The Determinants of Soil Quality: A Systematic Review

Abstract: *Soil quality is shaped by interdependent pedological conditions, climate, terrain, land use, and management, yet the strength and direction of responses differ across functions and assessment frameworks. This systematic literature review critically synthesizes 50 distinct, DOI-traceable primary journal reports published from 2022 to 2025, applying PRISMA-informed reporting principles and a narrative comparative synthesis. The evidence encompasses landscape conversion, erosion, soil texture and parent material, carbon and nutrient dynamics, tillage and cover cropping, organic amendments, salinity and irrigation, reclamation, and microbial processes. Long-running field trials indicate that soil structure may improve without corresponding increases in carbon stocks across the measured 0-20 cm soil layer, whereas short-term cover-crop responses can be muted under drought. Biological recovery following organic restoration can coexist with persistent contaminant concerns, and indices that emphasize chemical fertility can underrepresent structural or ecological constraints. This review distinguishes external determinants from indicators used to measure their consequences, compares treatment duration and soil depth, and identifies uncertainties arising from observational designs and non-equivalent soil-quality indices. More comparable, multi-functional, depth-resolved and longitudinal evidence is required to guide context-specific restoration and management decisions.*

Keywords: soil quality; determinants; soil quality index; land-use conversion; soil organic carbon; salinity; systematic evidence synthesis.

1. Introduction

Soil quality denotes the capacity of soil to maintain biological productivity, regulate water and nutrients, and sustain ecosystem functions within its environmental setting. The concept cannot be reduced to yield or to a single soil organic-carbon concentration, because stable aggregation, infiltration, acidity, salinity, biodiversity, contamination and biological turnover may respond differently to disturbance or restoration. In the Colombian Andes, a five-land-use comparison found changes in porosity, bulk density and macroinvertebrates accompanying active and passive restoration (González et al., 2024). A geographically distributed survey of 172 soil samples in Pakistan illustrates that even chemically focused fertility scores vary substantially across small spatial units (Nasir et al., 2024). These examples reveal why soil quality cannot be separated from reference land use, parent material, climate, landscape position or the functional goal of assessment. Irrigation, fertilization and tillage introduce further pressures, but their effects depend on initial physical constraints and the time elapsed since implementation. Therefore, identifying determinants requires a comparison of mechanisms, rather than ranking soils only from an aggregated index score.

A two-decade conservation-agriculture experiment in Denmark improved soil structural stability under no-tillage without increasing the 0–20 cm soil-carbon stock, challenging a simple carbon-first interpretation (Rocco et al., 2024). Four Canadian Prairie field sites showed only limited soil-health responses after three years of cover crops during dry conditions, even though rotation phase influenced microbial activity (Wu et al., 2024). In contrast, a synthesis of primary observations from 19 North American experiments associated cover cropping with improvements in organic carbon and aggregate stability but found that climate and inherent soil properties strongly conditioned those

responses (Peng et al., 2023). Evidence from contaminated or reclaimed soils also complicates uniform recommendations: a reclaimed urban brownfield exhibited better microbial functions under compost, although measured organic pollutants did not simply disappear (Ndour et al., 2025). These tensions justify a review organized around environmental constraints, modifiable practices and measurement choices. Soil formation and landscape-process perspectives explain background heterogeneity; ecological-function thinking links indicators to ecosystem services; and conservation-management frameworks connect interventions to multiple, potentially competing soil outcomes.

The aim of this review is to synthesize the determinants of soil quality across natural and managed systems while explicitly distinguishing causes, measurable responses and indices. Four questions guide the synthesis: which land-use, climatic, terrain, edaphic and management conditions are associated with soil quality; through which physical, chemical and biological pathways do these conditions act; when do primary empirical findings converge or conflict; and which combinations of design and measurement limit the generalizability of soil-quality assessments? The review contributes a 50-study evidence matrix mapping reported soil-quality domains; research aims, study designs and principal findings are critically compared in the accompanying narrative synthesis. For example, changes in soil structure and drainage nitrate under long-term management differed between early and late years, indicating that a single post-intervention snapshot can be misleading (Waring et al., 2024). Because many primary studies are site-specific and their soil-quality indices are not commensurable, the synthesis evaluates consistency, methodological constraints and contextual dependence rather than pooling index scores. The discussion concludes with priorities for reproducible field measurement and review methods.

2. Methodology

This review uses a structured, PRISMA-informed approach to evidence mapping and narrative synthesis to examine contextual and management-related determinants of soil quality rather than estimate a universal treatment effect. Figure 1 summarizes the selection flow. Database records were reported from Scopus (n = 241), Web of Science (n = 253), and ScienceDirect (n = 352), giving 846 identified records. After 124 duplicate records were removed, 722 records underwent title-and-abstract screening, of which 273 were excluded. Retrieval was sought for 449 reports; 244 were not retrieved. The remaining 205 reports were assessed for eligibility, and 155 were excluded, leaving 50 studies in the review. The included corpus comprises 50 distinct, DOI-traceable journal reports published during 2022–2025. Eligible studies presented empirical analyses relevant to soil quality, including field experiments, land-use and restoration comparisons, soil measurements, spatial assessments, and analyses of primary multi-site field observations. They were required to examine at least one soil-quality determinant, attribute, or assessment method and to report interpretable physical, chemical, biological, or composite soil-quality evidence. Narrative reviews and review-only publications without original empirical analysis were not eligible. DOI and publisher records, accessible full texts, and official bibliographic summaries were cross-checked for study identity and reported results; statements based only on available abstracts were not extended beyond the information reported. Because complete dated search histories, reviewer-level screening records, and itemized reasons for full-text exclusions were not available for verification, the displayed flow is a descriptive selection summary rather than evidence of fully reproducible or exhaustively documented PRISMA 2020 compliance.

Information from the included reports was organized by author and publication year, study setting, research purpose, design or sampling context, reported drivers and soil attributes, measurement depth or treatment duration where stated, and principal findings. Table 1 preserves the 50-study evidence

matrix and its original headings. Its twelve thematic domains comprise Land Use, Organic Matter, Soil Texture, Soil Structure, Bulk Density, Soil Nutrients, pH / Salinity, Soil Biota, Tillage, Organic Inputs, Crop Rotation, and Soil Erosion; the separate Soil Quality column denotes an explicit soil-quality assessment or outcome rather than a thirteenth causal determinant. A checkmark indicates that a domain was substantively assessed, not that its influence was positive, statistically significant, or causal; a blank cell does not establish an absence of effect. To avoid confusing drivers with responses, environmental and management exposures were distinguished analytically from measured physical, chemical, and biological indicators and from composite index scores. The narrative synthesis compared convergent and conflicting findings across agricultural systems, land-use conversion, irrigation and salinity, restoration, disturbed soils, and index-development studies. Interpretation considered baseline land use, climate and moisture conditions, landscape position, soil texture, observation period, sampling depth, and the choice and weighting of index indicators. Cross-sectional and chronosequence results were treated as associations rather than direct longitudinal causal evidence, and overlapping study sites were not automatically regarded as independent observations. Formal meta-analysis was not appropriate because intervention contrasts, reference conditions, study designs, measured outcomes, and soil-quality index algorithms were insufficiently comparable. Accordingly, neither the frequency of matrix checkmarks nor the direction of an isolated composite score was used to rank causal importance. The substantial number of reports not retrieved and the absence of a source-level audit trail for exclusion decisions constrain the completeness and reproducibility of the evidence base.

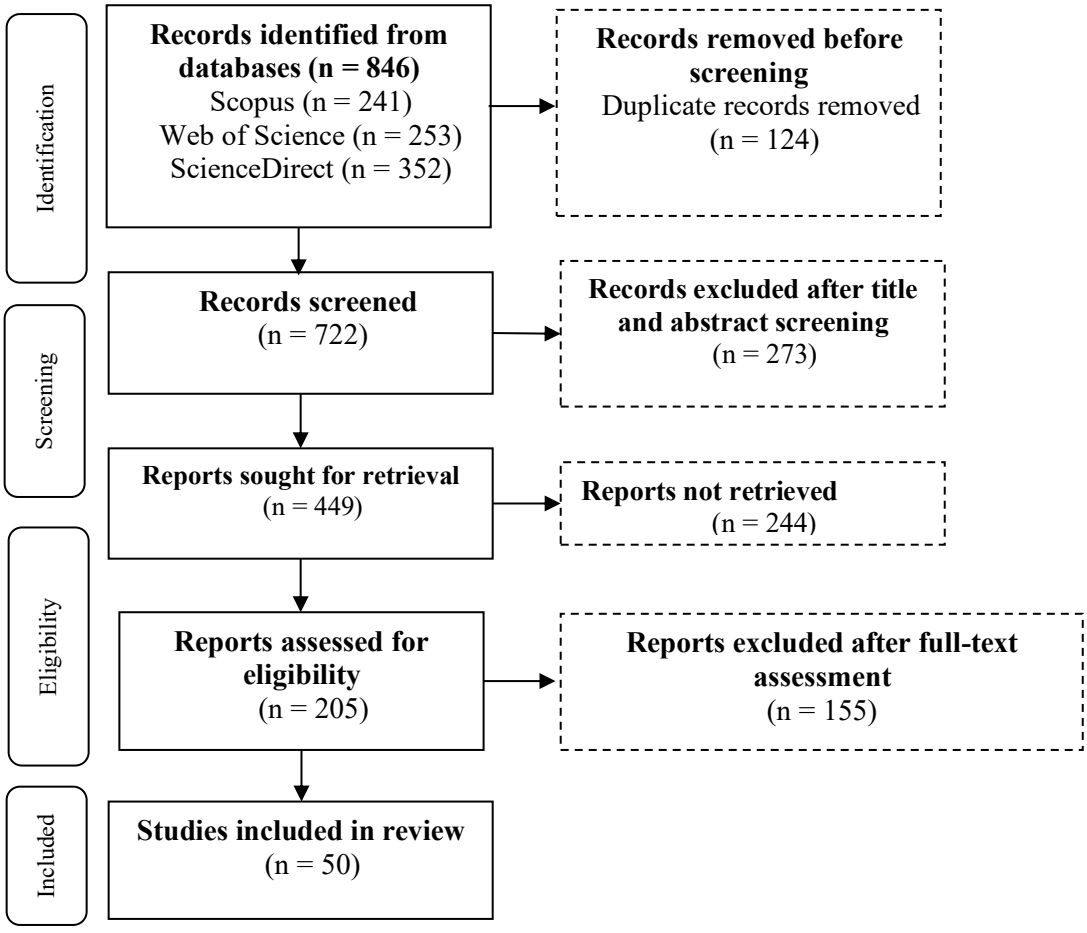


Figure 1: The Systematic Review Process

3. Soil Quality and Its Determinants

The central analytical distinction is between determinants that act on soils and indicators used to recognize their responses. Climate, topography, parent material and texture constrain water, mineral surface area and erosion potential; land conversion and management change residue input, compaction, microbial habitat and nutrient balances. Physical, chemical and biological variables then register consequences of these pressures but cannot always be treated as independent drivers. A comparison across the Andean forest, degraded, cultivated and restored land uses identified biological and structural changes that a strictly fertility-focused index could conceal (González et al., 2024). Similarly, minimum-data-set comparisons in tobacco systems ranked competing scoring models differently, underscoring index-design sensitivity (Teng et al., 2024). Index construction is useful for monitoring but may be circular if an organic-carbon variable is described simultaneously as both the treatment mechanism and the index-weighted outcome. Therefore, the review uses a layered framework comprising background constraints, management exposures, proximal physical–chemical–biological attributes and functional outcomes. The resulting evidence map can locate repeatedly assessed domains without turning their frequency into a measure of effect. Studies of geographic spatial gradients, for example, reveal heterogeneity but cannot by themselves establish that a soil type or location caused an observed index difference (Nasir et al., 2024). The framework also guards against treating a higher carbon concentration at the soil surface as proof of improved carbon stocks throughout a profile.

Management pathways are interdependent and often delayed. Carbon additions may feed microbial biomass and nutrient cycling, but the strength of response varies with amendment composition, soil moisture, depth and land-use history. A lowland-rice field study tested six rice-husk biochar rates and identified soil carbon, available zinc, pH and bulk density as prominent components of its quality index (Munda et al., 2023). After 40 months of amendment application in a semi-arid quarry, nutrient pools and bacterial functional-gene signals improved, but amendment combinations differed in their ecological consequences (Rodríguez-Berbel et al., 2025). The 14-year rice–wheat comparison further suggests that continuous organic nutrient management can alter biological-quality indices and crop responses beyond immediate fertilizer supply (Chanu et al., 2025). However, not all gains are uniform across soil functions or durations. A two-decade no-tillage trial improved structural outcomes while failing to produce higher full 0–20 cm carbon stocks, demonstrating partial decoupling between physical and chemical indicators (Rocco et al., 2024). Cover-crop performance under four Canadian semi-arid sites was limited after three drought-constrained years despite responses of nitrogen and respiration indicators (Wu et al., 2024). These contrasts make treatment duration, biomass production, moisture limitation and sampling depth indispensable effect modifiers rather than secondary background characteristics.

A third component is the distinction between measurement utility and ecological generalization. A soil-quality index derived from a short list of physicochemical variables may serve crop-fertility mapping yet be poorly suited to remediated, biologically active or contaminated soils. In Pakistan, simple additive scoring of 172 georeferenced observations displayed pronounced fertility differences, but its thresholds and variable selection are study-dependent (Nasir et al., 2024). Microtopographic index assessments in Chinese hilly–gully landscapes likewise emphasize the importance of slope-dependent limiting factors rather than a uniform soil-quality reference (Liu et al., 2025). Long-term cover cropping can affect microbial assemblages and multifunctionality, linking soil quality to processes beyond nutrient concentrations (Ding et al., 2024). Studies of reclaimed urban soils illustrate an additional diagnostic tension: function indices may improve while pollutant burdens remain detectable (Ndour et al., 2025). Consequently, multi-domain interpretation should distinguish

nutrient supply, physical structure, biological turnover, contaminant risk and service delivery. The matrix is deliberately a thematic exposure map; its twelve thematic domains and separate Soil Quality outcome column are neither a validated universal scorecard nor a model assigning causal weights. Study designs, sampling contexts and outcome definitions are therefore interpreted in the narrative alongside the presence matrix. Across settings, soil quality is most defensibly assessed against explicit local ecological functions and monitored with repeated, depth-resolved observations rather than presumed index equivalence.

Table 1: Literature Review Matrix

No.	Author(s) and Year	Land Use	Organic Matter	Soil Texture	Soil Structure	Bulk Density	Soil Nutrients	pH / Salinity	Soil Biota	Tillage	Organic Inputs	Crop Rotation	Soil Erosion	Soil Quality
1	De et al. (2022)	✓	✓	✓	✓	✓	✓							✓
2	Marion et al. (2022)	✓	✓		✓	✓	✓	✓		✓				✓
3	Martín-Sanz et al. (2022)	✓	✓		✓	✓	✓	✓	✓					✓
4	Ozlu et al. (2022)		✓		✓		✓		✓		✓			✓
5	Wang et al. (2022)		✓		✓	✓		✓	✓					✓
6	Aranguren and Cañón (2023)	✓			✓		✓		✓					✓
7	Kooch et al. (2023)	✓	✓		✓	✓	✓	✓	✓					✓
8	Li et al. (2023)	✓	✓				✓						✓	✓
9	Mukhopadhyay et al. (2023)		✓		✓	✓	✓	✓	✓					✓
10	Munda et al. (2023)		✓		✓	✓	✓	✓			✓			✓
11	Peng et al. (2023)		✓	✓	✓		✓		✓	✓		✓		✓
12	Weldewahid et al. (2023)	✓	✓		✓		✓	✓						✓
13	Zahedifar (2023)	✓	✓		✓		✓		✓					✓
14	Zong et al. (2023)		✓		✓	✓	✓	✓	✓			✓		✓
15	Acharya et al. (2024)		✓		✓		✓	✓	✓			✓		✓
16	Blanco-Canqui et al. (2024)		✓		✓	✓	✓	✓			✓			✓
17	Chaudhry et al. (2024)		✓				✓	✓						✓
18	Ding et al. (2024)		✓				✓		✓			✓		✓
19	Emami et al. (2024)	✓	✓	✓	✓	✓	✓							✓
20	Endrias et al. (2024)	✓	✓	✓			✓						✓	✓
21	Fagodiya et al. (2024)		✓		✓	✓				✓		✓		✓
22	Fang et al. (2024)		✓		✓		✓						✓	✓
23	Gan et al. (2024)	✓		✓		✓	✓		✓				✓	✓
24	González et al. (2024)	✓	✓		✓	✓	✓	✓	✓				✓	✓
25	Li et al. (2024)	✓	✓				✓	✓	✓		✓			✓

No.	Author(s) and Year	Land Use	Organic Matter	Soil Texture	Soil Structure	Bulk Density	Soil Nutrients	pH / Salinity	Soil Biota	Tillage	Organic Inputs	Crop Rotation	Soil Erosion	Soil Quality
26	Liu et al. (2024)	✓	✓	✓			✓	✓					✓	✓
27	Nasir et al. (2024)	✓	✓	✓			✓	✓						✓
28	Rocco et al. (2024)		✓		✓	✓				✓		✓		✓
29	Saha et al. (2024)		✓		✓	✓				✓		✓		✓
30	Song et al. (2024)		✓		✓		✓	✓	✓		✓			✓
31	Teng et al. (2024)	✓	✓	✓	✓	✓	✓	✓						✓
32	Vasu et al. (2024)	✓	✓	✓	✓	✓	✓		✓					✓
33	Villafuerte et al. (2024)		✓		✓		✓	✓	✓		✓			✓
34	Wang et al. (2024)		✓		✓		✓		✓		✓	✓		✓
35	Waring et al. (2024)		✓		✓					✓		✓		✓
36	Wu et al. (2024)		✓		✓		✓		✓			✓		✓
37	Yeneneh et al. (2024)	✓	✓	✓	✓		✓	✓					✓	✓
38	Zhu et al. (2024)		✓	✓	✓		✓					✓		✓
39	Awoonor et al. (2025)	✓		✓			✓	✓	✓					✓
40	Chanu et al. (2025)		✓				✓	✓	✓		✓			✓
41	Chen et al. (2025)		✓		✓	✓	✓	✓	✓		✓			✓
42	Deepana et al. (2025)	✓	✓	✓	✓	✓	✓	✓						✓
43	Gao et al. (2025)	✓			✓		✓						✓	✓
44	Kahsay et al. (2025)	✓	✓		✓		✓							✓
45	Khan et al. (2025)		✓		✓		✓	✓	✓		✓			✓
46	C. Liu et al. (2025)		✓		✓	✓				✓		✓		✓
47	L. Liu et al. (2025)	✓	✓	✓	✓	✓	✓	✓					✓	✓
48	Ndour et al. (2025)	✓	✓				✓		✓		✓			✓
49	Rana et al. (2025)		✓		✓	✓	✓		✓	✓		✓		✓
50	Rodríguez-Berbel et al. (2025)	✓	✓				✓	✓	✓		✓			✓

Table 1 maps twelve reported soil-quality domains and the separate Soil Quality assessment column across the 50 included studies. Checkmarks indicate substantive assessment, not beneficial effects or causal strength; blank cells do not demonstrate that an influence is absent. Column frequencies reflect research coverage rather than effect sizes. Study settings, designs, and outcomes are compared in the thematic discussion.

4. Discussion: Thematic Synthesis of Determinants

Land-use history and existing soil properties consistently condition observed soil quality, although the direction and magnitude of change depend on the indicators chosen. Comparative field sampling in eastern India found higher index scores in forest than in cultivated soils, with an intermediate response on converted land (De et al., 2022). A forest-to-rangeland comparison in Iran showed that favorable shifts in some nutrients did not compensate for reduced faunal, microbial and enzymatic functioning (Kooch et al., 2023). A long-term spatial–temporal analysis of agricultural land in China identified interactions between precipitation and temperature as important drivers of soil-quality change, while land conversion contributed to deterioration in some settings (Li et al., 2023). Cultivated areas also scored less favorably than less disturbed land uses under network- and factor-analysis approaches in Iran (Zahedifar, 2023). In Ethiopian highlands, field comparisons distinguished grassland, restored sites, conservation-bund treatments and barren land, with organic carbon, clay and nutrients contributing to their rankings (Endrias et al., 2024). A watershed study found that croplands were depleted in carbon and nitrogen relative to forest even though available phosphorus could be greater under cultivation (Yeneneh et al., 2024). Evidence from the Ghanaian forest–savannah transition likewise found higher soil-quality scores under forest than cropland and variation between sampled depths (Awoonor et al., 2025). A comparison of evergreen forest, plantation, horticultural and agricultural systems in India placed evergreen forest highest at both sampled depths (Deepana et al., 2025). Together, these observations support land use as a contextual determinant, not a claim that a particular land-cover class universally maximizes every soil function.

Terrain, erosion and spatial heterogeneity can modify soil-quality ratings independently of the nominal land-use category. In northeastern China, slope-form sampling linked erosion patterns to the spatial behavior of a soil-quality index, with strong agreement between full and reduced indicator sets (Fang et al., 2024). Karst field comparisons found more favorable ratings on anti-dip slopes and on forest or grassland sites, with enzyme activity and particle-size attributes among the important discriminators (Gan et al., 2024). A study of cultivation age and slope position in Chinese Mollisols observed lower quality with longer cultivation but higher downslope scores where carbon and nutrients had been redistributed (Liu et al., 2024). Network-based analysis across contrasting land uses provided stronger separation than a conventional principal-component approach in one study, while forest or grassland conversion to cropland was associated with poorer soil-quality scores (Gao et al., 2025). Land-use comparisons from northern Ethiopia also showed reduced cropland quality relative to shrubland and grassland, with soil carbon and aggregation among the more informative indicators (Kahsay et al., 2025). Microtopographic sampling further demonstrated that both the composite score and its apparent limiting factors vary with position within a landscape (L. Liu et al., 2025). These results caution against attributing a spatial difference solely to management when slope, initial soil texture, inherited carbon stocks and erosion processes are not controlled. They also explain why results from a single topsoil depth or field position should not be generalized across heterogeneous catchments.

Management experiments provide stronger temporal comparisons, but their findings do not support a uniformly positive response to any one practice. A multi-experiment North American synthesis of original long-term field data found that cover cropping tended to increase soil organic carbon, with moisture and clay conditions modifying the response (Peng et al., 2023). Semi-arid irrigated field work associated cover crops with greater soil carbon storage and changes in microbial activity (Acharya et al., 2024). Comparisons of cover-crop monocultures and mixtures found improvements in nutrient-related multifunctionality alongside microbial-community changes (Ding et al., 2024). Conservation-tillage and crop-residue contrasts in India produced more favorable quality-index

values under several reduced-tillage and residue-management combinations (Fagodiya et al., 2024). A long-running Danish factorial trial showed improved aggregate stability under no-tillage without a corresponding gain in the integrated 0–20 cm carbon stock, separating structural benefits from carbon-stock responses (Rocco et al., 2024). A field study comparing no-tillage, rotation, cover crops and drainage reported higher topsoil organic matter and aggregate stability but greater bulk density and lower saturated conductivity under no-till (Saha et al., 2024). A decade-scale drainage experiment found that soil indicators and water-quality responses changed at different times, with nitrate outcomes dependent on the conservation-treatment combination (Waring et al., 2024). On the Canadian Prairies, three years of cover cropping gave limited indicator shifts under dry conditions, whereas crop rotation and perennial phases influenced biological responses (Wu et al., 2024). A five-year experiment reported that cover-crop mixtures favored macroaggregation and protected carbon fractions, especially near the surface (Zhu et al., 2024). Straw return and tillage depth interacted with physical condition and yield in a Mollisol experiment, so treatment performance could not be assigned to residue retention in isolation (C. Liu et al., 2025). Early conservation-agriculture responses also varied among biochemical indices, carbon fractions and enzyme activities (Rana et al., 2025). These contrasts distinguish the timescale of observation, depth of sampling and functional endpoint from the underlying management determinant.

Irrigation and the movement of water and salts form another determinant system in which direction of response depends on water quality and initial site constraints. A drip-irrigated cotton experiment in northwestern China associated more saline irrigation water with weaker aggregate stability, hydraulic conductivity and composite soil quality (Wang et al., 2022). Subsurface drainage of salt-affected fields in India was associated with reduced salinity and more favorable conductivity, soil carbon, enzymes and productivity (Mukhopadhyay et al., 2023). An Ethiopian long-term irrigation comparison reported greater soil-quality index, carbon and nitrogen stocks and structural stability on irrigated than non-irrigated fields (Weldewahid et al., 2023). However, an investigation across years of mulched drip irrigation found improvement during earlier reclamation followed by a plateau, with plastic residues and compaction among the longer-term concerns (Zong et al., 2023). Subsurface organic-amendment placement in saline soil improved index values across sampled depths and changed microbial functioning, linking amendment location to the salinity context (Song et al., 2024). A two-year comparison showed that biochar improved soil-quality scores under full irrigation, whereas the effect under deficit irrigation was not statistically clear (Chen et al., 2025). Consequently, irrigation quantity, water salinity, drainage, time since reclamation and amendment placement should be interpreted together rather than as separate universal drivers. It is also important to separate a temporary improvement in soluble salts from more persistent recovery of structure, soil carbon and microbial activity.

Organic nutrient inputs may improve several soil functions while creating trade-offs that depend on material, rate, climate and observation period. A US field trial comparing dairy manure with mineral fertilizer found higher composite soil-quality scores under greater manure rates but also greater greenhouse-gas-related impacts (Ozlu et al., 2022). A rice-soil field study in eastern India observed improved quality-index values across tested biochar treatments and identified organic carbon, zinc, pH and bulk density as influential indicators (Munda et al., 2023). A five-year semi-arid biochar assessment found some fertility and crop benefits while several physical responses were weaker or declined with time (Blanco-Canqui et al., 2024). Pyrite-modified biochar reduced copper and lead leaching in laboratory incubation and improved an index-based assessment of mine soil; evidence for sustained field performance remains limited (Li et al., 2024). In a short-term compost comparison, an animal-derived treatment improved index and enzyme measures while reducing some aspects of bacterial diversity (Villafuerte et al., 2024). A 13-year fertilizer experiment showed substantial gains

in soil quality and ecosystem multifunctionality under organic inputs, with compost and straw often outperforming biochar at comparable carbon inputs (Wang et al., 2024). Nutrient programs that combined organic inputs or biofertilizer improved biological-quality measures and rice-equivalent yield compared with less diversified regimes (Chanu et al., 2025). A two-year organic-fertilization comparison found gains in carbon, nutrients and microbial attributes, with responses varying by treatment and sampling depth (Khan et al., 2025). Together these studies argue against treating amendment addition as one determinant with a uniform effect; amendment chemistry, environmental objective and possible off-site effects must be specified.

Restoration studies show why soil-quality improvement should be evaluated against functional targets and site histories rather than a single composite benchmark. In a Colombian nature reserve, active and passive restoration were associated with improved porosity, bulk-density conditions and soil macroinvertebrate richness, whereas chemical properties did not respond uniformly across sites (González et al., 2024). A French study of compost application to contaminated urban soils found improvements in soil-function index values, but petroleum-hydrocarbon and dioxin measures did not consistently decline (Ndour et al., 2025). In semi-arid mining-degraded soils in Spain, different organic amendments altered carbon, nutrients and microbial-cycling measures in treatment-specific ways relative to natural reference soils (Rodríguez-Berbel et al., 2025). The first study highlights the risk of using nutrient recovery alone to represent ecosystem recovery; the second shows that enhanced biological activity does not by itself demonstrate contaminant removal; and the third emphasizes the dependence of restoration outcomes on initial degradation and amendment choice. Thus, biotic recovery, physical habitat, fertility, toxicity and landscape stability are related but distinct assessment targets. Across these settings, apparent improvements are more persuasive when multiple functions converge and sampling takes account of prior disturbance, controls and monitoring duration. Longer comparisons are particularly needed because a one-season biological response may not persist after amendment decomposition, rewetting or renewed contaminant exposure.

Index construction affects which determinants appear important, even when underlying field measurements do not change. Comparisons among six scoring approaches in Brazilian cropping systems showed that a compact weighted set of physical and chemical indicators could distinguish management similarly to a more extensive dataset (Marion et al., 2022). In Spanish calcareous soils, network-selected enzyme and bulk-density indicators distinguished land uses better than a conventional principal-component-selected chemical set (Martín-Sanz et al., 2022). A response-ratio and geometric-projection method preserved indicator-specific gains and losses that additive scores can mask (Aranguren & Cañón, 2023). A Canadian spectroscopy study reported that predicting the composite soil-quality index directly outperformed aggregating individually predicted soil properties (Chaudhry et al., 2024). An Iranian land-use comparison selected clay, organic matter, nitrogen, phosphorus, aggregate size and bulk density as useful indicators, and found differences among weighting schemes (Emami et al., 2024). A study mapping 172 sampled locations in Pakistan demonstrated that fertility-oriented index classifications depend partly on selected variables and score-normalization thresholds (Nasir et al., 2024). A tobacco-field assessment favored a weighted nonlinear minimum-data-set index over several alternative scoring procedures for its particular purpose (Teng et al., 2024). A multi-property Indian index incorporated soil morphology and earthworm observations with conventional measurements and was related to crop yield (Vasu et al., 2024). Taken together, the evidence does not identify a universally superior index: indicator selection, study design, land use and target function influence rankings. The matrix therefore represents reported determinant coverage, not a meta-analytic ranking of causal influence.

5. Research Gaps and Future Research Directions

Major gaps concern independence, duration and functional comparability. Few studies jointly track bulk density, porosity, soil carbon by depth, hydraulic function, biota and nutrient losses with replicated baselines and common analytical protocols. The Danish two-decade trial and the Canadian three-year study illustrate how apparently contrasting cover-crop conclusions may follow from observation period and moisture conditions rather than disagreement about a single soil process (Rocco et al., 2024). Research using 19 long-term sites makes a stronger case for climate and inherent texture as effect modifiers, but even multi-site analyses depend on nonrandom site histories and diverse management backgrounds (Peng et al., 2023). A related gap is the absence of routinely published absolute indicator values and standardized thresholds that would allow equivalent SQI comparisons. The number of publications assessing an indicator does not validate its weight in a composite index. Future coordinated experiments should report a core physical–chemical–biological indicator set, sampling depth and bulk-density-adjusted carbon stocks, and identify planned contrasts for climate, parent material, irrigation and land-use histories. Explicit reporting of sampling units and independent study locations is essential to avoid statistical and review-level pseudo-replication.

A second unresolved area is how restoration goals should be combined when nutrient cycling, contaminant control and ecosystem functions do not respond in parallel. Field restoration in an Andean reserve improved soil macrofauna and structure, but chemical properties varied between sites and restoration modes (González et al., 2024). Urban brownfield compost improved biological and soil-function metrics without equally resolving legacy organic contamination, implying that soil-quality recovery should be assessed alongside pollutant exposure and food-use constraints (Ndour et al., 2025). In reclaimed mine soils, treatment-specific responses indicate a need to separate short-term chemical passivation from durable microbial and physical recovery (Li et al., 2024). Future work should combine longer replicated interventions, measurements at several depths, explicit crop and ecosystem-service outcomes and multiple reference soils. Methodological development should prioritize cross-validation of minimum-data-set methods, transparent scoring weights and uncertainty analysis. For full SLR reproducibility, future updates must prospectively preserve exact database queries, dates, screening and quality-appraisal decisions, full-text exclusion reasons and independently verifiable documentation supporting the reported PRISMA selection counts.

6. Conclusion

This systematic evidence map brings together 50 DOI-traceable original journal studies addressing the determinants of soil quality in agricultural, forest, restored, irrigated and disturbed systems. The integrated findings identify land use and landscape position as major contextual influences, while tillage, crop rotations, cover crops, fertilizer regimes and organic amendments act through interacting carbon, aggregation, water, nutrient and microbial pathways. Evidence is not uniform: two decades of conservation management improved some physical properties without increasing carbon stocks within the sampled 0–20 cm soil layer; a short drought-affected cover-crop experiment produced limited soil-health effects; and longer or multisite studies found more favorable carbon outcomes under certain conditions. Restoration and contamination studies likewise demonstrate that better biological functioning may not imply elimination of legacy pollutants. A soil-quality indicator is a measurement of a soil response, not necessarily an external determinant that caused it, and study-specific composite scores should not be interpreted as interchangeable causal quantities. The review therefore favors depth-specific monitoring, explicit account of climate and inherent soil texture, longer replicated field comparisons, and multiple soil functions rather than a single fertility or carbon surrogate.

Its central practical implication is that soil-quality improvement depends on matching interventions to the limiting process and the relevant ecosystem service. The numerical selection flow is presented in Figure 1; however, the lack of complete dated search and screening records prevents independent verification of every selection decision and does not support a claim of exhaustive screening or full PRISMA 2020 compliance. Future reviews should pair these substantive insights with prospectively auditable records and study-level quality appraisal. In practice, site-specific diagnosis should begin by identifying the intended soil function and comparing physical, chemical, biological and contamination indicators against an appropriate local reference. Crop productivity, water flow, carbon retention and microbial activity may respond on different time scales and should not be collapsed into a single unqualified improvement claim. Monitoring programs should document measurement uncertainty, repeated sampling intervals, field replicates and the distinction between concentrations and stocks. Because the original evidence spans different ecological contexts and partially incompatible indices, the review's strongest conclusions concern recurring mechanisms and conditional responses, not an absolute global ordering of determinants. Such restraint makes soil-quality interventions more scientifically defensible and relevant to sustainable land management.

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