizon layering, redox stratification and microbial inoculation. Studies show artificial soils can support vegetation, improve structure, enhance microbial activity and restore nutrient cycling. Applications include ecological restoration, urban greening and farming on degraded lands. However, replicating natural soil complexity, managing contaminants and achieving long-term stability remain challenges. Innovations in modular design, biotechnology and digital monitoring are advancing the field. With standardized, adaptive frameworks, artificial soils offer a promising, scalable tool for land rehabilitation and soil research.

## 1. Introduction

Soil health is vital for sustaining life, as it supports plant growth, regulates water, filters pollutants and maintains biodiversity. In urban and degraded environments, maintaining soil health can be especially challenging due to pollution, poor structure and limited organic matter. As a result, creating artificial soils also known as 'technosols' or 'reconstructed soils' has become an innovative approach to restoring land, improving plant growth and supporting ecological balance (Umarova et al., 2021).

Artificial soils are man-made mixtures of mineral and organic materials, often repurposing industrial by-products like drilling waste, sewage sludge, red mud and phosphogypsum. These engineered soils are designed to act like natural soils by supporting vegetation, recycling nutrients and even cleaning up contaminated land (Kujawska et al., 2018; Liu et al., 2016).

Understanding how microbes and chemical processes function in these soils is key to knowing whether they will work long term. Artificial soils make it possible to study how specific factors like pH,

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minerals or organic matter affect microbial behaviour, nutrient cycling and overall soil development (Valle et al., 2022).

Recent studies have used artificial soils in controlled experiments to explore how soil life responds to different conditions. For instance, researchers have developed artificial rice field soils to study decomposition under low-oxygen conditions and have tested artificial soil on slopes to support vegetation and improve soil recovery (Chen et al., 2016). These examples show how artificial soils can provide important clues about the relationship between soil makeup and microbial performance.

Even though artificial soils are proving useful for research and practical applications, it's still uncertain how closely they mimic the natural soil environment, especially in terms of microbial activity. More long-term studies are needed to answer this question. Still, as pressure on natural soil resources grows due to population increases and environmental change, artificial soils provide a valuable option for restoring degraded land, supporting agriculture and studying the complex functions of soil in a controlled way.

## 2. Materials Used in Artificial Soil Formation

Artificial soil systems are constructed using a variety of materials, each selected for specific structural, chemical or biological properties that replicate or enhance natural soil functions. The choice of material determines the artificial soil's performance in water retention, nutrient cycling, microbial activity and long-term stability.

### *2.1. Natural materials*

Natural mineral components are typically used as base substrates in artificial soil formation, serving as structural scaffolds and sources of essential nutrients. Quartz sand and feldspar contribute to drainage and bulk structure, while kaolinite—a low-swelling clay—enhances the soil's buffering and retention capacity. Clay minerals such as montmorillonite and illite are particularly valued for their high cation exchange capacity (CEC), which supports nutrient retention and facilitates plant uptake (Guenet et al., 2011). These clays also help in maintaining soil plasticity and aggregate stability.

In slope restoration efforts, engineered artificial soils composed of crushed rock fragments, humus, straw and fertilizers are used to replicate the fertility and structure of natural systems. These substrates are designed to support plant establishment by improving water retention, nutrient availability and structural stability, facilitating slope revegetation and ecological recovery but reconstructed soil on railway cut slopes was found to be less fertile, less stable and more erosion prone than natural soils (Chen et al., 2016).

### *2.2. Industrial by-products*

With growing emphasis on waste reutilization and circular economy strategies, industrial by-products have emerged as key ingredients in artificial soils. Drilling waste and treated sewage sludge provide a high organic and nutrient content, making them suitable for fertilization and microbial enrichment (Kujawska et al., 2018). However, careful monitoring is required to mitigate pathogen and heavy metal risks.

Red mud (a by-product of bauxite refining) and phosphogypsum (a waste from phosphate fertilizer production) can be combined to neutralize extreme pH values and supply essential elements such as calcium and sulfur. ( Liu et al., 2016) demonstrated that a 2.5:1 blend of red mud and phosphogypsum not only stabilized pH but also supported vegetation and microbial recovery on barren lands.

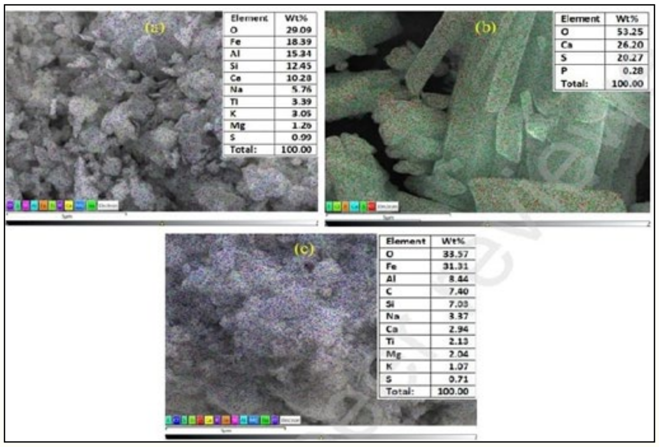


Figure 1: Micromorphology and Elemental Composition of Red Mud, Phosphogypsum and Artificial Soil Based on SEM -EDS Analysis (Liu et al., 2016)

### *2.3. Organic amendments*

Organic matter is vital for soil biotic activity, aggregation and nutrient cycling. Compost and well-decomposed manure introduce labile carbon sources, microbial consortia and a suite of macro- and micronutrients that jump-start biological activity (Bucka et al., 2019). Peat, while effective in increasing water retention and buffering capacity, raises sustainability concerns due to ecosystem disruption during extraction.

Crop residues and straw serve as slow-release carbon inputs and promote the development of microbial niches essential for nutrient mineralization and aggregate formation (Maeda et al., 2020). Their inclusion in artificial soils not only boosts microbial diversity but also increases enzymatic activity critical for organic matter turnover.

### *2.4. Synthetic additives*

Synthetic materials are often added to tailor specific functions in artificial soils. Hydrogels and superabsorbent polymers improve water-holding capacity and reduce irrigation frequency, particularly in arid and urban environments. Biochar derived from the pyrolysis of organic biomass is valued for its porous structure, high surface area and ability to host microbial communities. It also sequesters carbon and improves pH buffering.

Synthetic humic acids mimic natural organic matter and facilitate chelation of micronutrients, improving their availability to plants. These additives provide an engineered approach to enhancing biogeochemical performance and long-term resilience.

## 3. Soil Design Strategies

Artificial soil design must balance physical structure, chemical reactivity and biological functionality. Strategies often involve layering, stratification and biological activation.

### *3.1. Mimicking natural horizons*

To replicate the vertical structure of natural soils, artificial soils are layered into functional horizons. The A-horizon typically includes high organic content and microbial populations conducive to root growth and nutrient cycling. The B-horizon provides mineral storage and moisture retention, while the C-horizon is designed with coarse material for drainage and aeration. This stratification mimics pedogenic processes and supports root architecture and water flow dynamics.

### *3.2. Layering and Stratification*

Soil stratification promotes vertical gradients in redox potential, water content and nutrient availability conditions essential for microbial niche differentiation. Demonstrated that such gradients enable the coexistence of aerobic and anaerobic microbial communities, enhancing the soil's functional diversity. In particular, redox zoning supports processes like nitrification, denitrification and methanogenesis in rice paddy analogs and wetland soils.

### *3.3. Microbial inoculation*

Microbial activity underpins most soil functions from organic matter decomposition to nitrogen cycling. Artificial soils are often inoculated with microbial consortia via compost extracts, cultured microbial strains or slurries of native soils. This accelerates microbial succession and boosts enzyme production (Valle et al., 2022). Maeda et al. (2020) showed that tailored microbial inoculation could reestablish functional soil microbiomes in sterile substrates, aiding in nutrient mobilization and disease suppression.

## 4. Experimental and Field Approaches

Understanding artificial soil behaviour across different spatial and temporal scales requires a combination of laboratory experiments, field trials and modelling.

### *4.1. Soil column experiments*

Soil column studies offer controlled environments to observe water flow, microbial colonization and mineral-organic interactions. These systems are particularly useful in simulating pedogenesis, aggregate formation and redox transitions under constant boundary conditions (Pronk et al., 2016). They also facilitate the study of nutrient leaching and microbial succession.

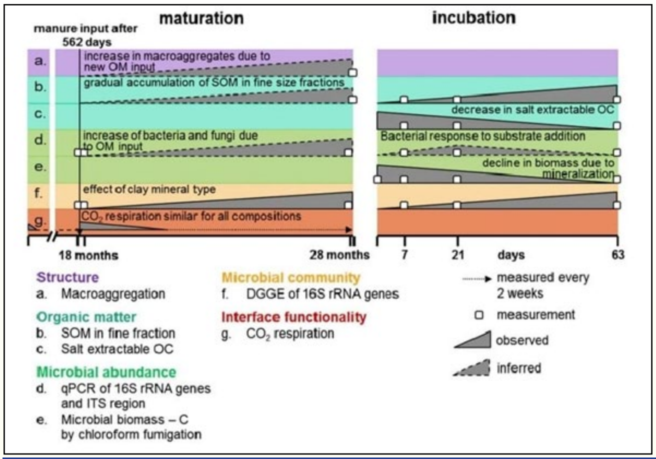


Figure 2: Microbial and Structural Responses During Soil Maturation and Incubation After Organic Matter Input (Pronk et al., 2016)

### *4.2. Field-scale artificial soil plots*

Field applications of artificial soils test real-world performance in ecological restoration, urban greening and land reclamation. Chen et al. (2016) and Umarova et al. (2021) reported that engineered soils improved slope stability, reduced surface erosion and supported rapid vegetation cover. These trials evaluate parameters such as plant growth rate, microbial biomass, infiltration and carbon sequestration.

*4.3. Modelling and simulation*

Simulation tools like HYDRUS (for water and solute transport) and SoilGen (for soil genesis) allow long-term predictions of artificial soil behavior. They model how layering, amendments and climate influence root growth, moisture retention, microbial processes and pollutant movement.

## 5. Physico-Chemical Properties of Artificial Soils

*5.1. Soil texture and structure*

Artificial soils can be engineered to replicate a range of textural classes. Clay content and organic matter influence aggregation and soil strength, directly affecting root penetration and microbial colonization. Bucka et al. (2019) demonstrated that compost-enriched soils improved aggregate stability, reducing erosion and enhancing water infiltration.

*5.2. Water retention and infiltration*

Water retention is a key challenge in sandy or degraded soils. Materials such as hydrogels, peat and biochar are integrated into artificial soils to enhance moisture-holding capacity and slow evaporation (Bhuyan et al., 2023). These properties are vital for plant survival in arid and rooftop settings.

*5.3. Chemical characteristics*

Artificial soils are calibrated for ideal pH ranges and high cation exchange capacity (CEC) to retain nutrients. Amendments may include lime or sulfur to adjust pH and bioavailable forms of NPK to support initial plant growth. When industrial residues are used, heavy metal content must be strictly monitored (Liu et al., 2016) to ensure that levels remain below phytotoxic or ecotoxic thresholds.

## 6. Key Findings from Recent Experiments

- **Biogeochemical Interfaces**: Pronk et al. (2016) highlighted the importance of mineral-organic-microbial interfaces in regulating nutrient cycling and redox transformations in artificial soils.
- **Organic Inputs and Aggregation**: Bucka et al. (2019) reported that compost and straw significantly improved soil aggregation and microbial enzyme activity, promoting soil structural development.
- **Anaerobic Microbial Activity**: Maeda et al. (2020) developed artificial rice field soils to simulate redox gradients, revealing insights into methanogenic pathways and their regulation by microbial community composition.
- **Restoration Soils:** Chen et al. (2016) showed that reconstructed soils on railway cut slopes is poorer in moisture, CEC, organic carbon and stability, with higher pH and erosion risk than natural soils.
- **Microbial Function Isolation**: Valle et al. (2022) created modular artificial soils to isolate how texture and pH influence microbial functions, showing distinct shifts in enzyme activity and microbial composition.

## 7. Applications and Potential

*7.1. Ecological restoration*

Artificial soils offer scalable solutions for restoring ecosystems affected by deforestation, mining or industrial pollution. Liu et al. (2016) demonstrated successful revegetation of barren landscapes using a blend of red mud and phosphogypsum. These materials not only neutralized soil pH but also encouraged microbial colonization and root penetration. The restored soils supported native plant growth, stabilized slopes and improved water retention, highlighting the potential of engineered substrates in ecological renewal.

*7.2. Urban greening*

Artificial soils are increasingly utilized in urban environments where natural soils are limited or significantly degraded. These engineered substrates are specifically designed for applications such as green roofs, urban parks and roadside plantings. By integrating lightweight and nutrient-rich components, artificial soils contribute to improved urban ecosystem services. These include enhanced stormwater retention, ambient temperature regulation and support for urban biodiversity.

*7.3. Agriculture on degraded lands*

By blending drilling sludge with compost and gypsum, researchers created a growing medium with adequate fertility, buffering capacity and microbial activity to support crops. Such systems may be especially valuable in regions experiencing desertification or where traditional topsoil resources are limited. Artificial soils thus offer an economically and environmentally sustainable solution for expanding arable land availability.

## 8. Experimental Platforms for Research

### *8.1. Microbial ecology studies*

Artificial soils allow researchers to isolate and test the effects of specific physical and chemical parameters on microbial community structure and function. Valle et al. (2022) developed modular systems with controlled pH and particle size to study enzyme activities and microbial interactions. Such controlled environments are invaluable for studying soil microbial ecology, as they eliminate the confounding variables often present in natural soils.

### *8.2. Fertilizer and amendment testing*

Artificial soils are useful for assessing the impact of soil amendments under reproducible conditions. Guenet et al. (2011) proposed standardized artificial soil protocols for testing biochar, fertilizers, lime and other soil conditioners. These testbeds can help manufacturers and researchers evaluate product performance in terms of nutrient release, microbial compatibility and long-term effects on soil structure.

### *8.3. Educational applications*

In educational settings, artificial soils provide a hands-on tool for teaching fundamental soil processes such as aggregation, microbial colonization, water movement and decomposition.

## 9. Challenges

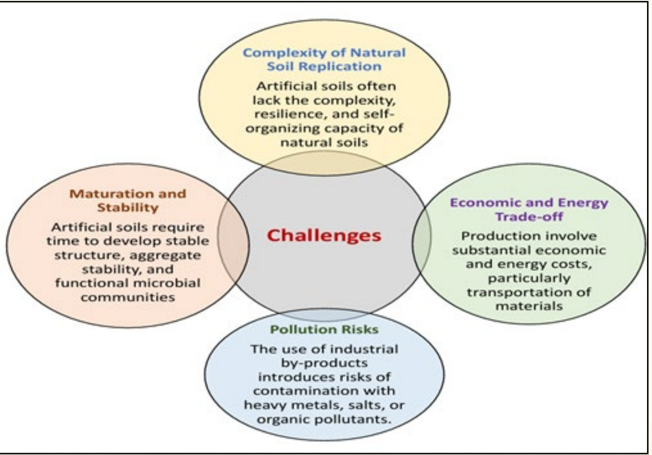


**Figure 3: Barriers to Developing Effective Artificial Soils for Improved Soil Health**

## 10. Future Directions

Artificial soils focus on using biotechnology, scalable design, monitoring and regulations. Engineered microbes can boost soil functions like nutrient cycling, pollution cleanup and carbon storage, making soils mature faster and stay resilient. Modular, site-specific designs help scale up deployment across different landscapes. Sensors and digital tools are key for tracking soil health and spotting problems early. Clear policies are also needed to set safety, quality and sustainability standards, including rules for materials and performance.

## 11. Conclusion

Artificial soil formation offers a promising solution to global soil degradation by combining minerals, organic matter, by-products and additives to mimic natural soils. These engineered soils support vegetation, nutrient cycling and biodiversity across applications like agriculture, restoration and urban greening. Challenges remain in replicating mature soil complexity and ensuring long-term safety, especially with industrial residues. Advances in synthetic biology, modular design and monitoring, along with robust policies and standards are key to maximizing benefits and ensuring safe and scalable deployment.

## 12. References

Bhuyan, S., Patgiri, D.K., Meena, R.S., Sandilya, M., Medhi, S.J., 2023. Artificial soils: Impact on agricultural sustainability. Vigyan Varta 4(3), 111–113.

Bucka, F.B., Kölbl, A., Uteau, D., Peth, S., Kögel-Knabner, I., 2019. Organic matter input determines structure development and aggregate formation in artificial soils. Geoderma 354, 113881.

Chen, S., Ai, X., Dong, T., Li, B., Luo, R., Ai, Y., Chen, Z., Li, C., 2016. The physico-chemical properties and structural characteristics of artificial soil for cut slope restoration in Southwestern China. Scientific Reports 6, 20565.

Valle, I., Gao, X., Ghezzehei, T.A., Silberg, J.J., Masiello, C.A., 2022. Artificial soils reveal individual factor controls on microbial processes. mSystems 7(4), e00301-22.

Guenet, B., Leloup, J., Hartmann, C., Barot, S., Abbadie, L., 2011. A new protocol for an artificial soil to analyse soil microbiological processes. Applied Soil Ecology 48, 243–246.

Kujawska, J., Pawłowska, M., Wasag, H., 2018. Possibility of forming artificial soil based on drilling waste and sewage sludge. IOP Conference Series: Earth and Environmental Science 150, 012008.

Liu, Y., Zhang, L., Chen, L., Xue, B., Wang, G., Zhu, G., Gou, W., Yang, D., 2016. Potential of artificial soil preparation for vegetation restoration using red mud and phosphogypsum. Biology and Fertility of Soils 53, 785–793.

Maeda, Y., Mise, K., Iwasaki, W., Watanabe, A., Asakawa, S., Asiloglu, R., Murase, J., 2020. Invention of artificial rice field soil: A tool to study the effect of soil components on the activity and community of microorganisms involved in anaerobic organic matter decomposition. Microbes and Environments 35(4), ME20093.

Pronk, G.J., Heister, K., Vogel, C., Babin, D., Bachmann, J., Ding, G.C., et al., 2016. Interaction of minerals, organic matter, and microorganisms during biogeochemical interface formation as shown by a series of artificial soil experiments. Biology and Fertility of Soils 53(1), 9–22.

Umarova, A.B., Arkhangelskaya, T.A., Suslenkova, M.M., Ivanova, T.V., 2021. Artificial soils for urban greening. IOP Conference Series: Earth and Environmental Science 862, 012048.