Ann PUBLISHER Journal of Agricultural Sciences (Agrosci)
e-ISSN 3047-2423
p-ISSN 3032-7547

# Soil Regeneration through Permaculture: Integrating Organic Matter, Soil Microorganisms, Biochar, and Conservation Agriculture for Sustainable Soil Fertility Restoration

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**Abstract**
**Background.** Soil degradation is a major challenge to sustainable agricultural development because it reduces soil fertility, disrupts microbial activity, degrades soil structure, lowers water retention, and decreases agroecosystem productivity. Permaculture-based soil regeneration offers an ecological restoration strategy integrating organic matter management, soil conservation, and biodiversity enhancement.
**Aims.** This article analyzes soil regeneration mechanisms by integrating compost, indigenous microorganisms, biochar, nutrient-supporting plants, cover crops, organic mulching, and minimum tillage.
**Methods**. This study used a conceptual review approach, employing descriptive analysis and thematic synthesis of soil regeneration materials and relevant scientific principles.
**Result.** The synthesis indicates that soil regeneration is a multidimensional process involving the simultaneous restoration of physical, chemical, and biological soil properties. Organic matter contributes to soil aggregation, cation exchange capacity, and substrate availability for soil organisms. Microorganisms facilitate organic matter decomposition and nutrient cycling, while biochar may improve selected soil properties depending on its characteristics and environmental conditions. Cover crops and reduced soil disturbance contribute to erosion control, surface protection, and biological activity.
**Conclusion.** This article proposes an Integrated Permaculture-Based Soil Regeneration (IPSR) conceptual framework linking regenerative management practices, soil health restoration, and agroecosystem resilience. The proposed framework requires empirical validation across different soil types and agricultural systems.

**Keywords:** soil regeneration; permaculture; soil organic matter; soil microorganisms; biochar; regenerative agriculture; soil health.

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## INTRODUCTION

Soil is a fundamental natural resource that supports food production, nutrient cycling, water regulation, carbon storage, and biodiversity. Soil functions not only as a plant growth medium but also as a complex biological system, with interactions among minerals, organic matter, water, air, plant roots, and soil organisms. In intensive agricultural systems, various management activities can reduce soil quality if not accompanied by adequate conservation measures. Over-tillage, limited return of organic residues, compaction from heavy equipment, erosion, and the use of unsuitable agricultural inputs can disrupt the balance of soil ecosystems.

The Soil Regeneration material compares soil that has undergone intensive tillage with soil managed without long-term plowing. The illustration emphasizes the importance of biopore channels, root tissues, and soil structures that support water movement and plant growth. Soil degradation is also linked to broader environmental issues, including climate change, organic carbon loss, and the decline in agroecosystems' ability to cope with droughts and extreme rainfall.

Conventional approaches focused on increasing production through nutrient inputs alone are not necessarily enough to restore the soil's full ecological function. Therefore, an approach is needed that not only improves chemical fertility but also restores the soil's physical structure and biological life.

Permaculture is an ecological design approach that emphasizes integrated resource management, the use of natural processes, biomass recycling, plant diversity, and reduced environmental disturbance. In the context of soil regeneration, permaculture principles can be applied through composting, using organic matter, managing microorganisms, biochar, mulch, ground cover crops, and reducing the intensity of soil tillage.

An evaluation is conducted on the present condition of agriculture, highlighting concerns related to soil degradation and reliance on fossil fuels, in relation to attaining food security for an ever-expanding global populace. Soil is described as "the delicate, living epidermis of the Earth," yet its vitality and vulnerability have often been overlooked amid agriculture's global expansion. Given its crucial role in the interconnected soil-water-air-energy system, how we manage soil can significantly influence climate change, with effects that can be positive or negative depending on whether we maintain or harm it. Regenerative agriculture fundamentally aims to boost soil health or rehabilitate severely damaged soil, thereby symbiotically improving water quality, vegetation, and land productivity. Using regenerative

agricultural techniques can increase soil organic carbon (SOC) in existing soils and support the formation of new soil. This process extracts carbon from the atmosphere while enhancing soil structure, health, fertility, crop yields, water retention, and aquifer replenishment—thereby mitigating flooding and drought, as well as further soil erosion through reduced runoff. Given that localized food production has been shown to maintain soil integrity and quality, urban agriculture ought to be regarded as a vital prospective asset to regenerative farming in the future, provided that the techniques utilized are inherently 'regenerative'. If localization is to emerge as a primary strategy for addressing the significantly diminished reliance on fossil fuels and maintaining soil integrity – alongside heightened food production in urban areas – it will be essential to integrate holistic ('systems') design methodologies like permaculture and the circular economy (which reduce and repurpose 'waste') into the current urban framework. Alongside cultivating food in urban environments, initiatives such as weatherproofing and thermally insulating existing buildings, as well as adopting a more localized lifestyle, will significantly reduce total energy use. To reduce our reliance on fossil fuels, strategies to lower total energy use should be considered at least as important as improving low-carbon energy generation. In summary, transitioning from the linear 'take, make, dispose' model to the systemic, circular approach of 'reduce, reuse, recycle, regenerate' is essential to meet future generations' needs. (Rhodes, 2017).

**Problem Formulation**

This article discusses three main issues: how degradation affects the physical, chemical, and biological properties of soils; how various permaculture practices contribute to restoring soil function; and how these practices can be integrated into a scientifically evaluable framework for soil regeneration.

**Research Objectives**

This article aims to identify the factors that cause soil degradation, analyze the mechanisms of soil health restoration through a permaculture approach, and develop a conceptual model for integrating soil regeneration technologies to support the productivity and sustainability of agroecosystems.

**State of the Art**

Soil science has shifted from a fertility-management approach dominated by external inputs to restoring soil ecosystem function. The soil health approach views soil as a living system that can support plant productivity, regulate water and nutrient cycles, and maintain environmental quality. Lal (2020) emphasizes the importance of soil management in supporting agricultural sustainability and environmental resilience. Lehmann and Joseph (2015) describe biochar's potential as a soil-improving material, while Bender et al. (2016) argue that soil biodiversity is essential to agroecosystem sustainability. Studies on conservation agriculture also show the importance of reducing soil disturbance, maintaining soil surface cover, and diversifying crops. These developments form the basis for integrating biological, physical, and ecological approaches in soil regeneration.

**Research Gap**

Although researchers have developed various soil restoration techniques, gaps remain. First, studies of compost, biochar, microorganisms, and ground cover crops often focus on the effects of individual treatments, but responses to combinations of these practices may vary with soil conditions.

Second, the effectiveness of integrating regeneration technologies cannot be generalized across all soil types, climates, and cultivation systems. Third, evaluations of soil regeneration success often focus on specific fertility indicators, whereas restoring soil function requires simultaneous physical, chemical, biological, and productivity measurements. Fourth, the permaculture approach requires a more measurable evaluation framework so that it can be tested through field research.

**Research Novelty**

This article proposes an Integrated Permaculture-Based Soil Regeneration (IPSR) conceptual framework that integrates seven soil management practices into a single soil health restoration system.

The conceptual contribution of IPSR lies in the incorporation of the three dimensions of recovery:

1. Physical: soil structure, aggregation, porosity, infiltration, and water storage capacity.
2. Chemistry: organic carbon, cation exchange capacity, pH, and nutrient availability.
3. Biology: microbial biomass, enzyme activity, soil organism biodiversity, and decomposition processes.

This model also links these three dimensions to plant productivity and agroecosystem resilience. This novelty is conceptual and has not yet been tested empirically.

## RESEARCH METHODS

### Research Design

This article uses a conceptual study approach with descriptive analysis and thematic synthesis. The main source is the Soil Regeneration document, which discusses soil properties, soil degradation, soil organisms, composting, local microorganisms, biochar, nitrogen-contributing plants, mulching, and minimal processing. This article is not an experimental study and does not use data from measurements in the field.

### Stages of Analysis

The analysis followed four stages.

First stage: Identify regeneration components. Group regeneration practices by ecological function and working mechanisms.

Stage two: Mechanism analysis. Identify the relationship between management practices and changes in the physical, chemical, and biological properties of soils.

Third stage: Integrative synthesis. Constructing conceptual relationships between regeneration practices to form an IPSR model.

Fourth stage: Preparation of evaluation indicators. Develop parameters for empirical testing.

### Variables and Indicators

Table 1 presents the variables and indicators in this article.

**Table 1. Research Variables and Indicators**

| Dimensions | Observation indicators | Suggested evaluation methods |
|---|---|---|
| Physical | Fill weight, porosity, aggregate stability | Ring sample, aggregate test |
| Chemistry | pH, C-organic, N-total, P-available, KTK | Laboratory analysis |
| Biology | Soil respiration, microbial biomass, enzyme activity | Microbiological analysis |
| Hydrology | Infiltration and soil moisture | Infiltrometer, humidity sensor |
| Agronomy | Biomass and crop yields | Growth and harvest measurement |
| Ecology | Land cover and biodiversity | Vegetation and biota survey |

## DISCUSSION

### Soil Degradation and Degradation of Ecological Function

Soil degradation occurs when the soil's ability to perform its ecological functions decreases. Physically, degradation can be characterized by compaction, reduced aggregate stability, the formation of impermeable layers, and an increased erosion risk. Chemically, degradation can involve decreases in organic carbon, nutrient imbalances, acidification, salinization, or contaminant accumulation. Biologically, degradation can shift microbial communities and reduce the activity of certain organisms. These three dimensions are reciprocally related. Degradation of organic matter can worsen soil aggregation, while compaction can reduce pore space and inhibit root development. Therefore, soil restoration requires an approach that goes beyond mere fertilizer application.

Regenerative agriculture aims to enhance soil fertility. Regenerative agriculture fosters robust soil that can yield high-quality, nutrient-rich food while improving the land rather than depleting it, ultimately resulting in fruitful farms, thriving communities, and prosperous economies. Regenerative agriculture is dynamic and comprehensive, incorporating permaculture and organic farming techniques such as conservation tillage, cover crops, crop rotation, composting, mobile animal shelters, and pasture cropping to enhance food production, raise farmers' incomes, and improve soil quality. Tenets of regenerative agriculture: Enhance soil fertility; collaborate with entire systems, not Isolated components; gradually enhance entire agroecosystems, soil, water, and biodiversity; integrate the farm with its broader agroecosystem and bioregion; develop designs and adopt a holistic approach. Choices that reflect the worth and connections of agricultural contributors; articulate the importance of each individual, farm, and system; make comprehensive decisions targeting particular systemic alterations; foster and cultivate fair and mutual relationships among all parties involved; create frameworks for non-linear, multi-capital reciprocity; perpetually advance and develop individuals, farms, and communities to realize their potential; consistently enhance agroecological practices and cultures. Agriculture shapes the global landscape.

### Organic Matter as the Foundation for Soil Regeneration

Soil organic matter is an important component that connects the physical, chemical, and biological properties of soil. Organic matter comes from plant residues, dead organisms, root exudates, and products of decomposition. In source materials, organic matter is described as forming aggregates, reducing bulk density, increasing cation exchange capacity, mineralizing

nutrients, and forming complexes with microelements. Increasing organic matter can help maintain soil moisture and provide energy for microorganisms. However, its effectiveness depends on the material's characteristics, the compost's maturity rate, the application dose, soil texture, and environmental conditions.

Aprilia et al. (2024) showed a significant effect of the proportion of vermicompost fertilizer on plant growth rate and root length of plants aged 15, 30, and 45 DAP, as well as root volume, stem diameter, plant height, number of leaves, fresh weight, and dry weight of plants aged 30, 45, and 60 DAP, but not significantly different from the observation of plant growth capacity at 7 and 14 DAP. Sondari et al. (2025) based fertilization recommendations on each plant's nutrient needs, following the fertilization recommendation guidelines in the Dry Land Soil Test Kit (PUTK). The study concluded that the nutrient status of dry land in Pamulihan District shows low phosphorus (P), medium potassium (K), and low C-Organic levels. The P, K, and C-Organic nutrient status in the dry land of Pamulihan District was mapped using a semi-detailed map at a scale of 1:50,000.

**The Role of Soil Microorganisms**

Microorganisms are a key component in the process of decomposition of organic matter and nutrient transformation. Bacteria, fungi, actinomycetes, and other organisms in the soil food network perform interrelated functions. Heterotrophic bacteria help decompose organic substrates. Fungi help decompose more complex materials and can contribute to aggregate formation. Certain microorganisms also support nitrogen fixation, phosphate dissolution, and symbiotic relationships with plants. Source materials include local microorganisms (MOLs), effective microorganisms (EMs), and some locally sourced fermentation formulations. The practice is interesting to study as a relatively low-cost biological approach. Nonetheless, home fermentation solutions do not automatically have a consistent microbial composition or proven agronomic benefits. Their effectiveness and safety need evaluation through microbial identification, contamination testing, and controlled assays.

Al Ghifari and colleagues (2024). The objective of this research was to examine the relationship between sweet corn cultivars and mycorrhizal applications on the growth and productivity of sweet corn (Zea mays saccharata Sturt) and to identify the varieties and mycorrhizal treatments that optimize the growth and yield of sweet maize plants (Zea mays saccharata Sturt). The study was conducted in Bumi Wangi Village, Ciparay District, Bandung Regency, West Java Province, at an elevation of 650 meters above sea level. Mean annual

precipitation is 2417.40 mm, and the soil is an Inceptisol with a pH of 6.4. The analytical framework uses a linear model of Group Random Design (RAK) with a Factorial structure and two factors. The first element is diversity (V), and the second is mycorrhizal dosage (M). Quadratic regression analysis was used to determine the ideal dosage of arbuscular vesicle mycorrhizal (MVA) that yields the highest-quality sweet corn variety. The findings indicated an interaction between the Sweet Boy, Paragon, and Scada cultivars and the application of 10 g plant-1 of arbuscular mycorrhizal vesicles on sweet corn (Zea mays saccharata Sturt) growth and yield. The Sweet Boy variety achieved the highest cob weight of 6.04 kg plot-1 with an optimal dose of 10.09 g plant-1 of arbuscular mycorrhizal vesicles, while the Talenta variety yielded 5.96 kg plot-1 at an optimal dose of 9.84 g plant-1. The Paragon variety produced a cob weight of 6.05 kg plot-1 with an optimal dose of 9.68 g plant-1, and the Secada variety resulted in a cob weight of 5.85 kg plot-1 with an optimal dose of 10.07 g plant-1 of arbuscular mycorrhizal vesicles.

Romadhona et al. (2025) highlighted that rice (Oryza sativa L.) is the principal agricultural crop and a primary food source in Indonesia. This crop is essential for meeting the nation's nutritional needs. A major obstacle to achieving national food security and self-sufficiency is declining productivity caused by soil fertility depletion from excessive chemical fertilizer use. To address these obstacles, measures have been implemented, including integrating organic substances and using soil microorganisms, which can be incorporated into modern farming techniques. Plant Growth-Promoting Rhizobacteria (PGPR) is a technique used to improve plant development. This research examined the effect of PGPR on the development and productivity of rice plants (Oryza sativa L.). The study was conducted from April to August 2025 in Babadan Village, Cirebon Regency, West Java. The experimental framework employed a Group Random Design (RAK) with six varying concentrations of PGPR, conducted in four repetitions, culminating in 24 experimental plot units: P0 (control), P1 (5 ml/l), P2 (10 ml/l), P3 (15 ml/l), P4 (20 ml/l), and P5 (25 ml/l). Measurements encompassed a range of indicators including plant height, count of sprouts per clump, leaf area, root volume, growth rate (LPT), productive sprouts per clump, panicle length, total grains per panicle, filled grain percentage per clump, filled grain weight per clump, weight of 1,000 grains, total harvested dry grain weight per clump, total harvested dry grain weight per plot, and milled dry grain weight per plot. The findings indicated that PGPR positively affected multiple growth and yield characteristics. Specifically, PGPR application significantly influenced plant height, root volume, the number of panicles per clump, length of panicles per clump, grains per panicle,

the percentage of grains per clump, weight of grains per clump, weight of 1,000 grains, weight of harvested dry grains (GKP) per clump, weight of GKP per plot, and weight of milled dry grains (GKG) per plot. The highest yields of harvested dry grains (GKP) and milled dry grains (GKG) per plot occurred with the PGPR treatment at a concentration of 15 ml/l, resulting in 6. 13 kg and 5. 81 kg, respectively. Anugrah et al. (2026) showed that a combination of wood vinegar and an ecoenzyme optimally enhanced the vegetative growth of Servo tomato plants. It can serve as a potential environmentally friendly organic biostimulant to replace chemical fertilizers. Andra et al. (2026) found that ecoenzymes from various fruit peels had a very significant effect on stem diameter at 15 DAP and had no significant effect on plant height at 15, 30, and 45 DAP, stem diameter at 30 and 45 DAP, number of productive branches at 50 DAP, flowering age, number of fruits per plant, fruit weight per plant, fruit diameter, and fruit length.

**Composting and Soil Fertility Restoration**

Compost is a controlled decomposition product of organic matter. Composting can be done in several ways, including windrow composting, hot composting, vermicomposting, bokashi, and household-scale composting. Mature compost can improve soil structure, provide nutrients, and support soil organisms. Composting success depends on the balance of carbon- and nitrogen-rich materials, moisture, aeration, temperature, and the duration of decomposition. Immature compost can cause nitrogen immobilization, root growth disorders, or phytotoxicity problems. Therefore, check compost maturity and quality before application. Noertjahyani et al. (2026) found that the combination of the Knia variety and goat manure produced the greatest plant length, while the combination of the Mencir variety and goat manure produced the highest number of flowers at 30 days after transplanting (DAT) and the greatest fruit weight.

**Biochar as a Soil Conditioner**

Biochar is a carbon-rich material produced by heating biomass under oxygen-limited conditions. Biochar can improve some soil properties, especially in soils with limited water or nutrient retention capacity. Using biochar with compost can provide complementary benefits: compost provides more easily decomposed organic matter, while biochar is more persistent. The source material introduces terra preta as inspiration for combining organic matter and charcoal. However, mixing compost and biochar does not automatically produce soil with the

same characteristics as historical terra preta soils. Biochar's influence depends on the biomass type, pyrolysis temperature, particle size, dose, pH, and the recipient soil's characteristics.

Komariah and colleagues (2026). Husk charcoal as a soil medium consistently produces better outcomes than manure across most growth metrics. Consequently, using 5% $HNO_3$ scarification with husk charcoal soil media is the most effective pre-planting method to improve germination, boost viability and vigor, and support superior early growth of Arabica coffee seeds. Kartini et al. (2024) found that leaching depletes soil nutrients, adversely affecting plant development and yield quality. Employing KCl fertilizer alongside humic acid is a strategy to enhance soil nutrients and promote plant growth and productivity. This study was carried out in Seda Village, Mandirancan District, Kuningan Regency, between June and August 2024. The methodology employed was an experimental approach with a completely randomized design (CRD), comprising 16 treatments replicated twice. Measured variables included leaf count, plant stature, tiller quantity, root volume, dry weight per cluster, relative growth rate, and fresh weight per cluster. The findings indicated that applying KCl fertilizer at 1.2 g/plant with 0 g/plant humic acid resulted in favorable spring onion growth and production.

**Ground Cover Crops and Nitrogen Contributors**

Ground cover crops function to protect the soil surface from rainfall, reduce erosion, provide biomass, and help maintain root activity. Certain legume plants form a symbiosis with nitrogen-fixing bacteria and contribute biological nitrogen. The source material lists several potential crops, including turi, lamtoro, gamal, kaliandra, soybeans, mung beans, and kecipir. Species selection should consider climate suitability, water needs, competition with main crops, and the risk of unwanted spread.

**Organic Mulching and Moisture Conservation**

Organic mulch is a layer of plant material that is placed on the soil surface. Mulch can reduce evaporation, protect the soil from erosion, suppress certain weeds, and add organic matter as it decomposes. The effectiveness of mulch depends on the material type, thickness, decomposition rate, rainfall, and cultivation conditions. Mulch also needs to be managed to avoid creating excessive moisture around the base of the plant or increasing certain pest problems.

Pamungkas and colleagues (2024). Diminished soil quality resulting from declining nutrient levels contributes to reduced plant quality and production. Using humic acid organic matter alongside nitrogen fertilizer is a strategy to enhance soil nutrients and promote plant

growth and productivity. This study was carried out in Heuleut Village, Leuwimunding District, Majalengka Regency, during May and June 2024. The research used an experimental approach with a randomized group design. The treatment comprised of 16 treatments that were done twice. The variables observed were plant height, number of leaves, root volume, plant fresh weight, leaf area, and plant growth rate. The results showed that using N fertilizer at 115 kg/ha (urea 250 kg/ha) and humic acid at 3 g/plant had a beneficial effect on all variables studied. The results of soil analysis showed an increase in N-total and C-organic.

**Minimum Tillage**

Minimum tillage aims to reduce mechanical disturbance to soil structures and organisms. This approach can maintain root tissue, biopores, and aggregate stability, especially when combined with soil cover and crop diversification. However, its application must be adapted to field conditions. In soils that have undergone heavy compaction, limited mechanical remedial measures may be required before minimum tillage systems can be implemented sustainably.

**Conceptual Model of Integrated Soil Regeneration**

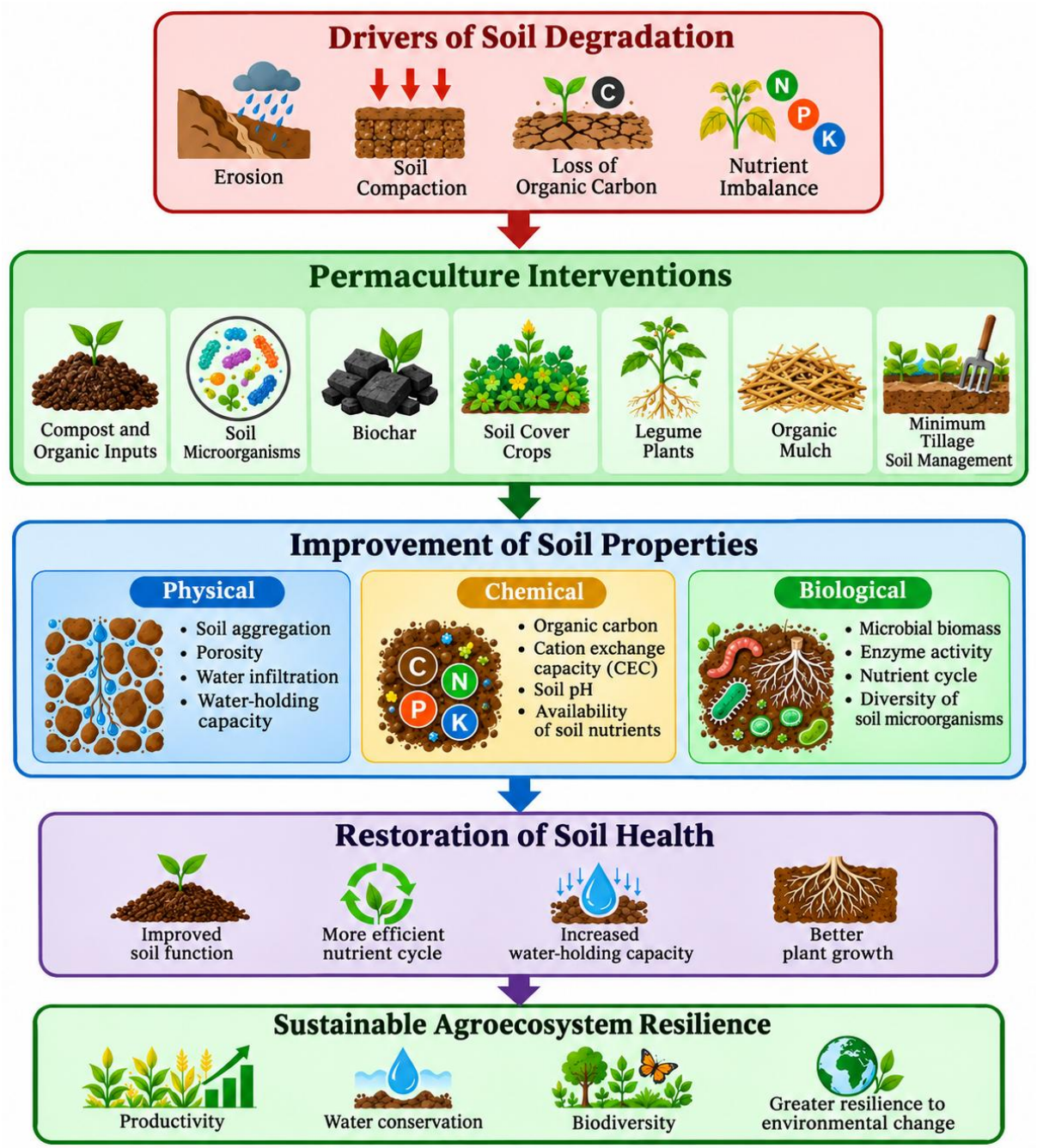



Figure 1. IPSR conceptual framework. The relationship between variables is a conceptual hypothesis, not the result of empirical testing.

**Advanced Research Hypothesis**

The model can be tested using several hypotheses:

H1: The integration of compost and biochar increases the organic carbon content and improves the physical properties of the soil compared to the control without the improver.

H2: The use of organic matter in conjunction with the characterized microbial inoculant increases the biological activity of the soil compared to the application of organic matter without inoculants.

H3: The combination of ground cover crops, mulching and minimum tillage improves aggregate stability as well as water infiltration.

H4: Integrated improvement of the physical, chemical, and biological properties of the soil is positively related to plant growth and productivity.

H5: The soil regeneration response is influenced by texture, initial pH, organic carbon content, and local climatic conditions.

**Research Implications and Recommendations**

The development of permaculture-based soil regeneration has implications for the management of agricultural land, plantations, food gardens, and degraded soil rehabilitation. From an environmental perspective, the integration of regenerative practices has the potential to increase soil cover and reduce soil loss due to erosion. From an agronomic perspective, improving soil conditions can support root development, water utilization efficiency, and nutrient availability.

From an economic perspective, the use of local biomass has the potential to reduce dependence on some external inputs, although the cost of labor, material processing, transportation, and maintenance still needs to be taken into account.

## CONCLUSION

Soil regeneration is an approach to agroecosystem management that is oriented towards the restoration of the physical, chemical, and biological functions of the soil in an integrated manner. Based on the synthesis of soil regeneration materials, organic matter, microorganisms, biochar, ground cover crops, organic mulching, and minimum tillage have complementary mechanisms in supporting soil health. Organic matter contributes to the formation of aggregates, nutrient provision, and soil biological activity. Microorganisms support the decomposition and transformation of nutrients, while biochar has the potential to improve certain soil properties. Ground cover crops, mulch, and minimum tillage play a role in protecting soil surface, conserving moisture, and reducing disturbances to soil structure.

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