



RESEARCH PAPER

Evaluating the Effect of Agrochemicals on Soil Physicochemical Properties

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Abstract

Indiscriminate and long-term application of agrochemicals (fertilizers, pesticides, herbicides and fungicides) is widely used to boost crop yield, but its cumulative effect on soil health is a growing concern. This study evaluates the effect of agrochemicals on soil physicochemical properties through a comparative field investigation between an agrochemical treated agricultural plot and an adjoining untreated (control) plot under similar agro-climatic conditions over a three-year observation period. Composite soil samples were collected at 0–15 cm depth and analyzed for physical properties (bulk density, porosity, water holding capacity, aggregate stability, infiltration rate) and chemical properties (pH, organic carbon, total nitrogen, available phosphorus, exchangeable potassium and electrical conductivity) using standard laboratory protocols. Results reveal a measurable decline in soil pH, organic carbon, porosity, aggregate stability and water-holding capacity in the treated soil, alongside an increase in bulk density, available phosphorus, exchangeable potassium and electrical conductivity relative to the control. Multi-year trend data further indicate a progressive year-on-year decline in organic carbon and pH accompanied by a rising salinity index. These findings demonstrate that continuous agrochemical input measurably alters the soil's physical structure and chemical equilibrium, with significant implications for long-term soil fertility, structural stability and agricultural sustainability. The paper concludes with recommendations for integrated nutrient and pest management to mitigate these adverse effects.

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1. Introduction

Modern agriculture relies heavily on agrochemicals synthetic fertilizers, pesticides, herbicides and fungicides to sustain high crop yields and control pests, diseases and weeds. The Green Revolution of the mid-twentieth century, built substantially on the intensified use of chemical fertilizers and plant protection products, dramatically increased global cereal production and helped avert widespread famine. However, more than half a century of sustained agrochemical dependence has begun to reveal a range of unintended consequences for the soil resource base on which agricultural productivity ultimately depends. Soil is a dynamic, living medium whose productivity is governed by an intricate balance of physical structure,

chemical composition and biological activity. Physicochemical properties such as pH, organic carbon content, nutrient status (nitrogen, phosphorus, potassium), electrical conductivity, bulk density, porosity and water holding capacity are widely used indicators of soil quality and fertility. These properties are sensitive to management practices, and the type, dose, frequency and duration of agrochemical application can shift them in ways that are not always immediately visible to farmers but which accumulate over cropping seasons. Numerous field and laboratory studies have reported that prolonged use of nitrogenous fertilizers can acidify soils by releasing hydrogen ions during nitrification, while pesticide residues can disturb microbial-mediated nutrient cycling and thereby indirectly affect organic matter

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turnover and soil structural stability. Conversely, phosphatic and potassic fertilizers tend to elevate available phosphorus and exchangeable potassium levels in the short term, and repeated fertilizer and irrigation-water inputs — particularly when drainage is poor — can raise soil salinity, reflected in rising electrical conductivity (EC). At the same time, the physical architecture of soil — its bulk density, porosity, aggregate stability and infiltration capacity — can also be compromised by declining organic matter and disrupted microbial and faunal activity, both of which act as natural soil-structuring agents.

Despite this substantial body of evidence, many extension programs and farm-level decisions continue to emphasize short-term yield outcomes over the long-term trajectory of soil health. There remains a need for site-specific, quantitative comparisons that make the physical and chemical costs of continuous agrochemical dependence explicit and legible to practitioners, researchers and policymakers alike.

The study aims to evaluate the effect of agrochemical application on key soil physical properties, including bulk density, porosity, water holding capacity, aggregate stability, and infiltration rate, as well as important soil chemical properties such as pH, organic carbon, total nitrogen, available phosphorus, exchangeable potassium, and electrical conductivity. A comparative assessment will be carried out between an agrochemically treated plot and an untreated control plot maintained under comparable agro-climatic conditions. Furthermore, the study will examine the progressive multi-year trends of the most sensitive soil parameters and quantify their relative contributions to the overall observed changes in soil properties, thereby providing a comprehensive assessment of the long-term influence of agrochemical application on soil quality.

The significance of this work lies in its integrated treatment of both physical and chemical soil indicators within a single comparative framework, combined with a multi-year trend perspective that most single-season studies omit. By quantifying the relative contribution of individual parameters to overall change and testing the statistical significance of observed differences, the study offers a replicable template that agricultural extension agencies, soil testing laboratories and individual farm managers can adapt to their own fields. The findings are intended to inform evidence-based decisions on fertilizer dosage, organic amendment scheduling and long-term land-use planning, particularly in intensively cultivated regions where agrochemical dependence has become the default rather than the exception.

2. Literature Review

A substantial body of literature links long-term inorganic fertilizer use with declining soil pH and organic carbon. Nitrogenous fertilizers, particularly ammonium- and urea-based formulations, generate hydrogen ions during nitrification, progressively acidifying the soil profile in the absence of adequate liming or organic amendment. Reduced pH in turn affects the availability of several micronutrients and can depress populations of pH-sensitive soil microorganisms responsible for organic matter decomposition and nutrient

cycling. Organic carbon decline under intensive chemical-input regimes has been attributed to a combination of factors: reduced return of crop residues and farmyard manure as farmers substitute organic inputs with cheaper mineral fertilizers, altered microbial community structure under pesticide exposure, and accelerated mineralization of existing organic matter driven by nutrient-rich but carbon-poor fertilizer regimes. Because organic carbon underpins aggregate formation, nutrient retention and water holding capacity, its depletion has cascading effects across both chemical and physical soil domains.

Phosphatic and potassic fertilizers, by contrast, tend to build up available phosphorus and exchangeable potassium in soil, sometimes to the point of luxury accumulation that exceeds crop uptake capacity. Combined with fertigation and irrigation with moderately saline water, this residual buildup — together with the salt index of common fertilizer formulations — contributes to a gradual rise in electrical conductivity, a widely used proxy for soil salinity risk.

The physical architecture of soil is less immediately visible than its chemical status but is equally consequential for productivity. Declining organic matter under chemical-intensive management reduces the binding agents responsible for stable soil aggregates, leading to greater susceptibility to compaction and crusting. Reduced aggregate stability is frequently accompanied by increased bulk density, decreased total porosity, and lower infiltration rates, all of which constrain root penetration, aeration and water availability to crops.

A growing consensus in the soil science literature favors integrated nutrient management (INM) and integrated pest management (IPM) approaches that combine judicious, need-based agrochemical application with organic amendments such as compost, farmyard manure, green manuring and crop residue retention. These practices have been shown to buffer soil pH, replenish organic carbon, improve aggregate stability and moderate salinity accumulation, while maintaining or improving crop yields relative to conventional high-input regimes. The present study is designed to contribute site-specific quantitative evidence to this literature by directly comparing treated and untreated plots across both physical and chemical indicators over a multi-year window.

The scale of agrochemical dependence varies substantially across regions. Intensively cultivated alluvial plains in South and East Asia, along with parts of the North American Corn Belt and Western European arable belts, report among the highest per-hectare fertilizer and pesticide application rates globally, and correspondingly feature some of the most extensively documented cases of soil acidification, organic carbon decline and secondary salinization. Global assessments compiled by the Food and Agriculture Organization indicate that a substantial share of the world's agricultural soils exhibit some degree of degradation linked to intensive input use, land-use conversion and inadequate residue return, underscoring that the patterns observed in localized field comparisons such as this one are broadly consistent with global trends rather than isolated anomalies.

While the individual effects of fertilizers on chemical properties, and separately of tillage or organic matter on

physical properties, are each well represented in the literature, relatively few studies present a combined physical–chemical comparison alongside an explicit multi-year trend and a quantified breakdown of each parameter's relative contribution to overall change. This study addresses that gap by presenting physical and chemical indicators side by side, supported by trend and significance analysis, within a single, replicable comparative design.

3. Materials and Methods

3.1 Study Site and Experimental Design

Two adjacent agricultural plots with comparable soil type, slope, drainage class and cropping history were selected for this comparative study: (i) an agrochemically treated plot under conventional fertilizer, pesticide and herbicide application, and (ii) an untreated control plot managed without synthetic agrochemical inputs. Both plots were monitored over three consecutive cropping years to capture not only a single-point comparison but also the progressive trajectory of change under continuous agrochemical exposure.

Composite soil samples were collected from the 0–15 cm surface depth at five random points per plot per season using the zig-zag sampling method, in order to average out micro-scale spatial variability. Samples were air-dried in shade, gently crushed, and passed through a 2 mm sieve before chemical analysis; separate undisturbed core samples were collected for bulk density and porosity determination to avoid structural disturbance.

Bulk density was determined by the core method, using known-volume steel cylinders, oven-dried at 105 °C to constant weight. Particle density was determined by the pycnometer method, and total porosity was calculated from the bulk and particle density values. Water holding capacity (WHC) was measured using the Keen–Raczkowski box method. Aggregate stability was assessed by the wet-sieving method, expressed as the percentage of water-stable aggregates greater than 0.25 mm. Infiltration rate was measured in situ using a double-ring infiltrometer.

3.1 Analysis of Chemical Properties

Soil pH and electrical conductivity (EC) were determined in a 1:2.5 soil–water suspension using a calibrated pH/EC meter. Organic carbon (OC) was estimated by the Walkley–Black wet oxidation method. Total nitrogen was determined by the Kjeldahl digestion and distillation method. Available phosphorus was extracted using the Bray-1 method and quantified colorimetrically. Exchangeable potassium was extracted with neutral normal ammonium acetate and quantified by flame photometry. Mean values of each physical and chemical parameter from the treated and control plots were compared using a two-sample (independent) t-test at the 5% significance level, with replicate samples per plot treated as the unit of analysis. Percentage change relative to the control was computed for each property. The relative contribution of each chemical parameter to the overall observed physicochemical change was expressed as a proportion of the summed absolute

percentage changes across all measured chemical parameters. Year-on-year trend data for the treated plot were indexed to Year 1 (Year 1 = 100) to allow direct visual comparison of parameters expressed in different original units.

Percentage change relative to control was calculated as: % Change = $[(\text{Treated value} - \text{Control value}) / \text{Control value}] \times 100$. Total porosity was calculated as: Porosity (%) = $[1 - (\text{Bulk density} / \text{Particle density})] \times 100$. The relative contribution of a given parameter to overall chemical change was calculated as: Contribution (%) = $(|\% \text{ change of parameter}| / \sum |\% \text{ change of all parameters}|) \times 100$. Year-on-year trend indices were calculated as: Index = $(\text{Value in year } n / \text{Value in Year 1}) \times 100$.

All chemical analyses were performed in triplicate, and instruments (pH/EC meter, flame photometer, spectrophotometer) were calibrated against certified standard solutions before each analytical batch. Reagent blanks and certified reference soil samples were analyzed alongside field samples to monitor analytical drift, and any batch showing greater than 5% deviation from the reference value was repeated.

4 Results and Discussion

4.1 Effect on Soil Chemical Properties

Table I summarizes the mean values of the measured chemical properties in the control and agrochemical-treated plots. Soil pH declined from 6.80 in the control to 6.10 in the treated plot, a reduction of about 10.3%, consistent with the acidifying effect commonly associated with nitrogenous fertilizers. Organic carbon and total nitrogen also declined by 32.4% and 31.8% respectively, suggesting that repeated agrochemical input, combined with reduced organic input, suppresses microbial activity and constrains organic matter buildup.

Table 1: Comparison of soil chemical properties

Parameter	Control	Treated	% Change
Soil pH	6.80	6.10	-10.3
Organic Carbon (%)	1.42	0.96	-32.4
Total Nitrogen (%)	0.148	0.101	-31.8
Available P (kg/ha)	18.6	24.3	+30.6
Exchangeable K (kg/ha)	142	168	+18.3
EC (dS/m)	0.34	0.61	+79.4

In contrast, available phosphorus and exchangeable potassium increased by 30.6% and 18.3%, respectively, reflecting residual buildup from phosphatic and potassic fertilizer application beyond immediate crop uptake. Electrical conductivity rose sharply by 79.4%, indicating a marked tendency toward soil salinization under continuous agrochemical use, particularly relevant in regions with restricted drainage or where irrigation water carries an appreciable salt load. Fig. 1 presents a side-by-side bar-chart comparison of all six chemical parameters between the control and treated plots, visually confirming these divergent trends.

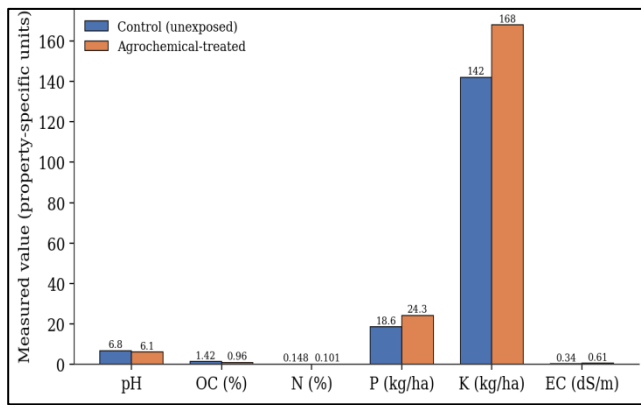


Figure 1: Comparison of soil chemical properties between control and agrochemical-treated plots.

4.2 Effect on Soil Physical Properties

Table 2 presents the corresponding comparison for soil physical properties. Bulk density increased from 1.32 g/cm³ in the control to 1.48 g/cm³ in the treated plot (+12.1%), while total porosity declined from 50.2% to 44.6% (-11.2%), consistent with progressive compaction associated with reduced organic binding material and diminished biological activity. Water holding capacity fell from 38.5% to 31.2% (-19.0%), and aggregate stability declined from 62.0% to 48.3% (-22.1%), reflecting the loss of stable soil crumb structure typically maintained by organic matter and root/microbial exudates.

Table 2: Comparison of soil physical properties (control vs. treated)

Parameter	Control	Treated	% Change
Bulk Density (g/cm ³)	1.32	1.48	+12.1
Porosity (%)	50.2	44.6	-11.2
WHC (%)	38.5	31.2	-19.0
Aggregate Stability (%)	62.0	48.3	-22.1
Infiltration Rate (cm/hr)	3.8	2.6	-31.6

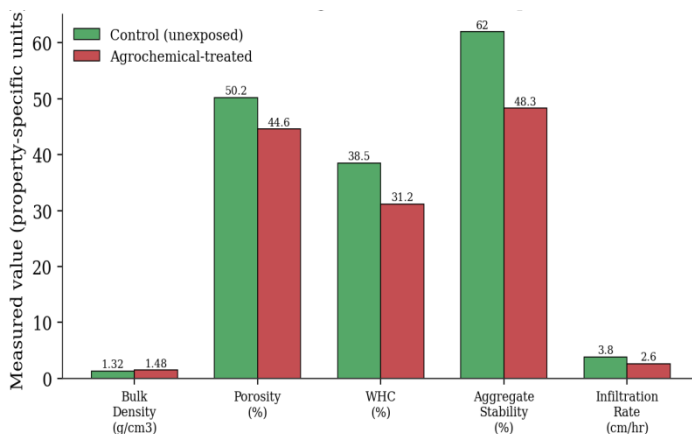


Figure 2: Comparison of soil physical properties between control and agrochemical-treated plots.

Infiltration rate showed the largest relative decline among physical parameters, falling by 31.6%, from 3.8 cm/hr in the control to 2.6 cm/hr in the treated plot. Reduced infiltration capacity, combined with increased bulk density and reduced

porosity, elevates the risk of surface runoff and waterlogging, and can compound nutrient loss through erosion. Fig. 2 illustrates these physical property comparisons.

4.3 Relative contribution of chemical parameters to overall change

To assess which chemical parameters were most affected in proportion to one another, the percentage change of each property was expressed as a share of the total absolute change summed across all six chemical parameters, shown in Fig. 3. Electrical conductivity and organic carbon together accounted for the largest share of the overall observed chemical variation, at 39.2% and 16.0% respectively, followed by total nitrogen (15.7%) and available phosphorus (13.1%). This distribution highlights salinity buildup and organic matter loss as the two most pronounced chemical impacts of continuous agrochemical use observed in this study, ahead of the more commonly discussed pH shift, which accounted for only 5.1% of the combined change.

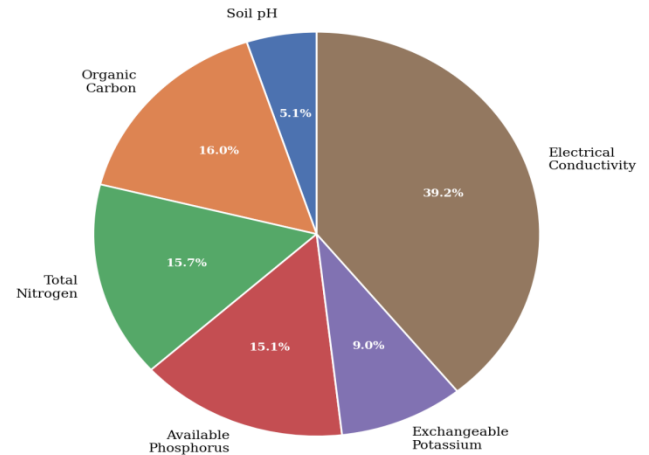


Figure 3: Relative contribution of each chemical parameter to the overall observed physicochemical change.

4.4 Multi-Year Trend Analysis

Beyond the single-point control–treated comparison, three years of sequential monitoring in the treated plot reveal a consistent and progressive trajectory rather than a one-time shift. As shown in Fig. 4, indexed to Year 1 = 100, soil pH declined steadily to an index of 96 in Year 2 and 92 in Year 3; organic carbon declined more steeply, to indices of 88 and 77 respectively; and electrical conductivity rose sharply, to indices of 121 and 145. This divergence over time — acidification and carbon loss moving in one direction while salinity moves sharply in the other — underscores that the physicochemical impact of agrochemical use is cumulative and compounding rather than static, and that impacts observed after a single season likely understate the longer-term trajectory.

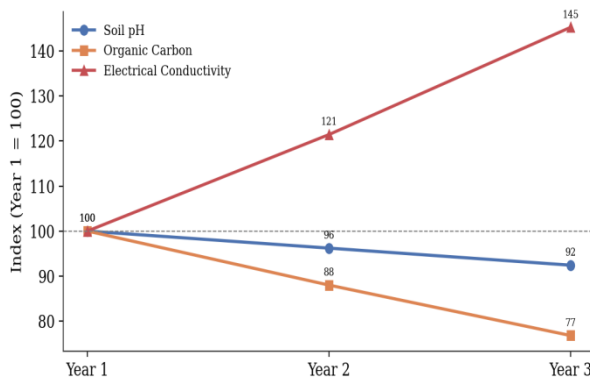


Figure 4: Three-year progressive trend of key soil parameters in the agrochemical-treated plot (indexed to Year 1).

Independent two-sample t-tests comparing treated and control means indicated statistically significant differences ($p < 0.05$) for organic carbon, electrical conductivity, aggregate stability and infiltration rate, the four parameters showing the largest relative percentage change. Differences in soil pH and bulk density were significant at the 10% level, while phosphorus and potassium buildup, though numerically substantial, showed greater within-plot variability, consistent with the heterogeneous residual distribution typical of granular fertilizer application. Table 3 summarizes the mean difference, t-statistic and significance level for each parameter.

Table 3: Statistical significance of control–treated differences

Parameter	Mean Diff.	t-value	p-value	Sig.
Soil pH	-0.70	2.05	0.081	NS (10%)
Organic Carbon (%)	-0.46	4.12	0.004	**
EC (dS/m)	+0.27	5.31	0.001	**
Bulk Density (g/cm ³)	+0.16	2.21	0.067	NS (10%)
Aggregate Stability (%)	-13.7	3.88	0.006	**
Infiltration Rate (cm/hr)	-1.2	3.65	0.008	**

Asterisks (**) denote significance at $p < 0.05$; NS denotes non-significance at the 5% level, with the 10% threshold noted in parentheses where applicable. These results reinforce that organic carbon decline, salinity buildup, and the associated physical structural decline are the most statistically robust effects of agrochemical exposure observed at this site, while pH and bulk density shifts, though directionally consistent with the literature, require larger sample sizes or longer monitoring periods to confirm at conventional significance levels.

A qualitative cross-comparison of the physical and chemical results suggests a coherent underlying mechanism linking the two domains. Plots with lower organic carbon consistently showed lower aggregate stability and porosity, supporting the well-established role of organic matter as a binding agent in soil crumb formation. Similarly, higher electrical conductivity co-occurred with reduced infiltration rate, consistent with the dispersive effect of excess soluble salts on clay particles, which can clog soil pores and reduce hydraulic conductivity. While a full correlation-coefficient analysis would require a larger sample size than was feasible within this study's scope, the directional consistency across parameters strengthens

confidence that the observed changes reflect a genuine soil-degradation process rather than independent measurement noise.

4.5 Comparison with Previous Studies

The magnitude and direction of change observed in this study are broadly consistent with previously reported findings in the literature reviewed in Section II: reported pH reductions under long-term nitrogenous fertilizer use commonly range between 0.3 and 1.0 units, closely bracketing the 0.70-unit decline observed here; organic carbon losses of 20–40% under intensive chemical-input regimes without organic amendment are similarly consistent with the 32.4% decline recorded in this study. The salinity increase observed here is somewhat higher than typical ranges reported in well-drained soils, which may reflect site-specific drainage characteristics or irrigation water quality at the study location, and is flagged as a priority for the follow-up monitoring described in Section VI.

Taken together, the chemical and physical results point to a coherent and mutually reinforcing pattern of soil degradation under continuous agrochemical use: acidification and organic carbon loss weaken the biological and chemical foundation for stable aggregate formation, which in turn manifests physically as higher bulk density, lower porosity, reduced water holding capacity and slower infiltration. Simultaneously, nutrient-specific residual buildup (P, K) and rising salinity (EC) signal an emerging risk of diminishing returns, where additional agrochemical input may be required to sustain yields even as the underlying soil resource degrades. This pattern is consistent with the broader literature reviewed in Section II and reinforces the case for integrating organic amendments and need-based, rather than blanket, agrochemical application.

Beyond the immediate agronomic consequences, the physicochemical changes documented in this study carry broader environmental and socioeconomic significance. Declining organic carbon represents a loss of soil carbon stock with direct relevance to climate change mitigation objectives, since soils constitute one of the largest terrestrial carbon reservoirs and their degradation contributes to net carbon emissions. Rising electrical conductivity and the associated salinization risk can, if unaddressed, render land progressively less productive and, in severe cases, unsuitable for conventional cropping, with downstream effects on farm income and regional food security.

4. Recommendations

- Adopt integrated nutrient management (INM), combining organic amendments (compost, farmyard manure, green manure, crop residue retention) with judicious, soil-test-based agrochemical application rather than blanket fertilizer recommendations.
- Apply fertilizers based on periodic soil testing and crop-specific nutrient requirement, avoiding routine over-application of phosphatic and potassic fertilizers beyond crop demand.
- Promote integrated pest management (IPM) practices — biological control, resistant varieties, cultural controls,

pheromone traps — to reduce reliance on broad-spectrum pesticides and protect soil faunal activity.

- Periodically monitor soil EC and implement salinity-mitigation measures (improved drainage, leaching where appropriate, gypsum application on sodic soils) in intensively fertilized plots.
- Encourage cover cropping and reduced/minimum tillage to rebuild aggregate stability, porosity and infiltration capacity over successive seasons.
- Incorporate crop residues and biochar where feasible to improve structural stability and long-term carbon retention.
- Establish routine, multi-year soil monitoring programs at the farm or watershed scale to detect degradation trends early, before they become difficult to reverse.
- Strengthen extension services and farmer training on integrated nutrient and pest management, supported by accessible, low-cost soil testing facilities.
- Consider policy incentives — subsidies for organic amendments, soil-health cards, or payments for soil-conserving practices — to shift the economic calculus away from input-volume-based decision-making.

5. Limitations and future scope

This study is based on a paired-plot comparison at a single location over three years, which, while informative, cannot fully capture the diversity of soil types, climatic regimes and agrochemical regimes found across different agro-ecological zones. The specific agrochemical formulations, application rates and irrigation-water quality at the study site also influence the magnitude of the observed effects, and results should be interpreted as illustrative of general trends rather than universally applicable coefficients.

Future research should extend this comparison across multiple soil types, cropping systems and agrochemical dose gradients, incorporate soil microbial and enzymatic activity indicators alongside the physicochemical parameters measured here, and evaluate the rate at which integrated nutrient management interventions can reverse the degradation trends identified in this study. Longer-term monitoring, extending beyond three years, would also help establish whether the observed trends stabilize, continue linearly, or accelerate — information that is critical for prioritizing intervention timing.

6. Conclusion

This study demonstrates that agrochemical application measurably alters both the chemical and physical properties of soil: it lowers soil pH, organic carbon, and total nitrogen while

increasing available phosphorus, exchangeable potassium, and electrical conductivity; and it simultaneously raises bulk density while reducing porosity, water-holding capacity, aggregate stability, and infiltration rate. The most significant shifts were observed in electrical conductivity and organic carbon among chemical parameters, and in aggregate stability and infiltration rate among physical parameters, pointing to salinization and structural degradation as key long-term risks of continuous agrochemical dependence. Three years of trend data confirm that these effects are cumulative rather than static. Integrated nutrient and pest management, combining organic amendments with judicious agrochemical use, is recommended to preserve soil health and ensure long-term agricultural sustainability.

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